

# Alexandria Digital Library: User Evaluation Studies and System Design

## Linda L. Hill

Alexandria Digital Library Project, University of California, Santa Barbara, Santa Barbara, CA 93106.  
E-mail: lhill@alexandria.ucsb.edu

## Larry Carver and Mary Larsgaard

Map & Imagery Laboratory, Davidson Library, University of California, Santa Barbara, Santa Barbara, CA 93106. E-mail: {carver, mary}@sdc.ucsb.edu

## Ron Dolin and Terence R. Smith

Computer Science Department, University of California, Santa Barbara, Santa Barbara, CA 93106.  
E-mail: {rad, smithtr}@cs.ucsb.edu

## James Frew

Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, Santa Barbara, CA 93106. E-mail: frew@bren.ucsb.edu

## Mary-Anna Rae

Graduate School of Education, University of California, Santa Barbara, Santa Barbara, CA 93106.  
E-mail: mrae@education.ucsb.edu

**The Alexandria Digital Library (ADL) is one of the six digital library projects funded by NSF, DARPA, and NASA. ADL's collection and services focus on information containing georeferences: maps, images, data sets, text, and other information sources with links to geographic locations. During this study period, three different user interfaces were developed and tested by user groups. User feedback was collected through various formal and informal approaches and the results fed back into the design and implementation cycle. This article describes the evolution of the ADL system and the effect of user evaluation on that evolution. ADL is an ongoing project; user feedback and evaluation plans for the remainder of the project are described.**

## Introduction

The Alexandria Digital Library (ADL) is a *geolibrary* (Goodchild, 1998; National Research Council, 1999) where a primary means of describing and finding information is with a geographic *footprint*. A *footprint* shows a location on the surface of the Earth associated with either a collection object (CO) (such as a map, an aerial photograph, or a

remote-sensing image) or with a user's query. The *footprint* may be represented as a point or polygon, with latitude and longitude coordinates. When a user queries the ADL collections through the user interface, the user creates a *footprint* on an interactive map to indicate the area of interest (the *query area*). The *query area* is matched with the CO footprints recorded in the metadata to retrieve relevant collection objects—that is, COs “about” the query area. This means that the user can choose arbitrary query areas, not just geographic areas that have placenames. This also means that COs about the query area do not have to have the names associated with them that the user enters for a text-based query. For example, the user's query might be of the type “What do you know about the Santa Barbara area?” which can be translated into a *query area* for Santa Barbara, which can then be used to find COs with matching *footprints*. This approach opens up the possibility of finding all types of information related to an area, including aerial photographs, remote sensing images, data sets, and texts. Geographic *footprints* can be applied to both on-line-accessible (e.g., digital images) and off-line-accessible (e.g., paper maps) COs, giving the user an integrated means of locating information about a geographic location. This geospatial approach to digital library information management

and retrieval presents a new environment for users. Studies showing how the geolibary approach will affect user work practices are just beginning. ADL has proven to be a rich environment to begin to learn how users will use such a system, what they would like for it to be able to do, and how they react to the iterative designs of a developing geolibary prototype.

This article first describes the evolution of the ADL system and interface design and then provides a brief overview of the project's research and testbed activities. Descriptions are then given for ADL's three primary user communities (earth scientists, information specialists, and educators), the user evaluation methodologies applied, and the findings from working with these user groups. Finally, some thoughts are proposed about the potential impacts of geolibaries (ADL in particular) on user communities, on research libraries, and on teaching.

### *Evolution of the System and Interface Design*

The ADL is one of the six digital library projects funded by NSF, DARPA, and NASA. ADL's collection and services focus on georeferenced information: maps, images, data sets, text, and other information sources with links to geographic locations. The ideas for ADL grew out of a previous project funded by the Research Libraries Group known as GRIN—the Geographic Resources Information Network (Research Libraries Group, 1989). The first ADL prototype was called the Rapid Prototype and was distributed on CD-ROM (Alexandria Digital Library—UCSB, 1995). This was followed by a WWW version, known as the beta web prototype, in 1996 (Smith, et al., 1996). The web prototype was accompanied by an active user evaluation phase that included: (1) collecting data about the beta testers (anyone who signed up to use the web prototype), (2) an on-line survey of beta testers, (3) target user groups, and (4) ethnographic studies (Hill et al., 1997). There were also three ADL Design Review meetings during this time that brought together invited parties to discuss and advise on the goals and the progress of the project. Two of these took place over several days, and involved 30–50 people; the third was a panel of system designers who met for 2 days to advise on system specifications.

The results of these user evaluations were fed back into the design of the current Java-based interface and supporting system, which has been subjected to two formal internal evaluations involving personnel from the University of California, Santa Barbara (UCSB) and University of Colorado at Boulder. The Java user interface client, known as JIGI for "Java Interface to Geospatial Information," has undergone numerous interim releases. The database and middleware components of the system have been redesigned and the collections of data and metadata continue to grow in complexity. Table 1 provides a comparison of the major components of ADL from the web prototype to the current (May 1998) status. Although it is generally true that the design has moved forward, there are still some features in earlier de-

signs that have yet to be fully implemented in the newest version, as reflected in the table.

Current information about ADL, including descriptions of the current JIGI interface with screenshots and a brief overview of the functionality, is available at <http://www.alexandria.ucsb.edu>. Figure 1 provides a representation of the JIGI client interface.

Using ADL, one can

1. Find information about a geographic area—the "what's there" question that starts with a query area drawn on a map browser.
2. Find where a place or feature is located—the "where is it" question that starts with a place or feature name.

These basic query types can be combined into "what's there" questions that start with place names, as in the "What do you know about the Santa Barbara area?" example. The query to ADL can also contain other parameters such as a date range, a type of information (e.g., *maps* or a particular feature type such as *rivers*), a format (e.g., TIFF), freetext, assigned terms, originators, or identifiers (e.g., control numbers). A selection can be made among the multiple collections available for searching.

The items returned that match the query parameters can be evaluated by their footprints, thumbnail and browse images, and metadata attributes. Thumbnail images are small image representations, such as the one shown in Figure 1. Browse images are larger, and provide more detail. Selected items can be put aside in user-named folders. On-line data can be downloaded directly to local storage. Interfaces have been tested that provide access to application packages with which items from ADL's collections can be processed.

### *Interaction of Evaluation with Design and Implementation*

There are obvious problems with evaluating an innovative and evolving system, and with eliciting from users what they might do with such a system if it existed. With new software systems there is a degree of education involved, because users must understand the new capabilities to evaluate them. The process may be thought of as a cycle in which the implementers build certain functionality, users are introduced to the potential of the new features, the users request additional functionality (some of which may be part of the system but not recognized), and the implementers modify the design. This has been the pattern with ADL. This article will describe the formative evaluation process that has captured this development cycle and guided the evolution of the geolibary system and the understanding of potential use.

### **Design Goals for ADL**

The ADL project consists of three major efforts: (1) basic research; (2) building a testbed; and (3) user evalua-

TABLE 1. Evolution of major components of ADL.

