*A Model and Research Agenda for Educational Community-based Digital Libraries: The Digital Library for Earth System Education**

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Abstract

While digital library development has greatly advanced in the past five years, there is as yet little research demonstrating the efficacy of digital library technology on teaching and learning. This paper presents an initial articulation of a model of the critical dimensions of digital library implementation in educational settings, based on the development of the Digital Library for Earth System Education (DLESE). It also suggests how such a model may contribute to an understanding of how digital libraries are used and valued.

1 Introduction

With the Information Age, our notions of community libraries are evolving from bricks and mortar to disciplinary digital libraries. The past decade has witnessed the increasing ubiquity of the World Wide Web in homes and schools, the emergence of new kinds of "electronic communities" [11, 47, 50], and the widespread creation and distribution of digital educational materials. Digital libraries are becoming a means for disciplinary communities to share, organize, and assess their intellectual holdings. To date, there are many digital library efforts underway aimed at improving K-12 and undergraduate science education [5, 21, 35]. In the United States, the National Science Foundation (NSF) and other federal agencies such as NASA, the Defense Advanced Research Projects Agency (DARPA), and the Library of Congress have established a priority for the development of digital libraries and related technologies [48]. For the past three years, NSF has been supporting the establishment of the National Science Digital Library (NSDL), a national educational digital library that will constitute an online, integrated network of learning environments and resources for science, mathematics, engineering, and technology (SMET) education at all levels [39, 42]. These initiatives are, in part, a response to the larger national science education agenda put forth by NSF, the American Association for the Advancement of Science (AAAS), and others [38, 40, 41, 44-46]. This agenda calls for a variety of reforms, including inquiry-based science learning, an emphasis on the process of "doing science," and the integration of scientific research into education. Digital libraries promise to be a powerful tool in realizing the goals of these reform initiatives.

1.1 Digital library efficacy in educational settings

However, because educational digital libraries are still in their infancy, we lack data about their use and ultimate systemic effectiveness [5, 51]. Little research has been conducted on the actual implementation of educational digital libraries by one of their most important targeted classes of end users—educators and learners in formal educational settings. In addition, few of the technological, logistical, and economic aspects of integrating digital libraries into formal education have been studied [37].

Realizing the potential of digital libraries for education will clearly be hampered by the lack of data about their implementation in classroom cultures. This paper suggests an initial articulation of a model of the critical dimensions of digital library implementation in educational settings. From this model and subsequent research agenda, we anticipate that it will be possible to derive implications for "best practices" for embedding digital libraries in a variety of educational settings. The primary question of how educators in various formal educational settings use digital libraries to enable teaching and support learning should also, over time, yield valuable information about the factors that facilitate or inhibit use, as well as how use evolves over time and through experience. Without an understanding of these basic issues, the ultimate questions of the value of digital libraries to the educational enterprise will remain unanswered.

This model and research agenda is driven by the issues of how educators use and derive value from digital libraries. and the subsequent identification of critical variables to begin to explain conditions of

Proceedings of the 5th Russian Conference on Digital Libraries RCDL2003, St.-Petersburg, Russia, 2003

digital library use. It is our expectation that this model will provide a framework not only for continued understanding and development of our own digital library development efforts, but also for the efforts of others in the broader digital library community.

2 The Digital Library Agenda

2.1 A network of learning environments

A digital library is not merely a portal to collections of information; it is an organized and managed system of data that can serve as a rich resource for its user community. There is currently no standard definition of digital libraries; however, the presence of digital resources, community networking, managed collections, and services are widely held as elements that distinguish a library from a portal or search engine, such as *Yahoo* [1, 13]. NSF describes a digital library as "a network of learning environments and resources" that will be managed to promote reliable anytime, anywhere access to content and services. In their fullest sense, educational digital libraries should provide "reusable, shareable, and interoperable resources that enable learners at all levels to access and use reviewed materials both within and across traditional SMET disciplinary boundaries" [43].

