The Roles of Digital Libraries In Teaching and Learning

Gary Marchionini and Hermann Maurer

Libraries have long served crucial roles in learning. The first great library, in Alexandria 2,000 years ago, was really the first university. It consisted of a zoo and various cultural artifacts in addition to much of the ancient world’s written knowledge and attracted scholars from around the Mediterranean, who lived and worked in a scholarly community for years at a time. Today, the rhetoric associated with the National/Global Information Infrastructure (N/GII) always includes examples of how the vast quantities of information that global networks provide (i.e., digital libraries) will be used in educational settings [16]. This paper describes how digital
This paper describes how digital libraries are evolving to meet the needs of teaching and learning and identifies issues for continued development. We distinguish formal, informal, and professional learning and argue that digital libraries will allow teachers and students to use information resources and tools that have traditionally been physically and conceptually inaccessible. We illustrate the types of information resources digital libraries offer to teachers and learners and discuss some of the issues and challenges digital libraries present for teaching and learning.

**How Do Libraries Support Teaching and Learning?**

A library is fundamentally an organized set of resources, which includes human services as well as the entire spectrum of media (e.g., text, video, hypermedia). Libraries have physical components, such as space, equipment, and storage media; intellectual components, such as collection policies that determine what materials will be included and organizational schemes that determine how the collection is accessed; and people, who manage the physical and intellectual components and interact with users to solve information problems.

Libraries serve at least three roles in learning. First, they serve a practical role in sharing expensive resources. Physical resources, such as books and periodicals, films and videos, and software and electronic databases, and specialized tools, such as projectors, graphics equipment, and cameras, are shared by a community of users. Human resources—librarians (also called media specialists or information specialists)—support instructional programs by responding to the requests of teachers and students (responsive services) and by initiating activities for teachers and students (proactive services). Responsive services include maintaining reserve materials, answering reference questions, providing bibliographic instruction, developing media packages, recommending books or films, and teaching users how to use materials. Proactive services include selectively disseminating information to faculty and students, initiating thematic events, collaborating with instructors to plan instruction, and introducing new instructional methods and tools. In these ways, libraries serve to allow instructors and students to share expensive materials and expertise.

Second, libraries serve a cultural role in preserving and organizing artifacts and ideas. Great works of literature, art, and science must be preserved and made accessible to future learners. Although libraries have traditionally been viewed as facilities for printed artifacts, primary and secondary school libraries often also serve as museums and laboratories. Libraries preserve objects through careful storage procedures, policies of borrowing and use, and repair and maintenance as needed. In addition to preservation, libraries ensure access to materials through indexes, catalogs, and other aids that allow learners to locate items appropriate to their needs.

Third, libraries serve social and intellectual roles by bringing together people and ideas. This is distinct from the practical role of sharing resources in that libraries provide a physical place for teachers and learners to meet outside the structure of the classroom, thus allowing people with different perspectives to interact in a “knowledge space” that is both larger and more general than that shared by any single discipline or affinity group. Browsing through a catalog in a library provides a global view for people engaged in specialized study and offers opportunities for serendipitous insights or alternative views. In many respects, libraries serve as centers of interdisciplinarity—places shared by learners from all disciplines. Digital libraries extend such interdisciplinarity by making diverse information resources available beyond the physical space shared by groups of learners. One of the greatest benefits of digital libraries is bringing together people with formal, informal, and professional learning missions.

Formal learning is systematic and guided by instruction. It takes place in courses offered at schools of various kinds and in training courses or programs on the job. The important roles libraries serve in formal learning are illustrated by their physical prominence on university campuses and the number of courses that make direct use of library services and materials. Most of the information resources in schools are tied directly to the instructional mission. Students or teachers who wish to find information outside this mission have in the past had to travel to other libraries. By making the broad range of information resources discussed in this article available to students and teachers in schools, digital libraries open new learning opportunities for global rather than just local communities.
Like informal learning, it is mainly self-directed; but unlike formal or informal learning, it is focused on a specific field closely linked to job performance, aims to be comprehensive, and is acquired and applied longitudinally. Since professional learning affects job performance, corporations and government agencies support libraries (often called information centers) with information resources specific to the goals of each organization. The main information resources for professional learning, however, are personal collections of books, reports, and files; subscriptions to journals; and the human networks of colleagues nurtured through professional meetings and various communications. Many of the data sets and computational tools of digital libraries were originally developed to enhance professional learning.