	Web prototype components (1996)	Currently implemented components (as of May 1998)
Collections	<ul style="list-style-type: none"> <li>• ADL Catalog</li> <li>• Gazetteer (~6 million placenames with point locations)</li> </ul>	<p>Open architecture to accept any collection, now includes</p> <ul style="list-style-type: none"> <li>• ADL Catalog (expanded with more data and more thumbnail images)</li> <li>• Original Gazetteer</li> <li>• New Gazetteer with bounding box footprints</li> <li>• GeoRef Collection (for California)</li> <li>• Crustal Studies Collections (volcanoes and earthquakes)</li> <li>• Temporary subset for class assignment</li> </ul>
Metadata	<ul style="list-style-type: none"> <li>• ADL schema based on Federal Geographic Data Committee's (FGDC) Content Standard</li> <li>• Gazetteer schema</li> </ul>	<p>Open architecture to accept any schema; now includes</p> <ul style="list-style-type: none"> <li>• ADL schema</li> <li>• Original Gazetteer schema</li> <li>• ADL Gazetteer Content Standard</li> <li>• MARC (GeoRef Collection)</li> <li>• Collection Metadata schema</li> </ul>
Search	<ul style="list-style-type: none"> <li>• Map Browser for query areas and display of footprints of retrieved items</li> <li>• Gazetteer Search using SQL and fuzzy searching</li> <li>• SQL search of metadata attributes</li> <li>• Customizable search form</li> </ul>	<p>Search bucket architecture to provide high-level search parameters for all collections</p> <ul style="list-style-type: none"> <li>• Map Browser for query areas and display of footprints of retrieved items</li> <li>• Gazetteer is treated as a collection</li> <li>• Search buckets: location, date, type, format, originator, freetext, assigned terms, and identifiers</li> <li>• Query preview</li> <li>• Query history and reusable queries</li> </ul>
Retrieval and user workspace	<ul style="list-style-type: none"> <li>• Full and customizable view of metadata</li> <li>• Thumbnail images</li> <li>• Larger browse images</li> <li>• Links to data</li> <li>• Partially implemented "shopping cart" concept for user selected sets</li> <li>• Savable/Reloadable search session state</li> </ul>	<ul style="list-style-type: none"> <li>• Scan display of results</li> <li>• Result lists sortable by multiple parameters</li> <li>• Full metadata display</li> <li>• Thumbnail images that can be placed on the map within the footprint</li> <li>• Larger browse images</li> <li>• Access page for direct links to data and contact information</li> <li>• User folders to hold selected items from result sets</li> <li>• Enhanced functionality to save and reload search session state</li> <li>• Printable map and metadata</li> <li>• Links to other software for further processing of data</li> </ul>
Help support	<ul style="list-style-type: none"> <li>• Tutorial with walk through scenarios (HTML)</li> <li>• Glossary</li> <li>• Email contact for help</li> </ul>	<ul style="list-style-type: none"> <li>• Tutorial (HTML)</li> <li>• Context-sensitive pop-up help</li> <li>• Collection metadata providing overviews of collection contents</li> <li>• E-mail contact for help, with management system to process help messages</li> </ul>
System support for evaluation	<ul style="list-style-type: none"> <li>• Beta Tester registration (freetext responses)</li> <li>• On-line survey</li> <li>• Session logs with session IDs</li> </ul>	<ul style="list-style-type: none"> <li>• Registration form with controlled response options</li> <li>• Session ID linked to user ID</li> <li>• Exit polls for user comment/evaluation after each session</li> <li>• Session logs</li> </ul>
Underlying system	<ul style="list-style-type: none"> <li>• Illustra and Sybase database</li> <li>• Thin middleware layer tightly coupled to database server and client</li> <li>• HTML client</li> <li>• HTTP and FTP transfer protocols</li> </ul>	<ul style="list-style-type: none"> <li>• Informix Universal database server</li> <li>• Middleware system with well-defined interfaces to databases and to clients</li> <li>• Java application client</li> <li>• HTTP and FTP protocols and socket communication channels</li> </ul>

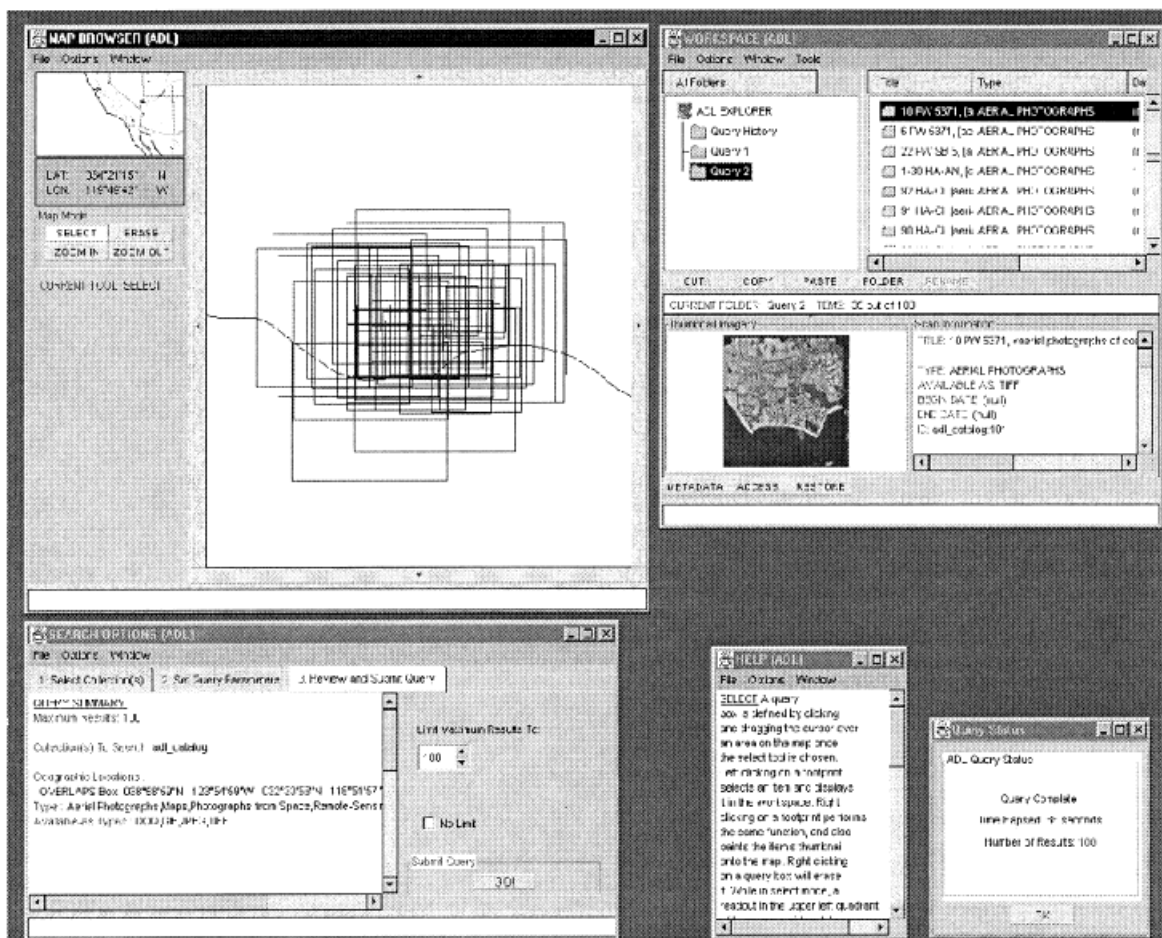


FIG. 1. Screenshot of the JiGi interface (version 1.7.1), showing collection object footprints (upper left) associated with a query result set (upper right). One item is highlighted at the upper right, a thumbnail view of the image is shown in the same window, and the associated footprint in the upper left window is highlighted in red (not shown in this black and white illustration). The windows along the bottom show (from left to right) the Search Window where query parameters are set, the context-sensitive Help Window, and the Query Status Window.

tion of the testbed. This article describes the evaluation part of the project, but a brief introduction to the research and testbed efforts are needed to put the evaluation in perspective.