Much of the momentum of the digital library movement rests on the assumption that, by providing ready access to high quality educational resources, teachers will teach better and students will learn more. While intuitive and appealing, this is a largely untested assumption [54]. The little evidence that does exist is encouraging: research on the University of Michigan Digital Library Project [60] indicates that the primary benefit of digital libraries in the classroom is improved means and opportunity for inquiry-based learning. There is also some evidence to suggest a positive correlation between integrating electronic information sources into the classroom and increased scholastic success [36].

2.2 Digital library research

As is the case with any emerging technology, the bulk of the digital library research has been conducted at the micro and technical implementation level. Studies concerning such topics as portal design, ways of indexing information, copyright privileges, and electronic journal pricing models [30] contribute to technical aspects of digital library development. Research addressing digital library usage by end users such as teachers and learners, however, has been less common.

The ongoing study of the Alexandria Digital Earth Prototype (ADEPT) at the University of California, Santa Barbara [5] is focused on student use of the library based upon geography education standards. Preliminary data on ADEPT usage from one year's classroom observations of teachers indicates considerable variation in teaching styles and course content. ADEPT's research plan will ultimately produce a set of student performance assessment instruments for quantitative measurement of skills particular to scientific thinking in geography. Other research at the University of Illinois compared attributes of digital libraries and traditional libraries in examining how readers used scientific journals in print and digital environments [51]. Results of this effort were formative and aimed at removing barriers to use. The Perseus Project, a body of multimedia materials and tools concerned with the ancient Greek world, performed an overall system evaluation based on four criteria: 1) learning, 2) teaching, 3) system, and 4) content. Their results were numerous and included evidence of recurring problems with library access due to hardware and software reliability problems, the need for guidance and support in using digital libraries (both for teachers and students), and issues concerning the speed and amount of information that digital libraries provide [31].

3 Libraries and Learning

Given the nascent state of digital library implementation research, it is reasonable to turn to traditional library literature to more fully inform our understanding of critical issues in this domain. In the realm of traditional library research, several library characteristics have been studied in terms of their impact on student learning. Size of school library collection has been shown to be a positive predictor of student learning achievement [15, 18, 28]. In the context of digital libraries, the problem shifts from building a collection of sufficient size to the problem of filtering an overabundance of data and maintaining collection quality [20].

Frequency of library use has also been shown to be a positive predictor of student learning achievement in traditional libraries [26]. This result may extend to digital libraries; in the similar context of Internet search engines, student facility with technology emerges as the primary success factor [4, 32], outranking domain or topic knowledge, or type of query. Many studies also show that well-planned and well-integrated uses of the library into the curriculum can have a positive effect on such student learning measures as reading comprehension, study skills and SAT scores [4, 10, 19, 32, 33].

Traditional library research has more recently examined the impact of library technology on library practices and student learning. Although access to library technology varies greatly, Wenglinksy [63] reports that it is not the amount of technology or computer use that affects student achievement, but how it is used and integrated with teaching and learning activities that matters. Further research shows the importance of the teacher's role in using the library effectively with students. "Well-used and integrated" implies that teachers know how to use the library and its materials. Todd, Lamb, and McNicholas [57] found that

integrating information skills into subject content with collaboration from classroom teachers and library media specialists had a positive impact on student learning (i.e., better understanding of subject content and improved test scores). Integrated information skills instruction in a 7th grade science class resulted in significantly higher annual science scores for the treatment versus the control group [56]. In the digital library, the role of the librarian expands to include the critical evaluation of information; earlier research indicated that although students like digital resources, they are less likely to use them as authoritative sources [22]. However, more recent studies indicate that this is no longer true: college students now use on-line resources almost exclusively, and lend significant credibility to them [7].

Lastly, we turn briefly to the growing literature on the implementation of technology in schools to inform our understanding of digital libraries. This literature is consistent with digital library and traditional library research and suggests that *effective* implementation is not easily achieved and depends upon access [2], teacher training [34, 55], and educational or school context [58, 64] —where *school context* means conditions of diversity and economic status, the roles and responsibilities of educators in a given school environment, and the expectations that are set for teaching and learning.