The information resources—both physical and human—that support these types of learning are customized for specific missions and have traditionally been physically separated, although common technologies such as printing, photography, and computing are found across all settings. This situation is depicted in Figure 1. Digital libraries combine technology and information resources to allow remote access, breaking down the physical barriers between resources. Although these resources will remain specialized to meet the needs of specific communities of learners, digital libraries will allow teachers and students to take advantage of wider ranges of materials and communicate with people outside the formal learning environment. This will allow more integration of the different types of learning, as depicted in Figure 2. Although not all students or teachers in formal learning settings will use information resources beyond their circumscribed curriculum and not all professionals will want to interact even occasionally with novices, digital libraries will allow learners of all types to share resources, time and energy, and expertise to their mutual benefit. The following sections illustrate some of the types of information resources that are defining digital libraries.

**Scientific Data Sets**

An enormous amount of attention is being given to making data sets collected by scientific projects available to broader communities of users. International efforts such as the Earth Observing System and the human genome project demand large investments of public resources and create huge volumes of data. Multiple forces act to promote the development of digital libraries of scientific data from these projects. First, the tools used to collect, transmit, and analyze data generate or require digital signals; thus, the information materials are in digital rather than paper form. Second, the data must be made available to scientists worldwide on a timely basis, and digital electronic networks make this possible. Third, the huge public investments involved encourage scientists to disseminate data as widely as possible to maintain public support and further educational and social progress. Providing access to these data sets through electronic libraries is an important challenge, especially in the U.S., where the law mandates that publicly supported scientific data be made freely available to citizens (see the sidebar by Gey).
Although electronic journals are becoming more common, they have not achieved as much penetration as many expected.

One example of how primary data sets are used in education is the Earth System Science Community Curriculum Testbed project, which links students and teachers in high schools and universities in an effort to build an earth system science (ESS) community (http://www.circles.org). The project aims to build a curriculum for the interdisciplinary field of ESS by linking teachers of physics, chemistry, biology, and other sciences to ESS scientists and NASA data sets. Teams of students in each classroom explore topics such as acid rain and global warming by taking advantage of a growing electronic community of students, teachers, and researchers. Using tools such as Mosaic, FTP, and Stella, teachers and students in schools in North America access data sets at different levels of representation, analyze the data, simulate scenarios, collaborate with scientists and students at remote sites, and publish reports. This project, funded as part of the NASA digital library initiative, illustrates how electronic technology can support collaboration among scientists and students and how digital libraries of data, messages, and student reports are grown and managed. The ESS community is thus manifested as an organic, evolving digital library that includes primary data sets, conversations about them, and the results of using them.

Other Data Sets
Textual databases of classic works (out of copyright) and image collections for important artistic exhibits or museums have been assembled by scholars and made available through the Internet. (See [13] for a collection of arts and humanities electronic resources and projects.) As more schools and individuals acquire access tools and funds, it is likely that private digital libraries will move out of specialized markets to provide access to primary information for a fee. For-profit companies such as publishers of print, music, and film products and radio and television broadcasters own enormous volumes of information, and international information infrastructures will create new markets for that information. Teachers and learners will likely not be heavy on-demand users for this information but rather want to use it as the raw material for study and for integration into instructional presentations. How these materials will be made available and what “fair use” policies will evolve remain to be determined.

Electronic Journals
Although electronic journals are becoming more common, they have not achieved as much penetration as many expected [23, 24]. As electronic journals develop, they will certainly improve informal and professional learning and will likely become useful resources in the K-12 arena, which has traditionally maintained only modest journal collections in schools. Two common approaches to electronic journals are (1) to store files in LaTeX, PostScript or ASCII form in a fileserver and email the files or allow FTP access to them (the “generic approach”); and (2) to store documents in hypertext/hypermedia systems and allow on-line browsing and perusal (the “hypertext approach”). The first sidebar gives a sample of electronic journals that use the generic approach; the second sidebar gives a sample of those using the hypertext approach.