### Basic Research

The basic research of ADL was organized into a set of research teams, each with a specific focus. The Information Systems Team, the Image Processing Team, and the Performance and Parallel Processing Team focused on computational research. This research was aimed at supporting a distributed digital library capable of storing, retrieving, and delivering geospatial and image objects efficiently and effectively. These projects include, for example, use of hierarchical metadata structure and multilevel servers for resource discovery on the Web, use of “materialized views” to improve retrieval performance, and texture based image retrieval. In addition to these, the concept of “fuzzy footprints” for item description and query regions, metadata issues such as the design and use of gazetteers and thesauri

in the digital library environment, and issues connected with collection-level metadata have been explored. For more detailed research reports, we refer you to annual and quarterly reports and the bibliography of publications available at the ADL website. The Evaluation Team did not evaluate these research projects.

### Testbed

An Implementation Team has been engaged in the design and implementation of the system architecture and user interfaces for ADL. The composition of this team includes computer scientists, geographers, librarians, and interface designers. This mix brings with it many debates about terminology, concepts, and design, and has resulted in the various testbed implementations that incorporate ideas and techniques from all of these domains. Several members of the Implementation Team are also members of the Evaluation Team. These overlapping responsibilities have proven to be valuable in our ability to adjust the designs to the findings of the evaluations and to user feedback. Because

the teams are so closely linked, the Implementation Team has also been helpful in providing the system support required for the user evaluation studies.

The ADL testbed is in the process of becoming an operational system. The Java client has been released to the University of California campuses, and it is planned to include a version of the ADL client in the California Digital Library (University of California Library Planning & Action Initiative, 1998).

## User Communities

The ADL project is designed to serve the needs of a broad spectrum of user communities: the geographic information system (GIS) specialist, the earth science researcher, the teacher in the classroom, and the general public. It is designed to be a library in the traditional sense where materials at all levels of sophistication are in the collections and the search and retrieval services that provide access to those materials are useable by the diverse customer base of the library. The challenge is to reach this goal in an electronic environment where the traditional reference librarian is not present, and where the range of materials extends to complex geospatial collection objects: aerial photos, remote sensing images, digital maps, etc.

To provide a more focused understanding of the way particular user communities would use ADL, three Target User Groups (TUGs) were formed in 1996: earth scientists, information specialists, and educators. They met several times to learn about ADL and to discuss the ways in which they would use such a system. A set of user scenarios was gathered from the TUG participants and from other sources (see <http://www.alexandria.ucsb.edu/~lhill/scenarios.html>) and each group was asked to select from the list those scenarios that best represented their potential use of ADL. They indicated through their choice of the user scenarios, and by their requirements for such a system, that the communities have very different task environments and expectations of a system such as ADL. We have subsequently worked more closely with particular user groups that exemplify each of these user communities.

The user communities are described here with a short descriptive statement and the top scenarios selected by each group. The scenarios are left in the style in which they were submitted, representing the topic in the user's voice.

### Earth Scientists

Members of this group work extensively with data sets and maps and expect a geolibary to have the data sets they need and to provide appropriate access to them in terms of search parameters and access paths to the data itself. They typically work in sophisticated information processing environments and want ADL to be tightly integrated into the working environment in which they manipulate data. They are also interested in having geospatial access to bibliographic files such as GeoRef (American Geological Insti-

tute, 1998). Staff of the Institute for Crustal Studies (UCSB) have contributed several data collections (volcanoes and earthquakes, for example) to ADL, and been involved in interface design.

The Earth Science TUG chose scenarios such as the following to represent their needs:

#### *Environmental data*

I am a Ph.D. student in chemical engineering. I am currently working on an environmental partition model that will be used to calculate risk indices for use in preliminary industrial design. Some of the parameters for the model includes, the plant areal density, (kg plants/m<sup>2</sup>), and fraction organic carbon content of the soil and sediment. We are looking for region specific data, (i.e. midwest, southwest, east coast, west coast, etc. . .). I realize this data varies greatly over any region specified as large as this, however, in a more general sense the data will, for example, vary from southwest to midwest. I am told that studies such as this have been conducted, and would like to know if you have access to this data or know of a source where I could find it. Any help is greatly appreciated.

#### *Basemaps*

The most important use that I have had for spatial data has been in the acquisition of digital basemaps. For example, Digital Line Graph (DLG) or Census tiger files for various areas about the United States.

#### *Aerial photography*

From the Blue Oak Project. This project required identifying available historical aerial coverage between 1938 and 1950 at scales of either 1:20,000 or 1:24,000 for 150 site locations throughout California's vast Blue Oak Woodland habitat areas. Sites were identified by lat./long. coordinates. Also, roll and frame identification for the same 150 sites from recent National Aerial Photography Program (NAPP) coverage at 1:40,000 were needed.

#### *Aerial photos and remote sensing*

Researcher wants to know the available air photo and remote sensing coverage for a region. And what is available in the library. More specifically, the researcher might want to find out what the earliest photo available is and the latest photo and what photos are available with scales greater than 1:40,000.

#### *Environmental monitoring over time*

Environmental change research tied to specific locations. Examples: habitat loss, landscape changes following development, flood and fire events, regional biodiversity.

### *GIS analysis*

Find a map, at a scale no smaller than 1 to 200,000 that: covers any part of the Mississippi Valley; shows a town with a population of over 500,000 people; shows roads; is within a 30-minute drive of some Indian burial sites for which the library has 19th century photographs in digital form.

### **Information Specialists**

This group includes librarians in academic, public, and museum settings as well as nonlibrarians who specialize in information or data description, retrieval, and supporting services. Members of this community will spend more time learning the broad capabilities of ADL to serve a variety of needs brought to them by the end users. They are more likely to handle difficult search and retrieval tasks and less likely to process the data itself. The information specialists, to the degree that they work with earth scientists, reflected this commonality in their orientations; to the degree that they work with other groups (in the general university community, with the general public, or in special library situations) their interests are broader. University map librarians are the group with which we have worked most closely in this community. They were well represented at the Design Review Panel meetings, and they will be heavily involved in the introduction of ADL to the University of California campuses.

The Information Specialist TUG chose scenarios such as the following to represent their needs:

#### *Locate named place*

Student wants to know location of river, or land feature, described in an article.

#### *Location of place with uncertain spelling*

I'm looking for a small town in Germany, I don't know if it's east or west Germany. It's called Heidebring, or Hiedebring, or something like that. I'm not sure of the spelling.