4 Research Questions and Usage Model

The following questions can guide the development of this research agenda. These questions are designed to determine how particular strategies and instances of use support teaching and learning.

1. How do teachers in various educational settings (middle school, high school, and four-year colleges and universities) use a digital library to support teaching and learning?
2. What kinds of use patterns develop and under what conditions? What are the specific motivators, facilitators, and inhibitors for use?
3. Do the teachers find the digital library usable and useful? And in what ways (e.g., for resource discovery, professional development, community networking)?

As a starting point, we turn to prior research that suggests that educational implementation of digital libraries and subsequent student learning could be affected by:

- size of library collection
- frequency of library use
- level of curricular integration
- level of educator training
- access to technology
- school context

These factors provide a basis for a use model of digital libraries in education. We have expanded these factors to develop the initial research framework shown in *Figure 1*.

4.1 Initial research framework

Saracevic offers that future digital library research should be guided by *user-centered* and *system- centered* criteria. User-centered criteria can be studied at the social, institutional or individual level, while system-centered criteria can be examined from engineering, processing, or content perspectives [51]. Our research questions will address both domains—the individual level of user-centered criteria, in addition to several levels of system-centered criteria, as operationalized by our examination of both barriers and enablers of digital library use.

Use (What purpose do users have in accessing the digital library

- ***Finding***
  - Learning materials—use as classroom teaching and learning materials
  - General background reading or knowledge building for users
  - Readings/knowledge or information sources for users
  - Datasets for classroom analysis
- ***Networking/community building***
  - Finding a geoscience professional contact
  - Finding another user who meets some criteria
  - Engaging in a discussion board, message board, or email list
- ***Contributing to the digital library***
  - Submitting any type of material for consideration for use in the library collection

Usability

- Can users find what they want?
- Are the searching mechanisms appropriate?
- How are inquiry and discovery enabled or enhanced?

Usefulness

- Do users value digital library resources?
- How relevant are the resources to users? How are resources used?
- Does the library provide users with an integrated or interdisciplinary view of the subject (in this case, Earth system science)?

Figure 1. Initial research framework.

This research framework is closely coupled with the intended outcomes of the first DLESE Evaluation Plan [27]. Library evaluation activities are conducted to ensure that library services and resources meet community needs and contribute to the larger goal of educational reform. Library building processes are also evaluated to ensure sound technical engineering of library infrastructure and to ensure that mechanisms are in place for timely and appropriate community involvement in library design and development.

5 The Digital Library for Earth System Education as a Research Testbed

Over the past four years, the Digital Library for Earth System Education (DLESE) has emerged to support the specific educational needs of the geoscience community within the larger NSDL network. In the tradition of community libraries, DLESE can fundamentally change how students learn, instructors teach, and researchers interact, by providing new ways of sharing information, tools, and services. As such, DLESE provides unprecedented opportunities for scientific learning and discovery, for increased access to and diversity within the geosciences, and for revolutionizing teaching and learning about the Earth.

6 A Community Framework for Educational Digital Libraries

DLESE is a significant undertaking, and our library building effort is as much a social experiment as it is a technical challenge. DLESE's community participation framework and participatory design process emphasize inclusiveness and promote a process of cultural change [14], and are essentially the intersection of three primary functions: policy, operations, and community.

Policy. Critical to the construction and management of DLESE is a governance structure that supports wide involvement in policy decisions. Library policy is set by the DLESE Steering Committee, broadly representative of Earth science education in K-16 and informal education, informed by Standing Committees reflecting the diverse needs of the community DLESE seeks to serve.

Operations. The DLESE Program Center (DPC) performs key operational functions for the library, and is headquartered at the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado. Critical activities underway include the development of the DLESE system architecture, user interface, and standards and protocols for metadata and interoperability.

Community. A third, and crucial, leg of the DLESE framework is an informed and engaged community. By shaping the conditions of library use, they are subsequently better positioned to influence policy decisions [62]. Community members have contributed user scenarios, resources, developed review criteria, reviewed metadata standards, and articulated policies for academic recognition and intellectual property.