The main problems that these publications solve to different degrees are related to information retrieval support, display of complex graphics and formulas, and distribution speed and reliability. A recent journal using the “hypertext approach” is J.UCS, the Journal of Universal Computer Science (see http://www.iicm.tu-graz.ac.at/Cjucs_root or send an email for general information to jucs@iicm.tu-graz.ac.at with subject [info]). It addresses these three problems by using a range of searching techniques, including scoped searches; using HFT, RTF, and particularly LaTeX and PostScript as file formats to provide high-quality display; and using a worldwide network of what started as 65 “foundation servers” to remove many of the access-time problems associated with earlier attempts.

Newsgroups, Listservs, and Mail Archives
Perhaps the first examples of digital libraries in networked environments were the archives produced by the many USENET newsgroups and listservs available through global networks. News reading and filtering programs [21, 25] and search tools such as Archie and Veronica [7] provide rudimentary aids for locating information in these electronic discussions. Listservs are used for specialized projects (the ESS project previously mentioned and the Perseus project both have listservs) and for distance education courses. In a cable television course taught by Marchionini, a listserv was used by students to present “one-minute papers” at the conclusion of each session. This provided continuity between sessions and personalized the interactions between the instructor and students, who would otherwise have only remote telephone access during live sessions. In another semester, students in graduate seminars
in human-computer interaction taught by Marchionini at the University of Maryland and Borgman at UCLA collaborated on term projects through email and FTP services. Students gained broader perspectives by virtue of the diversity in backgrounds that students from the different schools brought to the courses, and both positive collaborations and “techno-bullying” were observed. See [15] for a set of experiences in the virtual classroom.

In another setting, Maurer used Hyper-G [17] as both electronic library and discussion forum. In a 200-student class on “Societal Aspects of Computer Science,” some 50 high-quality papers from specialists were made available to students via Hyper-G as the basis of a wide-ranging electronic discussion. Students were able to comment on papers and earlier comments, the structure of the discussion being visualized using the XWindows client Harmony [11]. The experiment created a network of over 4,000 hyperlinked documents. Students remained “semi-anonymous” to encourage free discussion: that is, students were allowed to choose arbitrary pen names known only to each individual and to the instructor (the latter because student evaluation was based on the quality of contributions). The experiment exemplifies blurring of the borderlines between electronic libraries and (CSCW) [8]—the semistructured threads of conversation that make up news archives and lists provide another type of digital library product that will find increasing use in both formal and informal learning.

**Selected electronic journals providing generic access**

**Numerische Mathematik Electronic Edition**
Sponsor: Journal of the same name  
Topic: Mathematics  
Format: TeX and LaTeX  
Features: Every electronic issue some two weeks before the printed issue  
Access: EM-Helpdesk@springer.de.

**Electronic Publication**
Sponsor: MIT  
Topic: Theoretical computer science  
Format: LaTeX or PostScript  
Features: Subscribers receive a notice each time an article is published; available for FTP  
Access: Fisher@mitvma.mit.edu.

**EJournal**
Sponsor: University of Albany  
Topics: Theory and practice surrounding electronic “text”; social psychological, literary, economic, and pedagogical implications of computer-mediated networks  
Format: Plain Ascii  
Features: Listserved  
Access: EJOURNAL@ALBANY.bitnet.

**Asia-Pacific Journal (APEX-J)**
Sponsor: University of Hawaii  
Topic: Education in multicultural, international campuses  
Format: Plain Ascii  
Features: Quarterly  
Access: JamesS@UHunix.UHcc.Hawaii.edu.

**Digest of Physics News Items**
Sponsor: American Institute of Physics, by Phillip F. Schewe  
Topics: Physics  
Format: Plain Ascii  
Features: Posted in the Internet newsgroup sci.research; back issues can be downloaded by FTP from NIC.HEP.NET.  
Access: physnews@aip.org

**Specialized Hypermedia Corpora**
A variety of hypermedia materials are becoming available, and these collections are often served from a library rather than through dedicated machines in classrooms. The Perseus hypermedia corpus (2.0) includes about 200 plays, books, poems, and text fragments in Greek and in English translation; almost 25,000 24-bit color images of vases, sculpture, coins, and sites; maps; site plans; and a variety of search, navigation, and display tools [6, 20]. Hundreds of colleges and scores of high schools are currently using Perseus to support instruction in Greek language, ancient history, Greek literature, religion, archaeology, and art history. At many sites, Perseus is delivered through a campus network. In some sites, Perseus is provided on a standalone machine in a library. The many CD-ROM corpora now available for specialized topics challenge schools and individuals to be judicious in acquisition and use of these materials, thus increasing the need for resource-sharing functions of libraries.