#### *Text and image search*

At 10 year or less intervals, find all documents describing Mascalitan island and images with a resolution more than 2 meters during summer periods and maps prior to 1930 at a scale greater than 1:24,000. Mascalitan island is a land-locked feature in Santa Barbara County.

#### *Country-related information*

What do you have about the political regions of Brazil as well as data you have concerning the country's infrastructure in all the main built-up areas of Brazil's municipios.

### *Aerial photography*

From recent searches in preparation for pending litigation stemming from the La Conchita landslide, Ventura Co., CA. All available coverage from aircraft platforms of La Conchita regardless of scale, film type, date, or perspective (vertical and oblique). Stereo coverage preferred. Because site is located near Ventura/Santa Barbara counties border, it is necessary to search existing analog record (organized by county) under both counties because coverage often slops over county boundaries. A subset of this search (and one more common to our usual requests) would be to search for best (most detailed) stereo coverage of site as close to 5-year intervals as possible from earliest to present.

### **Educators**

Public school educators (district administrators, technology coordinators, middle and secondary school educators, and college-level educators) represented this community in the TUG. ADL will only be useful to them if they can work it into their classroom activities. They are interested in the potential for group activities and in content and functionality that supports their education goals. Recently, we were able to work with a professor and an undergraduate university class in an initial attempt to use ADL in a classroom setting (see below).

Members of the Educator's TUG chose scenarios such as the following to represent their needs:

#### *Classroom*

Students using historical maps and photographs for research projects on their own communities.

#### *Classroom*

In science, students would be looking for weather patterns, erosion patterns, geologic formations, etc.

#### *Earth science class exercise*

A computer tells us there is an earthquake today in Lodi. Find information about the following:

- (a) emergency services;
- (b) roads;
- (c) population density; and
- (d) evacuation centers.

The scenarios proved to be an especially good approach to describing and understanding these user communities, in terms of their expectations for functionality and content and in terms of the ways in which they think about their georeferenced information needs.

## User Evaluation Methodologies and Findings

Beginning with the first Rapid Prototype, continuing with the Web Prototype, and finally with the current Java-based interface (JIGI), ADL has put serious effort into understanding its potential user community and also into incorporating user feedback into the design of the system. Although the major research efforts have been in the development of system functionality, user studies have been a continuing study area.

### *Evaluation of Web Prototype (1996): Methodologies and Results*

During the course of the project, the ADL Evaluation Team has used multiple methods of soliciting and analyzing feedback from ADL users and potential users, including an on-line survey, ethnographic observations, target user groups, internal evaluations of interface design, and analysis of the use of ADL in university classrooms. We have also hosted three ADL Design Review sessions where invited external reviewers have made specific recommendations for ADL development. From such multiple sources of evidence from ADL users and potential users we have derived an understanding of the expectations that people have of a geolibrary such as ADL, and we have incorporated their evaluations and requirements into the on-going design of the system. (The following overview of the methodologies used is very brief; for a fuller description, see Hill et al., 1997.)

The ADL Beta Tester program began during the spring/summer of 1996. At that time, interested persons were able to sign up with ADL to gain access to the library. A short Web Access Request Form was completed in order to receive a username and password, which enabled access to the full functionality of ADL on the Web. At the time of this writing, there are over 6,000 (6,141) registered beta testers. There is continued use of the web version, even though it is no longer maintained, because the current Java-based interface is not yet open to the public.

There were 2287 beta tester registrations available to us when we analyzed the registration data. The responses were analyzed manually to see what could be learned about the set of interested users who wanted to test the ADL web interface. Forty-nine countries were represented among this group, with 65% of the beta testers coming from the U.S.; 42% of the group indicated that they were engaged in scientific occupations.

### *Survey*

From an on-line survey, which was completed by 109 “earlier adopters” of the web prototype, we discovered that 80% are male, 87% have college degrees, 63% have a Master’s or Ph.D. degree, the average age is 35–36 years old, and 24% said that English is not their native language.

They were, as a group, frequent users of computers, libraries, geographical data, the web, and on-line catalogs.

Given the small percentage of beta testers who completed the survey (approximately 6 to 10% of the beta testers who actually used the system at least once) and that the sample of respondents was very nonrepresentative of the population of eventual users of systems like ADL, statistically significant correlations were meager. Factor analysis using multivariate data reduction techniques (e.g., Mulaik, 1972) produced six factors that accounted for 58.5% of the variance in the original data. Three of these factors—which we labeled “overall appeal,” “terminological clarity,” and “navigational clarity”—showed strong and significant approval from the respondents. The factor labeled “overall ease of use” showed weak but significant approval. The other two factors—“overall usefulness” and “overall performance”—were not statistically different from neutral.

The results paint a mixed picture: they point to the existence of important difficulties with the web prototype implementation, but also provided support for many of the directions that were taken. Average reaction to the web version of ADL, as derived from the survey, may be described as “mildly approving.”

The only significant relationship between user characteristics and reactions to ADL was to the respondents’ sex, with females being less approving of ADL than were males. Female respondents were found to have higher rates of library use, fewer computer accounts, and used ADL a bit more often before filling out the survey, but none of these background variables were significantly related to their overall approval index. Given the small number of female respondents (19), this finding should be considered very provisional in any case.

The comments to the open-ended questions painted a somewhat more negative picture of the web prototype than did the Likert-scale responses; the great majority of the comments expressed problems or difficulties. This is consistent with the idea that people are motivated to comment when they encounter problems.

### *Ethnographic studies*

A team from the UCSB Graduate School of Education conducted ethnographic studies to inform the on-going development of ADL. These studies describe and analyze user activities and interactions both in the physical workspace of the Map and Imagery Laboratory (MIL) in the UCSB Davidson Library and in the virtual workspace of the ADL web interface. A domain analysis of the user feedback obtained through the web interface and the on-line survey was also done.

Given that one goal of the ADL is to create the electronic equivalent of the services and collections of the MIL of the UCSB Davidson Library, and because the design of ADL originated in the actual practices of MIL, one of the studies was based on audiotaped recordings of reference interviews conducted by MIL staff. Visitors to MIL were informed of

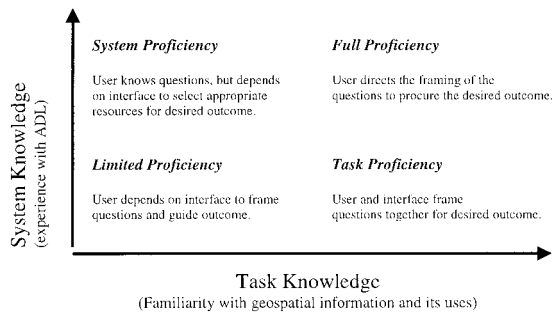


FIG. 2. Domain knowledge and its effect upon interaction with ADL.

the study and invited to participate. If they agreed, the staff person tape recorded the reference interview, which resulted in 13 recorded and transcribed sessions.

Two distinct modes of interaction between user and reference staff were discovered. One mode was for the user to pose a question, and depend on the reference person to expand and develop the question and recommend appropriate resources. The other mode was for the user to direct the reference interview, tapping the knowledge of the staff person as needed. On analysis, these modes were expanded into four different patterns based on two domains of knowledge: task knowledge (along the continuum of familiarity with spatial information and its uses), and system knowledge (along the continuum of experience with the Map and Imagery Laboratory). The four patterns are illustrated in Figure 2.