Building on this community development model (*Figure 2*), significant progress has been made on many aspects of the library: the community has been organized, a governance structure has been established, a Strategic Plan has been developed, a useful collection is available, and a working version of the library is now in use. Version 1.0 of the library was formally released at the DLESE Annual Community Meeting in August 2001. Since that time, DLESE has had significant and growing user activity, expanded the resource holdings, and released several new tools to assist the community in the distributed library development process. Version 2.0 of the library has just been released at the DLESE Annual Meeting in August 2003 *(Figure 3).* It enables searching by educational standards and by discrete thematic collections

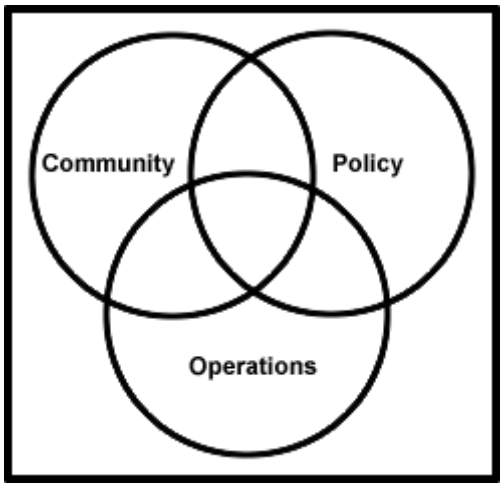

Figure 2: Community model

6.1 Future development

Future development of DLESE will continue to be guided by our development model and by community needs and priorities. Library development goals will be realized in stages and will be measured against two-year and five-year benchmarks outlined in the Strategic Plan. These benchmarks are articulated in two major library versions. They were crafted with broad community input, and articulate the stages necessary for library development, growth, and sustainability. In Version 2.0, collections development services and resource discovery efforts have been extended to support science

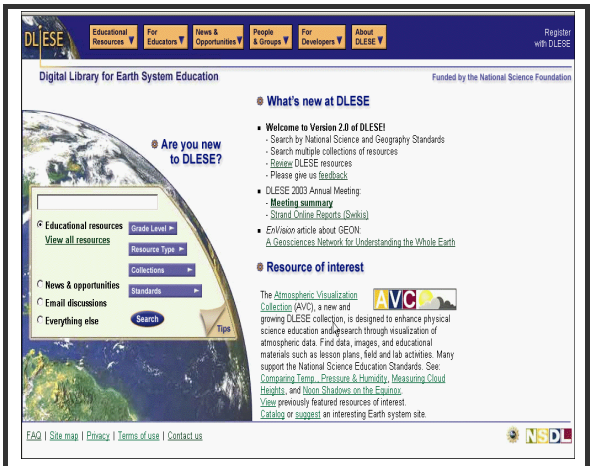

Figure 3. Version 2.0 of DLESE (www.dlese.org) was released at the DLESE Annual Meeting in August 2003. It enables educators and learners to search and browse for educational resources by grade level, keyword, and educational resource type, in addition to by educational standards and discrete thematic collections. Every month an educational resource created by a community member is featured.

literacy standards and the Earth system science (ESS) perspective. Users will be able to search across multiple peer-reviewed collections, according to an Earth system perspective and a variety of science education benchmarks and standards. Community forums and library services supporting the effective use of resources and professional development will be available. Version 3.0 represents a significant step toward supporting data use in geoscience education. Users will be able to search across spatially and temporally indexed resources, such as data, maps, images, and field guides.

Gazetteer services will support user-centered, geo-referenced discovery interfaces using place names and Earth system events. Integrated tools and services to assist with age-appropriate exploration of data will be available. Users will create and share a variety of personalized collections.

Core activities necessary for realizing Versions 2.0 and 3.0 will be carried out by both the DLESE Program Center and the DLESE community. This distributed building approach is essential to harness the community's diverse educational and technical expertise, to enable greater participation, and to engender the commitment and social capital [49] necessary for long-term library success. Active community participation in library building will ensure that community needs are met and that the library is responsive both to changing demands and evolving technologies.