Another instance of an emerging corpus of material entering digital libraries is the PC library [19], a product developed by a publishing consortium. Originally designed for standalone PC applications, it has now migrated to client/server architecture. At the time of writing, some 40 substantial reference volumes, including a 10-volume encyclopedia (“Meyer A—Z”), dictionaries for most European languages (“Langenscheidt dictionaries”), the famous German-English “Oxford Duden,” and standard scientific reference books on medicine,
computer science, and CAD are either available or in preparation. Some of them contain high-quality diagrams and pictures. Two aspects of the PC library are particularly worth mentioning. First, an arbitrary subset of the books in the library can be “activated” at any time, and all searches (including fuzzy full text) are carried out only within the books activated. Second, the PC library is not just a set of static books but can be used in a variety of modes other than read-only; users can leave comments (for themselves or for others); searches can be activated from other applications; books can be augmented by additional (personal) entries, including multimedia material (e.g., personal pictures or video clips); and material is automatically hyperlinked using a keyword-based technique.

Indexes and Directories
A host of bibliographic and catalog databases may be included in digital libraries. These range from the more than 20-million-record database of bibliographic citations in OCLC to the millions of citations in on-line databases for specialized literatures such as medicine (e.g., MEDLINE) and engineering (e.g., NTIS). Tertiary databases such as citation indexes and databases of directories make information-seeking more effective but require specific skill and effort on the part of information-seekers. Many of the thesauri for specialized literatures are available in electronic form (e.g., Medical Subject Headings, ACM Computing Reviews Classification System), and techniques for merging and filtering these languages to allow users to search across multiple databases are emerging. Although most indexes to image and sound collections currently use words from captions or titles, new pattern-matching techniques are emerging to categorize and classify multimedia objects [10]. In the past, bibliographic instruction has been provided by librarians as a supplement to “regular” courses, but widespread availability of digital libraries will require remote instruction and support related to information-seeking skills and knowledge.

Electronic Search and Display Tools
It has often been said that the Internet is starting to provide the largest library humankind has ever had. As true as this may be, the Internet is also the messiest library that ever has existed. Navigation and display tools such as Mosaic allow users to browse the World-Wide Web and display text and multimedia objects. Search tools such as the Wide-Area Information Server (WAIS), Archie, and Veronica allow people to search specific directories or list archives (see [22] for an overview of tools). However, in addition to index and directory services or navigation tools, it has become apparent that such “a posteriori” tools to organize the unstructured Internet universe are not sufficient. Rather, some “a priori” structuring is necessary. This was done quite successfully first with Gopher [3] and later with WWW [5]. However, “first-generation hypermedia

**Selected electronic journals providing hypertext access**

**MUSE**
- Sponsors: Johns Hopkins University Library and Homewood Academic Computing
- Topic: JHU Press journals
- Access: telnet://jhuniverse.hcf.jhu.edu:20001/

**Journal of Computer-Mediated Communication (JCMC)**
- Sponsor: Annenberg School of Communication, Univ. of Southern California
- Topic: Interpersonal and social aspects in communication networks

**Electronic Journal of Combinatorics**
- Sponsors: Georgia Institute of Technology and the American Mathematical Society.
- Topics: Combinatorics, graph theory, and discrete algorithms

**Newsletter of the National Research Center on Student Learning (NRCSL)**
- Sponsor: Learning Research and Development Center
- Topic: Education