Concurrent with the collection and analysis of the MIL reference interviews was the videotaping of users interacting with the ADL Web interface. As with the users of MIL, there were significant differences in how people interacted with ADL, depending on users' background knowledge in several areas. Unlike the MIL experience, however, users did not have the equivalent of a reference librarian to whom they could turn to reshape a question or to be guided toward a successful outcome. In the eight videotaped sessions of people's interactions with ADL, it became clear that success with the system was affected by the user's background knowledge. This knowledge includes the following criteria: (1) System Knowledge—computer platforms, WWW and browsers, programming and interface design, previous use of ADL, library search strategies; and (2) Task Knowledge—maps as representations of geographic information, other kinds of geospatially referenced data. Users' reactions were related to these background knowledge factors. Only one group of users (the three people who were responsible for developing the ADL web interface prototype) could be said to have all of the knowledge required for greatest success with the system. These users did not get frustrated; they were able to play with the system and discover alternative methods for reaching the data they knew existed.

The Education Team also found three broad types of user comments and requests relating to: (1) the purpose of ADL; (2) the language, functions, and processes that need better identification and explanation; and (3) requests for addi-

tional data or additional functionality. Although many problems were identified, most users also recognized the complexity of the problem that ADL is battling to solve; i.e., to make ADL both understandable and useful while still providing sophisticated functionality. User comments identified some problems with being able to understand the presentation given by the interface, indicated by wanting more information about the mission, goals, and intended uses of ADL and wanting tutorials or scenarios that present different models for use. Some comments revealed a mismatch of user expectations for an operational system that was designed to meet their needs with the research and prototype nature of the ADL version they were using.

### *Classroom Study Using the Java Interface*

Because a primary goal of ADL is to become useful for educational purposes, an undergraduate class was chosen to find out how an early application to education would work out. The classroom also turned out to be an effective environment in which to observe how background knowledge affects users' reactions to and ability to use ADL. The students' inexperience in the field and lack of familiarity with the tools and data made them a representative sample for general inexperienced use of the system. The teaching assistants (TAs) and the professor, on the other hand, provided an opportunity to analyze how more background knowledge of the field and familiarity with the tools and data inform use of ADL.

The class used for the study was available in part because the professor was familiar with the work of ADL through his involvement in the ADL interface redesign discussions. He saw a way he could incorporate student use of the system into one of the laboratory sessions for his course. The course was an introduction to mapping science, and it had not been taught before. The students worked with an area defined by the U.S. Geological Survey topographic map of the Goleta, CA area (the 7.5-minute quadrangle, 1:24,000 scale). Subsets of the ADL collections (the Catalog and the Gazetteer) were created for class purposes that were also limited to this area. The subset enabled much faster response time from the system, allowing users to explore more of ADL's functions in a shorter period of time. Moreover, the subset was more functional and practical for these users because of its focus on their geographic study area.

The class met twice a week for 10 weeks, and students were expected to attend one of three possible laboratory sessions each week. The two TAs who facilitated the laboratory sessions were graduate students in the department. Because the course was new, and being designed and revised throughout the quarter, there was little time for the professor to consider how to implement ADL within the curriculum. Added to this constraint was the further difficulty of how quickly ADL itself was changing. We were unable to provide the professor with a stable version, including the subset of the collections, until midway through

the quarter. Consequently, he was unable to explore the system in much depth before creating the assignment, nor were the TAs able to spend much time exploring the system and testing the assignment.

In the laboratory sessions, there were three computers available to the students, who worked in groups of two to four. Their assignment was called, "The Map and Imagery Laboratory and the Alexandria Digital Library," and it was intended to introduce them to the resources and services of each. The MIL tasks involved locating specific items, identifying who produced them, and describing the information derived from them. The ADL tasks introduced students to the use of the Gazetteer to find parks and schools in the Goleta area. The assignment culminated with the hypothetical assignment of an article that would require students to query ADL to select several different kinds of maps and other information sources that would address the article topic, "The Drainage, Flora and Fauna of the Goleta Slough: Natural Protection in a Dynamic Setting." They were asked to submit only the reference list, identifying the following information for each item selected: scale, date, source/agency, coverage, series name, map name and index number, type of features shown, and possible uses. The assignment became more of a workbook exercise than a session where georeferenced information was used for a more in-depth study.

Students and TAs interpreted the assignment to mean that they needed to search ADL by scale or resolution to find the relevant items. Because ADL does not currently support using scale or resolution as a query parameter, this proved to be an immediate frustration. When the TAs circumvented this problem by requesting full metadata records for likely items, they discovered that the necessary information was sometimes missing there, too.

Even the more experienced TAs sought support inside the system, and depended on the researcher and ADL project members to answer questions. Their greater experience allowed them to have alternative strategies for seeking assistance. The students, just learning the language of the field of discipline and still struggling with some of the concepts, had few methods to apply to work around the problems they encountered. They were much more likely to attend to the pop-up messages, and to note and infer meaning from the order in which windows opened and the sequence of choices within each. Because the introduction to the system was part of their curriculum, they were also predisposed to expect terms and concepts in the system that matched what they had learned from class.

The assignment also led to the discovery of a problem with the way that date searching had been implemented—items with date ranges that overlapped the query date range were not returned. These difficulties and other compounding factors (end of quarter, students making up missed work, additional time in second week doing make-up of introduction assignment, differences in TA teaching styles), scuttled the plan to extend the use of ADL for additional assignments.

The classroom study proved to be very useful for interface design, even though ADL was not fully ready for classroom use at that time. Some feedback, such as the date-range searching problem, were not known before, and resulted in an immediate fix to the software. Problems with the metadata contributed to the ongoing efforts to correct errors and omissions. Other feedback confirmed the need for additional functionality or redesign that were known before, and gave these particular improvements more priority in the implementation schedule.

Another limitation of this particular classroom trial should be mentioned. Because access to ADL was limited to the UCSB domain during this period, students could not access ADL directly from their off-campus computer access points (if they had them). Because they were introductory-level students, they were also prohibited from using the Geography Department's equipment. They were limited, therefore, to the use of MIL's computer lab where there were only three computers available with the JIGI client. Although this made it convenient to observe their interactions with ADL, it also limited the students' ability to explore the system on their own time.

#### *User Evaluation Findings*

It is useful to present the results of the ADL user evaluations in relation to the following questions:

1. What have we learned about our users?
2. What have we learned about the evaluation and user study approaches?
3. What have we learned about the ADL interface?
4. What have we learned about the functionality and content of ADL?