6.2 Evaluation

To date, our evaluation activities have focused on: (1) formative studies of current and potential library users to inform library design [3, 54, 61]; (2) ethnographic studies of library building processes [24, 25]; (3) participant surveys to gauge the usefulness of each Annual Meeting and to provide broad input into library planning; and (4) on-line survey instruments for the beta test program.

An example of a recent formative study is the rubric evaluation exercise conducted with 22 K-12 educators, where the educators analyzed the DLESE discovery system using a Portal Evaluation Rubric designed by the Long Beach Unified School District. This analysis provided significant feedback on the needs of K-12 educators regarding the design of the discovery system, the on-line help functions, and the interface in general. We have also established the DLESE Usability Lab and instituted task-based design methodology procedures [8, 29]. Recognizing that evaluation activities within DLESE occur on many different levels, and in a distributed fashion, we are developing a DLESE Evaluation Toolkit that will support users in determining the value of DLESE and its resources to their curricular goals.

DLESE will continue these ongoing formative activities. We anticipate that there will be several community research and evaluation efforts of DLESE products and services, and that the DLESE Program Center (DPC) will play a supporting role in sharing data, instruments, and findings across distributed efforts. In Version 2.0, a critical library development will be the technical instrumentation of the library infrastructure to enable continuous data collection on aggregate library use and the use of specific resources, services and collections. This instrumentation will include: (1) automatically collecting and analyzing web server logs to form a picture of aggregate use [52]; (2) implementing a 'referral service' that will enable us to collect data on resources and collections use; and (3) embedding into the collections management system facilities for automatically describing collections coverage, depth, and link availability. This instrumentation will enable the DPC to provide metrics to inform library design, policy development, and community outreach strategies. Referral service metrics on the use of resources and collections will be provided to library contributors. A survey conducted by the DLESE Academic Recognition Task Force indicated that the provision of such metrics is important for contributor recognition, particularly at the collegiate level [6]. Collections metrics will be provided to the collections assessment effort, in accordance with the Collections Assessment Plan being developed by DeFelice [23].

In a project of this depth and breadth, there will undoubtedly be mid-term corrections to meet changing community priorities and to accommodate evolving technologies. Mid-term corrections will be guided by ongoing formative evaluation data, coupled with the guidance of the DLESE Steering and Standing Committees. In order to determine the overall impact and value of DLESE products and services, a comprehensive summative evaluation will be funded through an independent community solicitation. This

evaluation will inform the next planning stages for DLESE and the DLESE Program Center, and will include information about the overall value and effectiveness of DLESE, the viability of the management structure, and a prescription for long-term sustainability.

7 Relationship to the Broader Digital Library Community and Geoscience Education

By their very nature, the concept of digital libraries extends the physical walls of traditional community-based facilities. We have both contributed to and benefited from a variety of ongoing digital library efforts, especially the NSF-sponsored NSDL and Digital Library Initiative (DLI) projects. The emerging NSDL effort holds the promise of creating a nationwide network of scholarly and educational digital libraries with the potential to transform teaching, learning, and research practices across the full spectrum of science and mathematics disciplines.

We anticipate that these linkages between DLESE and NSDL will result in improved services to DLESE community members, access to greater depth and breadth in library collections, and ultimately, cost savings in library operations and development. Because of our association with NSDL, there are certain services and infrastructure currently under development through NSDL that DLESE can utilize. These include user-profiling tools and profiling management systems, access rights management systems, automated metadata creation tools, and virtual reference desk services.

7.1 Earth system focus

Although DLESE is closely aligned to the NSDL, we recognize the importance of maintaining our unique focus on Earth system science and our service to our community. The NSDL serves all STEM disciplines; DLESE infrastructure and services are tailored to the specific needs of geoscience learners, educators, and researchers. DLESE helps its community integrate with NSDL by providing tools, services, and technical support. NSDL, in turn, provides access to and integration with important related disciplines, such as chemistry, biology, physics, life sciences, engineering, and anthropology, all necessary for the study of an integrative field such as Earth system science.