**Journal of Universal Computer Science (JUCS)**
- Sponsors: Springer Publishing Co. and Graz Univ. of Technology
- Topics: All areas of computer science
- Access: http://www.lcim.tu-graz.ac.at/Jucs/hr-root
techniques” do not seem to be sufficient for large amounts of data; “second-generation techniques” [4], involving distributed database mechanisms, scope definition facilities for searches, bidirectional link databases [14] for automatic link maintenance, and other advanced techniques, are emerging. For example, Harmony [11], the XWindows client for Hyper-G, WWW, Gopher, and WAIS, provides sophisticated navigational facilities when used in conjunction with a Hyper-G database: The facilities include visual “local maps” of all in- and outgoing hyperlinks, a 3D landscape generator, a history and hierarchy browser, Boolean searches on attributes, and full text searches including approximate matches in user-defined scopes that may arbitrarily cross even the physical boundaries of servers. Such features will make working with large electronic libraries less frustrating than it sometimes is now, and will certainly ensure the use of electronic libraries is more efficient than using large amounts of printed material. As these tools evolve, better integration of search and display will be necessary. One approach is dynamic queries [2] that provide graphical representations for database elements and sliders for adjusting parameters on those elements. As parameters are changed, the graphical display is immediately updated, providing immediate visual answer sets.

Digital Libraries In Education: Promises, Challenges, and Issues

The examples above illustrate that digital libraries have obvious roles to play in formal learning settings by providing teachers and learners with knowledge bases in a variety of media. In addition to expanding the formats of information (e.g., multimedia, simulations), digital libraries offer more information than most individuals or schools have been able to acquire and maintain. Digital libraries are accessible in classrooms and from homes as well as in central library facilities where specialized access, display, and use tools may be shared. Remote access allows possibilities for vicarious field trips, virtual guest speakers, and access to rare and unique materials in classrooms and at home. The promise is one of better learning through broader, faster, and better information and communication services. These physical advantages promise several advantages to teachers and learners by extending the classroom; however, as with all technologies, there are costs and tradeoffs associated with these advantages.

One clear difference between traditional libraries and digital libraries is that digital libraries offer greater opportunity for users to deposit as well as use information. Thus, students and teachers can easily be publishers as well as readers in digital libraries. The number of student-produced “home pages” continues to grow as teachers and students not only bring digital library information into the classroom but move the products of the classroom out into the digital libraries. Just as distinctions between publishers and readers are becoming less clear in networked environments, Internet access in classrooms blurs distinctions between teaching and learning. Students bring interesting and important information to class discussions and in many cases lead teachers and classmates to new electronic resources and tools. Teachers increasingly will find themselves in the important roles of moderators and critics, modeling for students ways to examine and compare points of view and look critically at information. Teachers who have begun using networked materials in their classes are early adopters of new ideas and technologies and are comfortable sharing power with students. Just as “authority of information” has become an issue in professional communities that leverage networks, the authority of information in classrooms, which has traditionally rested solely with teachers, will increasingly be challenged by students locally and remotely.

Digital libraries will support communities of interest and allow more specialized courses to be offered. For example, students at different high schools in the CoVis project collaborated by sharing a digital library of weather data [12], and students in the ESS Community Project described earlier share a variety of NASA data in classes in Washington, D.C., St. Louis, Los Angeles, and New Mexico. Telecourses have already allowed rural schools to offer advanced placement courses to a few students by sharing teachers across geographical distances. As network access improves in schools, highly specialized courses offered on a distributed basis will become common, and it is likely that some of these will be offered by.
students. Internet-based courses have already been offered successfully, although mainly on the topic of the Internet itself, and network-based electronic conferences have proven effective (e.g., University of Maryland Professor Thomas O’Haver recently ran a chemistry conference that involved 450 participants from 35 countries).

The most important changes digital libraries bring may be in advancing informal learning. The same advantages that accrue to classroom learning also accrue to individuals pursuing their own learning. In many ways, Freenets are extensions of the public library system. Digital libraries are digital schools that offer formal packaging for specific skills and topics as well as general browsing for creative discovery and self-guided, informal learning. The design community has already begun to consider ways to support learning on demand in electronic environments [9] to address problems of coverage (since no learning system can cover all things learners may need) and obsolescence (systems and knowledge changes).

For the promises to be fulfilled, issues of access and intellectual property must be addressed. Although the U.S. Library of Congress has committed to becoming a digital library, it can make available only documents or finding aids created within the library or government agencies, items out of copyright, and representations from exhibits or events sponsored by the library. Although these represent enormous quantities of information, the core holdings of the library—the books, films, and recordings—cannot be made available electronically under current copyright law. Whether the copyright law will change to allow materials to be accessed electronically under some educational fair-use arrangements remains to be settled. Curators, theater owners, and publishers are loath to give up restricted access, due to understandable self-preservation concerns. Some of these fears may be unfounded. For example, in the 1930s, owners of professional baseball clubs allowed only World Series games to be broadcast on the radio, because they feared that attendance at regular games would go down if all games were broadcast. When Lawrence MacPhail in Cincinnati began to broadcast the Reds’ games in 1938, entire new markets opened up beyond the traditional male attendees—women and men who previously did not know much about baseball became interested and attendance went up (Ken Burns’ PBS series Baseball). Additionally, entire new revenue streams from advertising became available, which today eclipse attendance profits. However, historical examples are not likely to be enough to convince publishers and other information industry entities to make their “property” available electronically without secure mechanisms for profit.

Even more challenging, however, is building intellectual infrastructures for digital libraries. These include techniques for using electronic information in teaching and learning [18]. Teachers must learn how to teach with multimedia resources and how to share informational authority with students. Designing activities that take advantage of digital library resources requires time and effort to examine what is available and integrate information into modules and sequences appropriate to the students and curriculum. Furthermore, modeling the research process for students requires teachers to grapple with problems on the fly, make mistakes, recover, react to dead ends, and demonstrate all the other uncomfortable and frustrating aspects of problem-solving. Like Euclid, who presented the products of geometric research in the form of neat, polished deductive proofs (rather than the empirical and intuitive thought that led to the theorems), teachers are more comfortable providing polished packages/modules rather than the messy details of discovery and problem-solving. Applying digital libraries in classrooms requires different attitudes and tolerances for such learning conditions.

Just as teachers must learn new strategies for using electronic tools in teaching, students must learn how to learn with multimedia (both actively and passively) and how to take increased responsibility for directing their own learning. In our observations of students in classrooms where Perseus was used, students expressed concerns about taking notes: because a screen of text, a screen of vases, and the instructor’s verbal comments were concurrently available, they did not know what to write down! Although better technological tools, such as networked laptop computers, may solve the technical problem, the issues of what to attend to and how multiple streams of information should be integrated require new combinations of perceptual, cognitive, and physical skills for learning. In short, building intellectual infrastructures requires intellectual, emotional, and social breakthroughs for teaching and learning.

At the nexus of physical and intellectual infrastructure is the interface to the digital library. Tools for finding, managing, using, and publishing electronic information must be both powerful and easy to use. Digital libraries must provide a mix of software and people to provide reference assistance and question-answering services (e.g., Ackerman’s Answer Garden system for handling XWindows questions [1]). The people in the digital library will go beyond reference to serve as teachers on demand. They must be aided by software that shunts “typical” questions toward pathfinders or frequently-asked-
question services. Thus, digital libraries will extend what has been the most beneficial feature of electronic networks—communication—to teaching and learning settings. Good interfaces will allow learners to take advantage of digital resources equally well in classrooms, homes, and offices.

Clearly, digital libraries have important roles to play in teaching and learning. Existing physical schools and libraries will continue to exist, since they serve cultural and social as well as informational roles. There will always be a need for physical objects and social settings in learning; the vicarious is not enough. Parents will continue to demand child care, assurances of organized and shared culture beyond television, and human direction and guidance in learning at all levels. These demands will also be augmented by digital environments. Digital libraries will allow parents, teachers, and students to share common information resources and to communicate easily as needed. In special cases, work, school, and play may become one—novice and professional learners collaborating with common information resources to solve real problems. In many respects, digital libraries will become digital schools. This represents a return to Alexandria, in which learners of all types will come together to share and explore information and expertise.

References

About the Authors:
GARY MARCHIONINI is associate professor of information science at the University of Maryland. Current research interests include human-computer interaction, information seeking in electronic environments, electronic publishing, and educational psychology. Author’s present address: College of Library and Information Services, University of Maryland, College Park, MD 20742, march@umd.md.edu.

HERMANN MAURER is professor and head of the Institute for Information Processing and Computer Supported New Media at Graz University of Technology in Graz, Austria. Current research interests include languages and their applications, data structures and their efficient use, telematic services, computer networks, computer assisted instruction, computersupported new media, hypermedia systems and applications, and social implications of computers. Author’s present address: University of Technology, in Graz, Schießsattgasse 4a A-8010 Graz, Austria, hmaurer@icm.tugraz.ac.at.