#### *What have we learned about our users?*

Our primary users are earth scientists, who are already familiar with the content, language, and georeferencing of ADL. For them the contents of the collection are familiar without explanation as to how aerial photographs and remote sensing images, for example, might be useful for a particular purpose. The terminology used in the system is no problem for them, in general. More importantly, perhaps, geographers in particular are familiar with the attributes of the various types of information and the potential value of these types for particular purposes. This is both an advantage for them and a problem in that they have expectations that cannot yet be met by ADL. Earth scientists have no problem with the map browser approach to finding information. But they also expect to be able to use scale and resolution parameters for searching, and this capability is not available in ADL yet. This expectation leads to initial disappointment; they have to accommodate themselves to the more general search capability available. Other users, on the other hand, may have an initial problem with the map browser approach, not understanding how to manipulate the

map and draw a query area. They need more help in understanding what different types of collection objects can be used for and the language used in the interface may be misinterpreted or not understood. They are more likely to be frustrated by this initially, and overwhelmed by the number of available query choices.

These observations were supported by the ethnographic studies of users in action. From the MIL reference interviews, the videotaped interactions with the web prototype and JIGI, and the classroom study, we saw how the experience and background knowledge users have affect the way they interact within either the physical workspace or the virtual one. In the physical workspace, users were able to situate themselves within any part of the environment that they found familiar, such as the reference desk. From this point, at least in the physical workspace of the MIL, users were able to interact with a reference staff person who facilitated the searching and retrieval process. The data show that all the users, regardless of where they are on the task/knowledge proficiency continuum, work well with this facilitated model. In the classroom, we saw how personal help was needed and was provided by TAs or by the study monitor to the degree that they were able to do so—a collaborative help environment among participants.

In both the physical and virtual workspaces, users expected to learn from the interaction, to be educated about the process, and to learn additional strategies for future interactions. In the physical workspace of MIL, this process was implicit in the interaction, with the reference staff working with the user to find the best way to accomplish the task. In the virtual workspace of ADL, the learning process was not as completely supported, and users expressed their frustration at various points throughout their interaction with the system as a result. Commonly, users would wonder aloud, or write in their comments, what they were doing “wrong” or what they did not understand, suggesting that they felt the difficulty resided more within themselves than it did within the system. More proficient users tended to identify problems with the system.

#### *What Have We Learned About the Evaluation and User Study Approaches?*

We are interested at this point in our evaluations in the return on investment (ROI) of the various studies of users. Did the studies yield a commensurate quantity and quality of information that can be used for digital library system modeling and development? Can we use our limited evaluation resources in better, more effective ways? What basis of understanding do we have now to guide what we do next? A related concern is how to structure incentives in such a way to initiate and keep user participation. In other words, the ROI for users who participate in our studies must also be a concern.

In a recent study (Weedman, 1998) on the process of involving clients in application-oriented research, evidence was found of a basic instability in the collaboration between

users and designers that stemmed from the incentives for participation of the two groups. From the system designer perspective, the investment in user studies must be beneficial to the design process. To get the necessary feedback for requirements analysis, the following must hold:

Users must learn enough about technological design to identify the aspects of their work that are relevant to the process and enough to contribute to the conceptualization of changes. Designers must learn enough about users to explore the tasks to be modified and the impacts of the modifications. The time required to converge on mutual understandings from these two different starting points makes the process costly. These costs are particularly difficult to assume for the users because the investment does not lead directly to scientific gain in their own discipline. (p. 338)

Weedman adds that “[a] second stage when resource investment is heavy and asymmetrical is that of testing. Users have difficulty with the need to repeatedly stress the system when the reward is identifying problems. . . .” This leads us to evaluate our study methods on the basis of the investments that were made by both the designers and the users and on the perceived benefits that were received. The best evidence of the results of the review of our evaluation methodologies is the plan for user evaluations for the remainder of the project.

The current ADL system requires user registration, justified by the research nature of the digital library project. ADL preserves the confidentiality of all user data according to University requirements. The registration form is based on our experience with the registration of beta testers for the web version of ADL, on the results of the online survey, and on our observations of users interacting with ADL. The registration form contains 16 parameters, shown in Appendix 1. Internal testing of the registration form showed that it could be filled out quickly; adjustments were made in the form where misunderstanding or sensitivities were discovered.

With this data, we are able to correlate user interactions (as seen in session logs) and user comments to user characteristics. We can view this data by any of the user characteristics, or combinations of characteristics, to inform system design and collection development. We will be able to target particular developments to meet the needs of particular user communities.

Early analysis of 9 months of transaction logs incorporating over 134,000 transactions with the Web prototype (Buttenfield & Kumler, 1996) graphically illustrated the navigation paths users chose through the available interface options. In the next phase of evaluation, both the Colorado evaluation team and the UCSB team will analyze the session logs and user comments in correlation with the user registration characteristics. For the first time, we will be able to distinguish patterns of use by different communities of users. The communities can be designated by registration

characteristics and by the use patterns themselves; for example, by the number of times that the user has accessed ADL, by the amount of time spent connected, by whether the user downloads data, etc. This design will also allow us to do longitudinal analysis on the patterns of use of individual users.

A general on-line survey of registered users will not be used again, based on the problem that we had with getting sufficient representative data. Instead, we have implemented an Exit Poll that is presented to the user after each session. This is an HTML page that is invoked when the user exits the Java client. It asks for a minimal amount of feedback, as seen in Appendix 2. It includes both qualitative and quantitative feedback. We will monitor this approach to see if it gives us more useful data and experiment with ways of presenting the form at other points during a session. If surveys are also used, they will be targeted to specific groups of users, and they will be used in such a way that one set of data can be compared to another—from one time period to another or between multiple sets of users.

The ethnographic studies will continue, and will focus on the use of ADL in university classrooms. The classroom situation has many advantages for the evaluation of ADL as it becomes an operational system. For a classroom assignment, the necessary collection components can be made available through additional targeted additions to the collections and through the creation of specific preselected subcollections for class assignment use. This eliminates the problem seen in other circumstances of users' disappointment with the collection contents. Because ADL is a new digital library system where technology development has taken precedence, the actual set of collections that can be searched have been relatively small. As ADL moves closer to being an operational system, the collections available continue to grow, but still there is not the depth of coverage to meet everyone's expectations. Collections can be built, or selected, for specific classroom assignments, allowing users to focus more on the functionality of the interface and the underlying system. Classrooms also provide an environment where ADL can be used as more than just a retrieval system. Ingest software for adding new data to the collections (e.g., new entries in the gazetteer) and links to processing software (e.g., computer modeling) are planned for ADL, and when this new functionality is available, potential uses in the classroom will greatly expand.

In addition, classrooms are useful because they are temporarily bounded communities, where the identification (and articulation) of terms and their meanings is necessary to build a set of shared knowledge. There is discussion of these matters that can be tracked. Classrooms also have identifiable goals (assignments, requirements) and a context that frames the interaction with ADL, both temporal and subject orientation. The students in a class will tend to have characteristics in common that reduce the variability in user characteristics. Working with a professor and TAs in the use of ADL in the classroom also brings with it the advantage of having those with in-depth knowledge of the subject area,

and information resources in the subject area, engaged in making ADL a useful geolibary system.

The Target User activity was very productive in giving us a basic set of user scenarios and user requirement statements, which the ADL staff used to focus subsequent discussions within the team and with the ADL Design Review Panels. These will be carried forward by scheduling sessions for (1) University of California map librarians, and (2) for UCSB professors who are most likely to be able to use ADL with their classes. In both cases, the participants from the earlier Target User Groups will be invited to participate in these sessions. Because our interactions with the Earth Science community continues through the Institute of Crustal Studies, through classroom activities, and other means, we will not continue the Earth Science target user group per se.

The scenarios we used were relatively simple statements of user interest, and they proved to be very useful in understanding user communities and potential needs for system functionality. We plan to develop these further into more fully described scenarios with additional information such as expected response or delivery time, the equipment and connectivity available, the level of expertise of the user, types of information and formats needed, and more about how the user wants to use the information (e.g., the reason why the information is needed). For more discussion of the use of scenarios in system design, see Carroll (1995).

#### *What have we learned about the ADL interface?*

An outcome of the evaluations of the Web prototype and the Design Review Panel meetings was a set of user requirements for the redesigned system and interface. This was a concrete result that was adopted by the Implementation Team as part of the requirements to orient the new design. Other requirements came from the need to make the system response faster and more reliable, and to create a system design that was scalable and adaptable to changeable components. These requirements include, for example, new basemaps for the Map Browser, new text search functionality, additional collections, distributed collections and queries, and multiple user interfaces using standard interfaces to the system's middleware. Multiple user interfaces is seen as the way in which the system can be adapted to the various user communities.

The user-based requirements list for the new interface is shown in Table 2. Many, but not all, of these have already been implemented.

#### *What have we learned about the functionality and content of ADL?*

As a testbed system, ADL exists more to demonstrate capabilities than to serve communities. However, we have taken the position from the beginning that the best way to demonstrate a digital library is to build one that is as close to operational as possible. This implies target user commu-

TABLE 2. Partial list of requirements for new ADL interface that came from user evaluation studies.

- 
1. Search functions
    - 1.1. The system shall present a unified search screen to the user (integration of gazetteer, catalog and map-based searching)
    - 1.2. Reduced, simplified set of search types for metadata attributes (search buckets); map to ADL and MARC schema
    - 1.3. The user shall be able to select search areas on map (rather than use whole map window as search area)
    - 1.4. User shall be able to search noncontiguous spatial areas
  2. Session management
    - 2.1. A summary view of the session log shall be viewable by the user during the session (query history and corresponding results sets).
    - 2.2. Session log shall be available to ADL help desk personnel.
    - 2.3. User shall be able to stop a query and issue a new one.
    - 2.4. User shall be able to return to a previous point in the session.
    - 2.5. User shall be able to modify and reissue a query.
  3. Result display
    - 3.1. The total number of items in the result set shall be displayed to the user.
    - 3.2. User shall be able to sort result set by type, date, etc.
    - 3.3. System shall display footprint distribution of a result set.
    - 3.4. Set of display formats for metadata shall be defined and implemented.
    - 3.5. Low-resolution browse images that can be enlarged for evaluation will be provided.
  4. User workspace
    - 4.1. The system shall provide a user workspace where selected items can be collected in a set of user-named collections.
    - 4.2. User-saved queries may be reissued to the system during a later session.
  5. Holdings visualization
    - 5.1. The system shall present the user with an overview of the contents of collections by geographic coverage, genre and date.
  6. User help functions
    - 6.1. Search examples will be added to the interface to aid user in creating a query.
    - 6.2. Context-sensitive help will be added.
    - 6.3. Tutorial with FAQ-type information will be available.
  7. Usability features
    - 7.1. Status of process indicator will be added.
  8. Data distribution
    - 8.1. Access to data through online links, offline references, or ordering processes will be clearly displayed.
    - 8.2. The functionality of slicing and dicing large files for delivery will be available.
- 

nities, which in turn, has two major impacts on the system design.

First, a digital library system for a particular community will necessarily be different from one that is designed to simply showcase the system's capabilities. The latter kind of system is relatively easy for engineers to build by themselves, whereas the former requires input from the target user communities, almost always mediated by a nontrivial process of translation between the user and engineering domains.

Second, the library's content will be quite different if it is selected to satisfy the needs of a particular community. Again, engineers can easily load the library with data that exploit specific system capabilities (e.g., image manipulation), but they will likely have no clue as to which data are important to particular external users.

The major advantage of designing for particular user communities is that it gives the designers some goals that are easier to define and engineer than "make the system look good," and it gives the system a high probability of success, at least with the target communities, if those goals are met. The major disadvantage is that the system could wind up embedding idiosyncrasies of the target community (e.g., be exclusively oriented towards remotely sensed imagery), and sacrifice easy generalization to the needs of other communities.

## Future and Potential of ADL

### *Impact on User Communities*

The geolibrary concept that raises the geographic "aboutness" of information of all kinds to a more prominent role will fundamentally reorient our approach to information (National Research Council, 1999). Earth scientists, who are familiar with geospatial orientation when they work with maps, images, and data sets, will be able to extend this approach to other types of information also—to expect that they will be able to search library collections by latitude and longitude coordinates, for example. The general public, on the other hand, is being exposed to more map-oriented services and products. These include weather maps, Web map servers that can display street addresses on maps at various scales, travel atlases that plot out routes between points, and personal Global Positioning System (GPS) units that show current location by receiving signals from satellites. With the development of geolibraries also, *geolocation* will become a more familiar way to view the world and the world of information.

Information services, such as library catalogs, bibliographic search services, and Web search engines, will need to evolve toward including spatial georeferencing for searching and display. Image searching and manipulation and visual displays of all kinds will be expected by users as research, technology, and network bandwidth make it more widely available.

### *Impact on Research Libraries*

Development of the infrastructure to support digital library technology in research libraries requires new and innovative thinking that challenges traditional modes of library management. It requires new service campaigns to the user community; new organizational paths within the library; and new types of personnel, such as systems and network programmers and technologists for operations such as material scanning, digital data ingest, and object processing. Each of these components has its own set of requirements ranging from technology installation and maintenance to skill sets supporting public relations and digital collection development. ADL has started the process by providing personnel for data-metadata ingest; systems personnel for computing and network support and scanning

personnel for converting high-use data sets to digitally accessible files via the Web. This has required adjustments in general library priorities and allocation of resources and space, as well as facilities construction and policy generation for the new operations. As ADL evolves into a general service for the California Digital Library whose charge is to serve the university system as a whole, other issues will require an investment in personnel, resources, and new organizational structures. These issues include: (a) scaling for larger and more complex collections and a significantly larger user community; (b) system interoperability; and (c) distributed collection development and data sharing that involves not only formal libraries but also campus research and teaching units, that will be creating and making available their own digital collections.

Intellectual property rights, which have been a minor concern in the research environment, will have to be addressed and resolved for the operational environment.

### *Impact on teaching*

Geolibraries, when they are fully developed for educational applications, will enable students and teachers to jointly discover and examine information about a broad range of geospatially referenced information. A key capability in this regard will be the ability for teachers to develop collections and have their students create information that is added to these collections. Eventually, with the ability to build specialized collections, the use of ADL can spread out to disciplines ranging over physical and social sciences and the humanities and arts. It will probably be necessary to develop customized interfaces to serve the needs of the broad range of educational settings, from beginning public school level through college, and it will most certainly be necessary to have a well-developed set of terminology and process descriptions to bridge the gaps in expression and background knowledge. To realize this potential of broad use at many levels and across many disciplines, support of mediated use (i.e., help from ADL staff and experts in the subject fields) will also be very important, ideally implemented through collaborative on-line help functions (Prince, Su, Tang, & Zhao, 1999).

### **Conclusion**

The Alexandria Digital Library (ADL) Project has had three main goals: (1) basic research related to digital library issues, (2) development of a geolibrary testbed, and (3) user evaluation of the testbed. The user evaluation work described in this article has shown us many of the needs, practices, and expectations of certain user communities. As a result, this work has not only extended user evaluation into the digital library and geolibrary frameworks, but also has influenced the Project's implementation goals and priorities. Similarly, the user evaluations have provided invaluable user logs, which have been used as case studies in the basic research. For example, they have provided statistics on

typical spatial query diversity used for performance analysis of multidimensional index studies. They have also given the researchers initial access patterns for the development of client/server caching models and analysis. One of the main lessons to be learned from ADL is that when evaluation is completely integrated into digital library research and development, the benefits extend well beyond isolated reports on user reactions to the usability of iterative versions of the system. User evaluation is a critical component of digital library development, both in terms of understanding user communities and in the collection and analysis of use patterns and user comments.

Another aspect of the evaluation, only briefly mentioned, is that of education and outreach. ADL needed to seek out potential users of a geolibrary and educate them as to the potential uses of such a system. As a result, otherwise disparate groups of people have come together to discuss their general spatial data needs, both for access mechanisms as well as content. The users involved in the studies have been able to benefit in many ways. Novice users have increased their knowledge of spatial data and the possibilities of spatial searches. Advanced users, through ADL and other related projects, have been able to impact not only the development of tools of potential use to them, but also the development of standards that greatly assist in the accessibility of spatial data in general.

### **Acknowledgments**

The Alexandria Digital Library project is supported by NSF, DARPA, and NASA under NSF IR94-11330. Dan Montello (UCSB) is responsible for the statistical analysis of the online survey data. Please see (Hill et al., 1997) for more details of the findings. Robert Nideffer and Nathan Freitas, ADL interface designers, worked with the Evaluation Team in the design of the registration form and the exit poll. We also acknowledge the contributions from the ADL Design Review Panel and other members of the ADL Evaluation and Implementation Teams. The comments of reviewers were very helpful in putting the important finishing touches to this article.

### **Appendix 1—ADL User Registration Form**

01. Name: *[freetext]*
02. Email Address: *[freetext]*
03. Sex: {*male, female, other, decline to answer*}
04. Age range: {*13 or under, 14–18, 19–22, 23–29, 30–34, 35–39, 40–49, 50–59, 60–69, 70 or over, decline to answer*}
05. Organizational affiliation: {*commercial, education, government, military, non-profit, other*}
06. Primary functional role: {*student: college/university or high school or middle school or elementary, teacher/professor, library/information specialist, application developer, administrator/manager, consultant, other*}
07. Primary area of interest: {*arts & humanities, computer*}

science, engineering, environmental sciences, GIS, law, library/information sciences, military, natural sciences, physical sciences, social sciences, other}

08. Highest degree achieved: {none, high school or equivalent, trade/technical school, Associate of Arts, Bachelor of Arts/Science, Masters, medical degree, law degree, doctorate, other}

PROFICIENCY LEVELS: {novice, intermediate, expert}

09. Geospatial Data  
10. Searching On-line Catalogs  
11. World Wide Web  
12. Computers  
13. How many times have you used the prior ADL Web Interface? {none, 1–4, 5–10, over 10 times}  
14. How did you discover the existence of ADL? {meeting presentation, teacher/professor, colleague, ADL contact, publication (e.g., article), library reference, WWW browsing, WWW search engine, other}  
15. Please list any physical limitation(s) that affect your use of ADL (optional): [freetext]  
16. Please list any language(s) you would prefer to use with ADL (optional): [freetext]

## Appendix 2—ADL Exit Poll Form

01. Please describe your session. Were you looking for or expecting something in particular? [freetext]

USABILITY RATING: {low, moderate, high}

02. Usability of ADL interface  
03. Usability of ADL content  
04. Suggestions, comments, and/or questions: [freetext]

Would you like to be contacted about the information you provided? {Yes I would, No Thank you}

## References

- Alexandria Digital Library—UCSB. (1995). Alexandria Digital Library prototype CD. Redlands, CA: Environmental Systems Research Institute.
- American Geological Institute. (1998). GeoRef. A description of this file can be found at <http://library.dialog.com/bluesheets/html/bl0089.html>.
- Buttenfield, B.P., & Kumlner, M.P. (1996). Tools for browsing environmental data: The Alexandria Digital Library interface. Proceedings Third International Conference on Integrating Geographic Information Systems and Environmental Modeling. Santa Fe, NM, January 21–25. Also available at [http://www.ncgia.ucsb.edu/conf/SANTA\\_FE\\_CD-ROM/sd\\_papers/buttenfield\\_babs/babs\\_paper.html](http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sd_papers/buttenfield_babs/babs_paper.html).
- Carroll, J.M. (Ed.). (1995). Scenario-based design. Envisioning work and technology in system development. New York: John Wiley.
- Goodchild, M.F. (1998). The geolibary. In S. Carver (Ed.), Innovations in GIS. London: Taylor and Francis.
- Hill, L.L., Dolin, R., Frew, J., Kemp, R.B., Larsgaard, M., Montello, D.R., Rae, M.-A., & Simpson, J. (1997). User evaluation: Summary of the methodologies and results for the Alexandria Digital Library, University of California at Santa Barbara. In C. Schwartz & M. Rorvig (Eds.), Proceedings of the American Society for Information Science (ASIS) Annual Meeting, Washington DC, November 1997. (<http://www.asis.org/annual-97/alexia.htm>) (pp. 225–243, 369). Medford, NJ: Information Today.
- Mulaik, S.A. (1972). The foundations of factor analysis. New York: McGraw-Hill.
- National Research Council Mapping Science Committee. (1999). Distributed Geolibraries: Spatial Information Resources. Summary of a Workshop held June 15–16, 1998. Washington, DC: National Academy Press. <http://www.nap.edu/html/geolibraries>
- Prince, R., Su, J., Tang, H., & Zhao, Y. (1999). The design of an interactive online help desk in the Alexandria Digital Library. Proceedings of the International Joint Conference on Work Activities Coordination and Collaboration, WACC'99, Feb. 22–25, San Francisco, CA.
- Research Libraries Group. (1989, Spring). RLG enters new sphere with geoinformation project. The Research Library Group News, 19, 3–9.
- Smith, T.R., Andresen, D., Carver, L., Dolin, R., Fischer, C., Frew, J., Goodchild, M., Ibarra, O., Kemp, R.B., Kothuri, R., Larsgaard, M., Manjunath, B.S., Nebert, D., Simpson, J., Wells, A., Yang, T., & Zheng, Q. (1996). A digital library for geographically referenced materials. Computer (IEEE), 29(5), 54–60.
- University of California Library Planning & Action Initiative. (1998). Planning the library of tomorrow. <http://www.lpai.ucop.edu/>.
- Weedman, J. (1998). The structure of incentive: Design and client roles in application-oriented research. Science, Technology, & Human Values, 23(3), 315–345.