7.2 Strategic relationships

We have also made important ties with a number of digital library research efforts and international digital library projects [16], including technical exchanges and partnerships with the UK Office for Library Networking [59], the EU-funded DELOS Network of Excellence [9], and the National Digital Library of Russia [17].

DLESE has established relationships with science and science education professional societies, including the American Association for the Advancement of Science (AAAS), the American Geological Institute (AGI), the American Geophysical Union (AGU), the Incorporated Research Institutions for Seismology (IRIS), the National Science Teachers Association (NSTA), and the emerging Center for Ocean Sciences Education Excellence (COSEE) and Earthscope efforts. These partners inform our library design and provide outreach opportunities for DLESE through their conferences and workshops.

Our rapid technical progress to date can be attributed to a number of strategic relationships with key information technology efforts, allowing us to build upon a strong foundation of digital library technology research. Partnerships in this area include the University of California, Santa Barbara, (UCSB), the University of California, San Diego (UCSD), and Cornell University. Our partnership with UCSB has resulted in significant knowledge and technology sharing to date. We are co-developing the ADN (ADEPT-DLESE-NASA) metadata framework and DLESE is providing the ADEPT project with resource cataloging tools and catalog management systems. ADEPT is providing DLESE with its search bucket middleware and expertise in geo-referenced material. We are working with UCSD to explore practical and cost-effective solutions to the resource persistence problem. We will leverage the special expertise of Cornell in the area of metadata harvesting approaches to digital library interoperability (i.e., OAI), and in turn, we will assist Cornell with technical outreach to distributed library contributors.

In the data arena, we have two important partnerships with the Unidata Program Center and the emerging Geoinformatics effort [53]. Both are developing mechanisms for describing Earth system data for discovery and use in educational and research settings. In the THREDDS project [12], the Unidata Program Center is developing services to enable users to create personalized and sharable collections of data and data analysis tools. Geoinformatics will create a database and a toolbox for the integration and discovery of Earth system data on a global scale, with a special emphasis on advanced Geographical Information System (GIS) capabilities. DLESE will build upon Geoinformatics' data collections and tool development efforts, and provide leadership with the educational metadata framework and project outreach.

All of these relationships and synergies are critical to our library development. They provide library content, digital library development technologies, and form the basis of our larger user community. As such, they may be considered as part of our evolving research plans as the library matures.

8 Conclusion

The promise of digital libraries for SMET education rests on the implementation and appropriation of digital libraries by educators and students. We have little knowledge of how educators and students use digital library environments: as information spaces to be navigated, as community centers in which to participate,

and/or as pedagogical tools to be mastered and appropriated (or resisted). Because DLESE is a new and rich digital library for education we have an opportunity to study how it comes to be used both by individuals and by the Earth system community. The knowledge gained in the research proposed here will make it more likely that the substantial investments being made in digital libraries will lead to improved teaching practices and learning outcomes. This knowledge will be reified in a description model outlining the critical dimensions of digital library implementation. This model will provide a baseline understanding for future researchers to test and refine, making it easier for subsequent research to build on our findings.

Developing this model not only represents a first step in understanding how digital libraries are used, it also contributes to our understanding of how to conduct research *on* digital libraries. We anticipate that the research design, which includes participants representing a broad range of critical characteristics, will be generalizable to other educational digital libraries. From this study, we will advance methodologies for implementation research, as we put best methodology practices into play and learn of their advantages and constraints in studying digital libraries in education.

Although we recognize that different communities will indeed possess varying degrees of cohesion and synergy, we are hopeful that our development model and research framework will be useful to other emerging educational digital library efforts. This model builds on the substantive advances of the past four years in articulating, prototyping, and refining the vision for DLESE, and reflects the high level of community interest, involvement, and support.

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* This material is based upon work supported by the National Science Foundation under Grants #9978338, #0085600, and #0215640. Any opinions, finding, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation