# Retrospective Essays

## on a Decade of Building a National Science Digital Library to Transform STEM Education

NSDL

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## on a Decade of Building a National Science Digital Library to Transform STEM Education

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THE NATIONAL SCIENCE DIGITAL LIBRARY

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## Acknowledgements

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Pathways to Progress Revisited website
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# Introduction

This report comprises a set of essays created during a two-and-a-half day writing workshop held in April 2012 at Carleton College in Northfield, Minnesota. The goal was to develop a retrospective review that captured the nuanced outcomes and impacts of the National Science Digital Library (NSDL). This work built on two previous efforts:

- *NSDL Reflections*, a series of essays completed in 2008, which captures the practical knowledge accrued around building NSDL
- A foundational document drafted at NSDL's start in 2001, which is referenced in the 2012 workshop's name—*Pathways to Progress*

Over the course of the NSF program, the term "NSDL" came to represent many things:

- **The NSF program**—the National Science (Science, Technology, Engineering, and Mathematics Education) Digital Library program that was envisioned in the mid-1990s and ran from 2000-2012
- **The website**—*NSDL.org*, a digital library of high-quality, online, educational STEM resources that supports teaching and learning, particularly for K-16 and informal audiences
- **The projects**—the more than 200 projects that were funded through the NSDL program
- **The community**—initially, anyone who worked on a project funded by the NSF-NSDL program; eventually, the network of teachers, learners, and partners who contributed or used NSDL resources or attended its events

Recognizing the huge scope and complexity of NSDL, the workshop participants chose to emphasize high-level results and lessons in their essays. Regardless of the topic, each small writing group used as its starting point the original NSF program solicitation (2000), which set the overarching goal for NSDL.

As several of the workshop participants noted, this vision for NSDL has not fundamentally changed over the course of its development. In fact, this vision has been the glue that held together a diverse, interdisciplinary group of people who dedicated large portions of their careers to creating a National Science Digital Library. What has changed are participants' understanding of what it means to realize and sustain the vision for NSDL within the context of a rapidly changing technology environment and evolving priorities for STEM education. (For more information see, Endnote 1: *Details about the Writing Process*).[1]

**National Science, Engineering, Mathematics, Engineering, and Technology Education Digital Library (NSDL),** *Program Solicitation, NSF 00-44*

> *To catalyze and support continual improvements in the quality of science, mathematics, engineering, and technology (SMET) education, the National Science Foundation (NSF) has established the National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL) program. The resulting digital library, a network of learning environments and resources for SMET education, will ultimately meet the needs of students and teachers at all levels—K-12, undergraduate, graduate, and lifelong learning—in both individual and collaborative settings. It will serve not only as a gateway to a rich array of current and future high-quality educational content and services but also as a forum where resource users may become resource providers.*

Since 2000, the NSDL program has made many direct contributions to STEM education. It has catalyzed significant technology developments and served to advance state-of-the-art teaching and learning practices during a period of dramatic technological change. The report summarizes and highlights a number of the most significant lessons learned and the contributions made by the hundreds of individuals who worked to advance STEM education as part of the NSDL program. It does not attempt to reach a single, definitive conclusion about the success or failure of building NSDL. Instead, it incorporates the workshop participants' perceptions of both success and disappointment across a complex, multifaceted endeavor.

## Who May Benefit from Reading this Report

These essays should not be considered a comprehensive review or evaluation of the National Science Foundation's NSDL program. Instead, they offer a set of reflections on some of the key areas where workshop participants felt their experiences building NSDL uniquely contribute to knowledge about future projects that are similar in scale and design. This report addresses both the technical and social challenges and the opportunities encountered in developing NSDL. The authors believe the following audiences will find the essays useful:

- **Funding agencies and policymakers** that are developing new programs with large, diverse, and ambitious goals similar to those that characterized the NSDL program
- **Principal Investigators and staff members** with projects comparable to those of NSDL in their scope, interdisciplinary nature, or integration requirements, who will find useful suggestions on governance, project management, communications, and community engagement

- **Individuals and organizations** interested in advancing technologies to support STEM education, who will find specific information on what worked and what did not in NSDL's efforts to "catalyze and support continual improvements in the quality of science, mathematics, engineering, and technology education"

## How to Read this Report

The authors of the essays assume some familiarity with the NSDL program. For those readers who lack this background knowledge, we recommend visiting the *Suggested Readings* portion of the workshop to learn more about its history.

The report is structured to take advantage of the flexibility of web publishing. A *Summary and Lessons Learned* preface each essay. To read each essay in full, click on the *Show Essay* link. You can also click within essays to show details and specific examples for some topics.

## Endnotes

### [1]Details about the Writing Process

Workshop participants were selected to represent the varied and interdisciplinary nature of NSDL project teams. The *Goals & Agenda* section details how essays were drafted during the highly collaborative writing process. Prior to the workshop, organizers posted recommended readings for the group to review, solicited additional documentation, and used a series of targeted online discussion boards to obtain formative ideas for the workshop. A group brainstorming session led to the selection of the essay topics. Small groups with specific expertise focused on creating first-draft essays for each topic. All participants then reviewed each of the essays and the *Concluding Remarks*.

The workshop organizers subsequently edited the essays for clarity and flow and returned them to the original writers to check for completeness and accuracy. Finally, each workshop participant had an opportunity to comment on a final draft of the report. While the essays reflect the unique perspectives of the initial small writing groups, the review process ensured that the final report represented each of the workshop participants' individual perspectives.

# Transforming Teaching and Learning

## Summary

The NSDL vision was to provide a nexus of resources and services to support STEM education that would build the foundation for transformative shifts in what and how we teach in the STEM disciplines (Macdonald et al, 2005). Because NSDL made innovation in STEM education easily accessible, planners envisioned that it would improve the teaching and learning capacities of teachers and students alike. NSDL's promise or potential was (and still is) in its ability to assume the following roles:

- Engage learners with authentic scientific practices and assessment
- Identify quality educational resources
- Empower content consumers to become content creators
- Support collaboration among diverse communities
- Integrate technology into teaching, learning, and professional development
- Support personalizing learning through context and metadata
- Help shape federal policy

## Lessons Learned

- The context of the *where*, *how*, and *why* of learning is important.
- First provide quality resources, and then design complementary services to help users discover them.
- Fostering user communities is essential to sustainability and growth.

# Transforming Teaching and Learning

## Essay

### Introduction

The creation of NSDL was motivated by a confluence of rapid advances in information and communication technologies, changes in educational practice, and a nationwide call to improve STEM education at all levels. The original vision for the National STEM Digital Library Program (National Science Foundation, 2000) was "to provide long-term support for maintenance, improvement, and expansion of high-quality digital science, mathematics, engineering, and technology materials for use by students and teachers at all levels."

From the very beginning, its planners envisioned NSDL as an online learning environment. It was to act as a gateway to a rich array of current and future high-quality educational content and services and a forum where content consumers could become content providers. NSDL would provide a nexus of resources and services in support of STEM education that would produce the foundation for transformative shifts in what and how we teach in the STEM disciplines (MacDonald et al, 2005).

This vision of networked learning, building communities, and creating and sharing knowledge has not changed in the decade of NSDL's existence. What has changed is a deeper and more nuanced understanding of (1) the socio-technical complexity of distributed, online learning; (2) the mismatch of timescales between technological and educational innovation; and (3) the roles that a vibrant, networked community of library builders and users can play.

In the years since that first request for proposals and the *Pathways to Progress* Report (Manduca, McMartin & Mogk, 2001), the technical, library, and education landscapes have undergone dramatic transformations. In this light, the initial educational goals of NSDL were laudable and ambitious, and, not surprisingly, also underestimated the complexities of the issues. It is fair to say, however, that NSDL made significant contributions to understanding issues surrounding technology integration to enhance teaching and learning at both the K-12 and undergraduate levels.

#### Evolving Educational Landscape

The educational landscape is rapidly evolving, and the instructor’s role is constantly being redefined as new opportunities and challenges emerge. Twenty-first century learners increasingly expect and enjoy access to a wide variety of media formats and rich, personalized, online experiences. They expect school experiences to complement their online lives.

The technical and social infrastructure afforded through the NSDL program enabled access to information, methodologies, and social networks that were previously inaccessible to most educators. Future development of large-scale instructional projects must simultaneously respond to and anticipate these changing conditions.

## Teaching and Learning Capacities Generated through NSDL

Networked environments, coupled with a participatory web culture, have increasingly blurred the lines between content producer and consumer. Lack of access to information—the "digital divide"—is no longer a major concern for users, as it was when NSDL was conceived in the late 1990s. Today, it is easier to focus on linking the appropriate digital resources to the right user at the right time in increasingly personal and mobile learning contexts. As a networked repository, NSDL enables access to dynamic, media-rich, online resources to enhance instruction.

### NSDL engages learners with realistic scientific practices and assessment.

NSDL provided a centralized context for undergraduate science instructors and K-12 teachers to learn about and explore 21st century teaching and learning approaches. Primary among these strategies is an effort to increase opportunities for students to learn science through engagement in realistic scientific practices. NSDL fostered the collection, distribution, and use of resources that integrate research science and science education through access to scientific data and analysis tools, by organizing instruction to reflect research-like processes, and by incorporating cutting-edge science findings into course content. Some projects also created opportunities for teachers and learners to interact directly with STEM professionals.

**Examples:**

**Engaging Students with Scientific Practices and STEM Professionals**

- The *Using Data in the Classroom* portal project promotes quantitative literacy by providing access to data sets and instructional resources for educators and learners in and beyond K-12.
- The *Climate Literacy and Energy Awareness Network (CLEAN)* Pathway provides a comprehensive collection of climate science and climate literacy resources for students in grades 6-16 and informal citizen learners to promote “civic science.”
- The *Integrating Research and Education* project demonstrates multiple approaches to guide students in using research methods and data to simulate or replicate true research activities.
- The *Earth Exploration Toolbook* provides step-by-step tutorials in the use of scientific data sets and analytical tools.

- *Ask Dr. Math*, a service of *The Math Forum*, connects students directly to mathematicians who help them understand concepts in new and different ways.
- *The Fun Works* (Education Development Center) introduces learners to a variety of scientists through a site designed by and for children.
- NSDL supported a service called *Ask NSDL* for a number of years that provided a "reference desk" service for all NSDL users to have their questions answered by content experts within the NSDL community.

### NSDL identifies quality educational resources.

Although NSDL library-building efforts initially focused on finding and organizing resources, the need to identify resource "quality" emerged quickly. A tension arose in defining what constituted quality in different circumstances (Sumner, 2003), making it a challenge to find a balance between restricting collections' content to serve the needs of a particular group and the desire to support wide use by any teacher or learner.

Both *NSDL.org* and individual projects developed and tested a wide variety of approaches to address this challenge. For example, instructional resources in some NSDL collections were reviewed according to codified standards. These reviews commonly relied on criteria such as scientific accuracy, pedagogic effectiveness, and technical reliability. Social networking features let users add reviews or recommendations and help them select resources. Reviews can also serve as an instructional tool to disseminate information about the growing body of research on learning.

**Examples: Determining the Quality of Educational Resources**

- Resources submitted to the collaborating partners of BEN, *BioSciEdNet*, undergo peer review processes similar to those for their print materials. The *BEN Scholars* program offers professional development for instructors who wish to create and publish educational materials.
- The *DLESE Community Review System* (Kastens, 2005) developed an online form that allowed resource users to rate a learning object according to three important dimensions: scientific veracity, pedagogic effectiveness, and "robustness" (i.e., all parts of the activity were available, stable, and functional).
- Since 1997, the *Engineering Pathway* has supported the *Premier Award for Excellence in Engineering Education*. Submitted courseware undergoes a rigorous review conducted by content and instructional design experts.

**NSDL provides tools for content consumers to become content creators.**

NSDL supports rapid, continuous cycles of improvement of STEM content and the capacity of teachers to use it in innovative and transformative ways. NSDL projects in both K-12 and higher education provided a continuum of options for users to become creators by annotating or creating collections of existing content or by constructing new content from scratch.

The ability for teachers and learners to repurpose resources in a number of diverse contexts is one of NSDL's most important contributions. Although a content creator may have targeted a specific learning goal, it is entirely possible that the same resource could be applied in novel and innovative ways in different domains and subject areas. For example, creative instructors could use a resource in a variety of new instructional settings defined by class level, class size, geographic location, or student learning styles.

**Examples: Tools to Support Teachers as Content Creators**

- The *Instructional Architect* allows teachers to combine web-based resources on the fly to created structured learning environments for their students. Teachers can tailor, modify, and comment on these resources and then contribute these enhancements back to the community via a web page. (*Read more about the Instructional Architect.*)
- Using a gestural interface, the *Content Clips* tool lets teachers quickly assemble and arrange multimedia objects drawn from distributed digital collections into searchable resource sets or simple, interactive, learning activities.

**NSDL supports collaboration among diverse communities.**

NSDL provided a supportive environment for collaborations among a diverse, scholarly community of educators. As a result, content specialists, curriculum developers, instructors, and experts in instructional technology worked together to identify, create, and adapt materials for different learning contexts in both K-12 and higher education. At least two aspects of NSDL were essential to supporting these cross-community collaborations:

- NSDL technology infrastructure and online tools made sharing different types of educational expertise much easier than ever before.
- The social connections needed to strengthen relationships across traditionally different groups took time to mature, and NSDL's decade-long duration and tight community structure provided that time.

**NSDL integrates technology into teaching, learning, and professional development.**

Often, the mere existence of digital resources inspired educators to take a fresh approach to designing learning activities and to convey concepts in new ways. NSDL continues to ease the use of technology by removing access barriers to digital materials and capturing metadata and paradata that reflect best practices for using a particular resource in the classroom. This relationship between research on teacher needs and the refinement of description and access approaches increased teachers' ability to focus on the task of instruction and may also have enabled them to employ innovative instructional approaches.

**Example: Integrating Technology into Teaching and Professional Development**

Over the past decade, NSDL has been a resource for educators that are shifting their instructional focus from content- to learning-centric approaches. Interviews with users of the *On the Cutting Edge* website, which offers professional development resources for geoscience faculty, showed that collections can support faculty in shaping their teaching behavior. As faculty adopt new approaches or topics, this change can be spread through a user community (McLaughlin, Iverson, et al, 2010). The same social networking enabled a new culture of sharing of resources, ideas, and data among college faculty.

**NSDL supports personalizing learning through context and metadata.**

Teachers often use search engines to find instructional resources, but they can become overwhelmed sorting through the deluge of information resulting from a browser search. Educational digital libraries focus on collecting and describing educational materials in ways that supports their discovery in a more manageable stream. Resources are commonly discovered or developed by working groups or recommended by community members and then placed into meaningful contexts for users. Through this vetting process, NSDL has built confidence in the quality and utility of resources in their collections.

The idea that educational learning objects need specific descriptive structures was not new to NSDL, but NSDL's leadership in metadata generation and standards was integral to its ability to connect K-16 users with digital resources. The metadata, paradata, and technology infrastructures developed in NSDL projects have enhanced resource discovery and access to a range of media formats, as described in this report's *Scaling Technology* essay.

Digital libraries can also facilitate the discovery of resources that meet very specific user needs. Depending on the way a search engine describes and indexes a collection, descriptive metadata goes far beyond the traditional library metadata standards and can include enhanced resource types, alignment to standards, and educational level.

**Examples: Metadata in Action**

- NSDL projects both anticipated and responded to the growing importance of curriculum standards and ensured that they were clearly associated with resources, for example as they were in *Teachers' Domain*.
- NSDL Targeted Research projects were also on the forefront of changing the way standards were included in the search process. Tools like the *StrandMap Service* gave teachers a way to locate standards-linked resources visually while keeping their instruction anchored in the standards' progression.
- Researchers also sought ways to automatically assign standards, as in the experimental work of the *Science Literacy Maps* and *Breaking the Metadata Bottleneck Generation* projects. The results of these research efforts are still used by *Achieve*, a non-profit organization that provides technical assistance to states on standards, assessments, curricula, and accountability systems.
- Many individual collections developed metadata fields and terminology that support specific disciplines or grade bands. For example, the *Middle School Portal2 (MSP2)* employed a Learning Object Metadata (LOM) approach that was adapted over time to become more streamlined.
- Two efforts to increase the effectiveness of resource discovery include the development of a new metadata schema, *Learning Application Readiness (LAR)*, and its associated paradata framework for collecting data about how a resource is used. Metadata and paradata support personalization through contextualization of exemplary resources in a variety of formats. Project staff may combine resources into teaching units, offered as completed guides, while other functionality lets users assemble resources into units, folders, or other personal spaces.

### NSDL shapes federal policy.

Larger trends affecting K-12 education created opportunities and challenges for the work of NSDL. NSDL could be seen as an outflow of the successful *NSFNET* project that catalyzed efforts to connect universities, schools, and libraries to the Internet. By 1998, educational policy began to emphasize the successful application of technology to learning, not just its presence in schools.

Initiatives such as the federal *Goals 2000* program, the ISTE National Educational Technology Standards (NETS), and Partnership for 21st Century Skills led to state and local requirements that couple technology expenditures with guidelines for effective classroom use. NSDL was able to build on these earlier efforts to influentially guide expectations for integrating digital resources for K-12 learning into and beyond STEM and to shape NSF RFPs that solicited projects to further enable such technology integration.

**Examples: The Role of NSDL in Shaping Policy**

Many NSDL projects, including the following examples, collected baseline data about educator readiness to infuse instruction and assessment with technology and applied this information to shape policy decisions at local, state, and national levels.

- Infusing NSDL in Middle Schools examined systemic issues that affect teaching and learning in STEM fields.
- *Faculty Participation in the NSDL—Lowering the Barriers* studied faculty use of digital education resources (Wolf, 2005; Morgan, 2007; McMartin, 2008).
- The *Speak Up* surveys conducted by Project Tomorrow documented student perceptions and needs.

## Lessons Learned

**Lesson 1: Context matters.**

- Ensuring effective technology integration in teaching and learning settings (e.g., K-12 classrooms, museum field trips, undergraduate lab courses) requires a good understanding of the local implementation context such as (1) the level of technology infrastructure, support, and knowledge available; (2) the local policies and culture regarding technology and curriculum innovation; and (3) the motivation of the stakeholders.
- Developing a collection of digital content or an online tool also requires considering local needs and technical capabilities in concert to successfully create a working system. An effective design and development process is likely cyclical, and the process from conception to implementation takes a distributed effort over a long period of time.
- Digital STEM learning resources require contextualization to facilitate their discovery and use. Providing access to resources was the initial NSDL challenge, but access must be accompanied by support services and professional development opportunities to leverage change in instructional

practice. Support services may be virtual (e.g., annotation, assessment, discovery search/browse services) or live (e.g., workshops) to help faculty effectively use the resources that are available.

- Effective use of instructional resources requires that other contexts and services be provided in areas such as scientific content, pedagogic approaches, assessment, and research on learning. Community input and contributions can result in comprehensive collections of teaching resources and methods for using them effectively.

**Lesson 2: Provide quality resources first, complemented by discovery services.**

- “Quality over quantity” should be the collection development motto for any educational collection. Time is a precious resource for educators. For these reasons, providing a limited set of targeted, contextually appropriate resources is imperative. In addition, the community needs to seriously consider and debate what constitutes "quality" in a variety of contexts.

- High-end discovery services should complement the quality collections. Educationally relevant metadata can help support effective resource discovery. However, as above, context matters, and automated techniques are emerging to complement and extend discovery, such as recommender systems and the collection and analysis of paradata.

- In the K-12 arena, educational standards are an important part of resource discovery and description, but standards linkages must be based on a match that goes beyond simple keywords. Determining whether a resource is relevant for teaching a certain standard requires matching concepts, which can be extremely difficult to achieve automatically.

**Lesson 3: Foster a user community.**

- Community-based design is essential to meet the needs, expectations, priorities, and possibilities of the many interests encompassed by the STEM disciplines.

- Community building is most fruitful when built on top of existing communities where potential participants are members, such as professional organizations. Building new communities requires focusing on emerging topics and diversifying interests represented in such existing communities.

- Communities need to share responsibility for defining and refining essential services. As an example, development of reviewed collections has proven to be both expensive and challenging. However, users desire and require rich descriptions that enable a variety of thoughtful, appropriate implementations, and authentic assessments must accompany tools, resources, and services. Planning for future facilities should anticipate the need for these services and budget time and resources appropriately.

- Projects need to be responsive to changing community needs and expectations. The NSDL Pathways structure is an example of how stewardship led to involved communities that participated in defining the scope of NSDL collections and the resources and standards needed to sustain teaching and learning in a specific domain.
- The development of thematic collections can be initiated and sustained through catalytic events such as workshops, communication networks, professional meetings, and a variety of professional consortia.

Educators must have access to programs of continuous professional learning and development. Dissemination and outreach are essential to raise awareness of collections and must complement methods such as commercial search engine indexing. Professional development communities need to be able to link virtually and face-to-face. The power of bringing developers and users together in face-to-face events, such as the NSDL Annual Meeting, led to new synergies, collaborations, and implementation of new services.

# Scaling Digital Library Technology from Research to Production

## Summary

The NSDL technology charge was to move out of the research realm into production mode. In doing so, it faced four main challenges:

- Balance the timescale disparity between technological and educational changes. Technology changes rapidly, while shifts in education policy and practice evolve at a much different and often slower rate.
- Provide one functioning product (the *NSDL.org* web portal) for library builders and users while simultaneously integrating new technologies or products being developed by projects supported by the NSDL program.
- Incorporate standardized metadata schema and vocabularies at a time when the purpose of metadata and philosophies about its use were in constant flux because the field itself had not come to agreement.
- Plan for the persistence of projects that were created with short-term funding.

Despite such challenges, NSDL made progress in the areas of metadata creation, automatic extraction, and the alignment between educational standards and curriculum resources.

## Lessons Learned

- Technology development processes and solutions do not scale easily, especially within the context of a distributed project.
- Assumptions about the ease of integrating new technology (i.e., that plug-and-play code was a solution for all projects) were not substantiated.
- Each NSDL project had different requirements, which made communication and technology integration difficult, time consuming, and resource intensive.

# Scaling Digital Library Technology from Research to Production

## Essay

## Introduction

At the time of NSDL's inception, other national and international organizations were building digital library prototypes and conducting research about metadata. The state-of-the-art in digital libraries advanced rapidly over the next decade and leveraged some of the infrastructure and lessons from the global technology sector. However, the vision for NSDL presented unique design requirements that distinguished it from other efforts. These requirements included creating both the *NSDL.org* web portal and a distributed network of integrated digital libraries, as well as building research components into the NSF's funding stream that would yield tools designed to add value to all NSDL projects.

The guiding principle of developing a central NSDL portal was somewhat eclipsed by the emergence of web search engines (e.g., *Google* and *Yahoo*), which allowed users to navigate directly to resources of interest. For that reason, NSDL needed to design and implement services and collections that added value for user groups that could not be delivered through searching on the open Web. Additionally, the Core Integration (CI) team also was charged with coordination, which included guidance and technical support to other NSDL projects. These requirements posed unanticipated challenges and created tensions between centralized and distributed collections and between operational and experimental capabilities, all of which played out in large and small ways throughout the decade. Pressure often existed to "go live" with research, which resulted in an experience for digital library builders (and users) that was somewhat analogous to building an airplane while trying to fly it.

Although NSDL faced a variety of challenges, its development resulted in research, collections, and tools that have been shared through more than 100 papers and presentations about NSDL projects at conferences and in journals in a variety of subject-specific disciplines.
(See the *NSDL Comprehensive Bibliography*.)

## The Multidimensional Integration Challenges for NSDL

### Balancing Operations, Educational Priorities, and Research

At the time the NSDL program was conceived, the Web was still primarily a medium to deliver and consume resources rather than a platform for interaction. It was inevitable that the technologies and infrastructure required at NSDL's inception would be largely obsolete almost as soon as they were built. In contrast, the educational issues NSDL hoped to address were often long-standing, systemic problems. Changes in teaching and learning typically require retooling of teacher education programs, curricula, educational materials, and policies, all of which happen slowly in comparison to the pace of technological change. Thus a challenge for NSDL—one faced by any similar project—was the difference in timescales between technological and educational change. This disparity had at least two technology-related consequences:

- Developing digital tools and services was a fertile field with a steady stream of new innovations that could be applied in the NSDL context. These innovations filled the technology research space with "bright shiny objects" that distracted NSF reviewers and evaluators from the more fundamental, education-oriented needs for infrastructure.
- Infrastructure developed for some of the earlier projects—although still useful and used—became outdated, and little or no funding was allocated to refresh these systems.

Compounding the timescale disparities were conflicting priorities with new development activities that often occurred simultaneously with the efforts to provide a production-ready system to builders and users. Among the many resulting challenges, it was especially difficult to disseminate lessons learned at both CI and project levels in time to dovetail with projects' development phases and their varied levels of need for CI support. This challenge grew at least in proportion to the number of projects funded by the NSDL program. (For more information, see Endnote 1: *A Brief History of NSDL Infrastructure Development.*)[1]

**Example:**

**The Challenges of Integrating Technology across NSDL Projects**

The Shibboleth authentication system was integral in early design requirements as a way to allow users to log in at one digital library and then be seamlessly passed to other libraries across the NSDL network without logging in again. This system would allow libraries to integrate services such as bookmarking and saving resources while also providing data about users' activities across NSDL in order to improve their experience. The Shibboleth technology was available long before most NSDL projects were ready to integrate its functionality. However, by the time a critical mass of libraries decided Shibboleth could be useful, they were not able to agree on the information that should be gathered from users at login or on data retention or privacy policies. By consensus, Shibboleth eventually was removed from the list of design requirements.

## Metadata and Standardization

From the inception of the NSDL program, the NSDL metadata repository had a pressing need to find a way to share metadata with other repositories and information providers using common descriptors. This goal endured, but a philosophical shift occurred around the purpose of metadata. Initially, it was regarded as a tool for search and discovery in the centralized *NSDL.org* portal. Now metadata is viewed as one tool, among many, to give teachers and learners a context for using STEM learning resources. Concurrently, a shift around the process of search and discovery occurred—from driving users to the *NSDL.org* portal for metadata discovery to putting metadata and STEM resources in the path of the user (i.e., in other websites or NSF-funded projects).

Also from the outset, NSDL emphasized standardization, especially for metadata. The level of standardization desired led to tension between those who saw standards as a requirement for interoperability (good) and those who saw them as constraints on creativity (bad). For example, requiring that resources be tagged with U.S. grade-level designations made it possible to conduct grade-specific searches. However, such tagging was irrelevant or even impossible for some collections and communities. Because of the wide differences among NSDL participants, committees and projects had difficulty agreeing on what level of detail should be required and even what standards should be used, excerpted, or adapted (e.g., IEEE LOM, Dublin Core-Ed, GEM). (We note that this conflicted view permeates the educational technology industry, not just the NSDL program, portal, or projects.)

Despite these challenges, exciting areas of advancement that are likely to have impact were achieved in metadata creation, automatic extraction, and standards alignment. NSDL projects developed remarkable tools for these purposes, ranging from manual approaches to fully automated systems that apply natural language processing and computational linguistics. These capabilities have gained importance with the advent of Common Core Standards, and they coincide with larger trends in data mining and data analytics. As an interdisciplinary community of practice that overlapped many standards-setting organizations, NSDL significantly influenced the broader metadata community. (For more information, see Endnote 2: *The Costs and Benefits of Using Different Metadata Schemas.*)[2]

The work involved in creating NSDL also led to technical, procedural, and scaling advances that were reflected in two seminal digital library research papers:

- *Metadata Aggregation and 'Automated Digital Libraries': A Retrospective on the NSDL Experience*. Best Paper award at the 2006 ACM/IEEE Joint Conference on Digital Libraries (JCDL)
- *Representing Contextualized Information in the NSDL*. Best Paper award at the 2006 European Conference on Digital Libraries (ECDL)

**Examples: Aligning Resources with Educational Standards**

- In 2004, the Syracuse Center for Natural Language Processing developed tools for aligning content to standards via semantic analysis, building on a standards database from JeS & Co. This effort led to funding for integration of the Content Alignment Tool (from Syracuse University) with WGBH's Teachers' Domain Educational Standards Correlation tool (TD-ESC) and the *Achievement Standards Network* (ASN).
- Also in 2004, Eduworks Corp and the New Media Center were funded to develop a tool for creating lifelong personal collections. Results underscored the importance of automatically tagging resources with metadata as they were uploaded into a collection rather than relying on users to provide it.
- Building on previous work on standards alignment, the last-funded Pathway, ICPalms (FY2011) is creating "a widget-based portal... with embedded tools, services, content, and professional development that together aim to bridge standards, curriculum, instruction, and assessment, through collaboration and customization by individual users."
- Many groups are using the NSDL metadata collection to represent NSDL resources in a context relevant to their specific audiences, including *Science.gov*, *netTrekker*, and a variety of commercial K-12 learning management systems. As of 2012, the central organization was also pursuing further work on two recent metadata standards initiatives: the *Learning Resource Metadata Initiative*, a project of the Association Educational Publishers and Creative Commons, and *Learning Registry*, a consortium that includes the U.S. Department of Education, the Department of Defense, non-profit organizations, and U.S. and international companies.

## Scalability, Project Support, and Persistence

The initial funding model for *NSDL.org* and NSDL projects did not realistically address the need for persistence of collections or services constructed with short-term NSF grants. Although ongoing funding was planned for the infrastructure maintained by the CI, these plans failed to reflect the fact that costs for archiving, harvesting, and other integration functions all grew in proportion to the number of collections added. Hence, as the number of NSDL projects increased, maintenance and sustainability became an issue for CI.

To address the need for more support in the areas of maintenance and persistence, NSF added requirements that new NSDL proposals include long-term sustainability plans so that content and services would continue to be available, at least at a project level. In some cases, projects met this requirement by forming successful partnerships with professional societies or by embedding collections and services within a university library or department. The NSF Pathways initiative further codified the emphasis on project sustainability by requiring explicit plans and Memorandum of Understanding agreements (MOUs) with organizations that would assume responsibility for projects' content and services once NSF funding ended.

In the final years of the NSF's NSDL program, its directors set up a mechanism to pool 15% of all project funding to support longevity (e.g., metadata migration, architecture refresh). This approach provided sustainability for the CI team and gave individual projects the moral authority to influence global technical plans while enabling a smaller group to make consistent decisions, including those that might disadvantage some projects to better support the larger community. Although this requirement came towards the end of the NSDL program and we cannot report on its long-term effects, this funding model is a solution that future projects might consider.

As the NSDL program transitions to different organizational and operational settings, it will be important to deal with archival issues to assure that NSDL resources continue to be available and to help NSDL projects such as Pathways take full advantage of the emerging NSF cyberlearning initiatives. Collectively and individually, the various NSDL projects have amassed considerable technical knowledge about what it takes to develop and sustain a technical infrastructure to support effective communication among projects as well as a repository architecture. We hope that NSF will find ways to build on this experience in future projects.

## Lessons Learned

- Technology development processes and solutions do not scale easily, especially in the context of a distributed project.
- Assumptions about the ease of integrating new technology (i.e., that plug-and-play code was a solution for all projects) were not substantiated.
- Each NSDL project required different levels of support, and this intensive communication and additional technical assistance were not initially anticipated or included in budgets at either the CI or project levels.

# Endnotes

## [1] A Brief History of NSDL Infrastructure Development

From 2001 to 2005, the CI created a central library infrastructure focused on accumulating a maximal set of metadata representing STEM-relevant resources. Metadata records about STEM resources were automatically harvested from a large number of existing digital collections and from the new digital collections of STEM-focused educational resources created by NSDL projects. Automatic harvesting posed significant challenges. Metadata quality, formats, and vocabularies varied dramatically across collections so it was difficult for either the CI or other NSDL projects to make use of the metadata. Based on what was learned from the initial research and implementation, much effort was given between 2006 and 2011 to agreeing on metadata schemas, aligning vocabularies, and cleaning up existing metadata in *NSDL.org*. This production-ready metadata provides the foundation for new research on metadata that pertains to the use of STEM resources, such as learning application readiness and paradata.

As the development of the library progressed, the CI learned that the initial database structure for the central library infrastructure could not scale to support the exponentially increasing number of metadata records. The next iteration of NSDL library infrastructure was based in part on the Fedora repository architecture, but the scale of NSDL required significant enhancements to this software, including the creation of a highly stable system backup configuration and a "network overlay" architecture. This architecture expresses relationships among resources and collections as links, potentially adding significant value for technical service providers and users. Where the earlier metadata-centric architecture supported basic search and discovery, the current network-overlay architecture allows *NSDL.org* to provide more context about resources. The results of research on these Fedora software enhancements were incorporated into the *Fedora Commons* distribution, now in use by over 300 repositories around the world.

In addition to the research outcomes resulting from work conducted by the CI, a number of software, tool, service, and application products were developed by projects funded from the NSDL program. It is difficult to identify, let alone classify, specific products separately from related collections, often because the products have become so seamlessly integrated into NSDL infrastructure. Sometimes the barriers to integration were as much human as technical, so not all products had uptake or broader use.

## [2] The Costs and Benefits of Using Different Metadata Schemas

To illustrate further the issues associated with standardization, a number of collection development projects were funded early in NSDL to explore the costs and benefits of using different metadata schemas and vocabularies to describe their collections. Naturally, their priorities—to meet the needs of discipline- or age-specific user groups—were valued more than providing metadata to the NSDL central metadata repository. To achieve uniformity during harvesting, descriptively rich metadata for specific disciplines or age ranges were simplified, prior to storage and display in *NSDL.org*, resulting in a significant loss of information,

## Endnotes

This simplification resulted in a confusing experience for users and frustration for projects because their efforts were not adequately displayed on *NSDL.org*. User interface studies and subsequent analyses of metadata yielded some lessons learned and generated further issues:

- **Granularity**. The level of resources being cataloged and displayed in *NSDL.org* ranged from small applets to large collections. Users need a way to distinguish among them and understand the difference.
- **Vocabulary**. Each STEM discipline and age group used different terms (e.g., for subject areas or pedagogical strategies). This variance presented both a problem for users searching a centralized portal, such as *NSDL.org,* and a coordination challenge for individual projects.
- **Ownership**. Projects viewed metadata as their intellectual property and a value-added contribution that would benefit users. One major challenge became how to build trust between projects and CI while showing the value of contributing to a central portal, even though data was lost through metadata "leveling."
- **Interchange**. If sharing metadata with a centralized portal resulted in loss of data, then how would projects that wanted to share metadata agree on common elements among themselves?

# Organizational Evolution and Effectiveness

## Summary

Over its lifespan, the NSDL community was a loose federation of more than 200 projects, recruited and sustained through an NSF funding model. Initially, the organization combined two main elements:

- A grassroots committee structure, comprised of volunteer representatives from individual projects funded by the NSDL program who were guided by policies and bylaws
- A Core Integration (CI) team, funded by the NSDL program to develop the library technical infrastructure and to support the NSDL community library-building efforts

The long experiment with the unique combination of community-based governance and a centralized, coordinating organization working together within the structure provided by NSF funding led to a number of lessons learned.

## Lessons Learned

- The NSF funding model poses challenges for creating organizational structures that support development of a coherent and comprehensive whole and of long-term, collaborative projects.
- Organizational structures need dedicated funding, time, and flexibility to develop.
- Effective communication across large, collaborative organizations must be open, adaptive, and inclusive.
- Evaluation activities require careful planning, systematic application, and integration into an organization's management.

# Organizational Evolution and Effectiveness

## Essay

### Introduction

The work to build NSDL was funded by the NSF, with more than 200 interdisciplinary projects supported under its NSDL program. As a result, NSF peer review processes and grant-funding structures had a huge impact on the ways work was organized, communities were created, and participants communicated. NSF provided strategic guidance through program solicitations and funding tracks but did not direct the daily activities of this large-scale collaboration.

Individual projects managed their own activities, but to accomplish cross-cutting work, a grassroots committee structure was combined with a coordinating *Core Integration (CI) team*, with the CI taking on increasing levels of responsibility as the NSDL project matured. This approach required a governance structure. Communication relied on face-to-face meetings, including an *Annual NSDL Meeting*, smaller working group meetings, and online tools.

This essay briefly examines several aspects of NSDL's organizational structure and their impact on organizational development. It then considers the role of evaluation within and across the organization. It concludes with lessons learned around the organizational development and evaluation of a large, federally funded, collaborative project.

### Evolution of NSDL as an Organization

Communication, organization, and governance were all essential for a federation of more than 200 projects to move towards the central goal of building NSDL. Initially, the organizational structure combined the following elements:

- A grassroots committee structure, comprised of volunteer representatives from small projects funded by the NSDL program who were guided by policies and bylaws
- A Core Integration (CI) team, funded by the NSDL program to develop the library technical infrastructure and to support the NSDL community library-building and governing efforts

The grassroots committee structure provided a mechanism for community input into the design and development of NSDL. These committees also completed a significant amount of cross-disciplinary work on a voluntary basis.

Although this all-volunteer effort was perhaps not sustainable as a part of the later organizational structure, the work of these committees included the following accomplishments:

- Defining a collections and privacy policy
- Determining metadata standards and guiding principles
- Identifying mechanisms for evaluating and studying the use of NSDL and its collections

This early work was fundamental to building NSDL. Committee participation also helped develop buy-in among the grant-funded projects and provide a foundation for creating the NSDL community.

As NSDL matured, the CI took on increasing levels of responsibility for all aspects of the library collections, community support, and technical maintenance, while the number of NSDL projects funded decreased but their scale and duration grew. The Pathways funding track, established in 2004, created projects of three to four years duration that were responsible for curating content for entire disciplines or "vertical" audience groups. As funding for small projects diminished, there was less need for committee representation, and the community governance structure seemed redundant with the evolving CI working relationship with Pathways projects.

The committee structure and the CI were each deemed important, but no clear organizational structure or accountability mechanism joined central organization to the Policy Committee, subcommittees, or individual projects. In 2008, the Policy Committee disbanded.

## Effectiveness of NSDL

Early in the NSDL development process, the grassroots committee structure and the CI began looking for ways to demonstrate program and project impact. Because NSDL was highly experimental, as were all digital libraries at that time, no theory or practice sufficiently addressed the specific evaluation issues associated with the emerging NSDL. The Education Impact and Evaluation Committee, formed to address these issues, was challenged by *what* to evaluate as questions persisted around which entities made up NSDL (i.e., the CI, the individual collections, and other NSF-funded projects). As the socio-technical and cross-disciplinary aspects of the program took shape, they created another evaluation challenge—to identify what exactly constituted impact. It became clear that measures for evaluating physical libraries (e.g., the number of collections and items, reference transactions, or books circulated) did not adequately capture the NSDL-specific context or its possible impact on STEM teaching and learning, although the *DigiQUAL* project was an early effort to develop new evaluation measures for digital libraries.

In the middle years of NSDL's development, the NSF perspective on what constituted "impact" shifted. Rather than identifying several areas of emphasis, the primary measure for impact became focused on student learning, de-emphasizing other impacts such as changes in teaching practice or developing communities of practice. Led by the Evaluation Committee, many NSDL projects worked together to attempt to find common evaluation approaches, metrics, and tools. However, shifting priorities between the need for formative evaluation and the summative evaluation of impact made it difficult to institute longitudinal evaluation studies. The end result was that evaluation worked well at the project level but was significantly more difficult to institute at the NSDL program-wide level, in part because of lack of funds for the scope of activity such an undertaking would require.

## Lessons Learned

The long experiment with the unique combination of community-based governance and a centralized coordinating organization working together within the structure provided by NSF funding led to a number of lessons learned:

### Long-term, collaborative NSF projects require a funding model that supports growth and sustainability.

NSF's culture and funding processes had profound effects on the organizational structure of NSDL. The NSDL program solicitations from NSF attracted proposals from a diverse, multidisciplinary group of software developers, librarians, STEM educators, professional societies, and publishers. A positive result was that the variety of funding tracks allowed collaborations among these disciplines, educational sectors, and organizations to build new types of collections and tools and reach new communities of users. There was substantial creative power in these collaborations, which would not have been realized without the program solicitation and multiple funding opportunities.

However, the NSF's peer review process posed a particular challenge by evaluating these interdisciplinary proposals on just two criteria: intellectual merit and broader impact. Within the existing review processes, there was no way to accommodate specific, time-sensitive needs (e.g., technical, content, service) that would support building a working digital library. As one NSDL program officer said, "When you build a house, you want a contract that specifies just one kitchen and a few bedrooms and bathrooms. But if you build a house using an RFP model, you are likely to get many proposals for kitchens and none for bathrooms."

At times, multiple projects addressed the same issues and created different kinds of "kitchens," some of which were more successful than others. Given the absence of a good model for the digital library at the outset of the work, this kind of exploration was important, as were the interdisciplinary connections that were forged to move forward these ideas.

### Organizational structures need dedicated funding, time, and flexibility to develop.

Collaborations among such diverse communities as those represented in NSDL are extremely complex and initially require a loose organizational structure to allow participants to find and create areas around which they can coalesce, focus their efforts, and create plans for moving forward. Such organizations also require time for people to build agreement, find focus, and determine ways to communicate to their constituents. Involving participants and creating a community require significant human and financial resources. As a large, collaborative, and grant-funded endeavor, NSF initially encouraged the growth of working groups and standing committees comprised of staff from NSDL projects. Ultimately, this structure was phased out, reflecting the flexibility of the NSF RFP approach to "start fresh" relatively easily.

These kinds of flexibilities can be viewed as a luxury in a production environment, yet they are necessary to create a common understanding and vision to move complex social and technological projects forward. The need to conduct research and rapidly move the results to a production environment contrasted with the needs of community building, which led to a number of tensions within NSDL. For example, (1) researchers needed time to iteratively work through complex issues, often in small, tightly knit teams; (2) the production environment required an agile and quick decision-making process across several distributed institutions; and (3) the governing system needed time to build consensus and agreement across highly distributed sites and the project.

### Effective communication across large, collaborative organizations must be open, adaptive, and inclusive.

Successful organizations rely on effective communication among their governing entities, participating members, and users of their products and services. Several communication strategies were implemented for sharing information over the duration of the NSDL program, and many tools were adopted during the rapid evolution of Internet-based communications.

Evaluation of these communication strategies and networking events showed mixed results. Participants often indicated that they did not know where to find the most recent information about other projects' work or CI activities. Managing project-wide communication was more challenging and time consuming for participants and leadership alike than was originally anticipated.

As NSDL matured, the CI expanded its support for communications around the NSDL brand. CI staff and NSDL project members regularly promoted NSDL at regional and national conferences and through blogs, webinars, and podcasts. Since the NSDL community had expanded to include users who were not invested in building a digital library, communication strategies subsequently shifted to align with the needs of these new users that just wanted to find and use STEM resources. One result was that individual projects saw a benefit to promoting their collections as part of the NSDL brand. However, some research-oriented projects had other audiences besides these new users and could not effectively take advantage of these targeted outreach activities. (For more information, see Endnote 1: *NSDL Communication Methods and Tools*.)[1]

**Evaluation requires careful planning, systematic application, and integration into an organization's management.**

The complexity, size, and vast reach of NSDL required that evaluation be embraced as an organizational value and fully integrated into its organizational and management practices. Integration would have helped mitigate barriers to gathering data (specifically, lack of access to K-12 student users to directly study impact on learning), strict IRB requirements or regulations, and privacy policies that limit use of certain data. Integrating systematic data collection would have ensured that timely results could be used by projects and across NSDL to improve collections and services and to provide strategic information to stakeholders such as funders and users. In addition to valuing evaluation and integrating evaluation activities throughout a project life cycle, additional lessons were learned:

- Methods of evaluating a large, complex organization need to parallel its life cycle.
- Evaluation depends on stakeholder agreement on who, what, and how the organization's products and services are intended to affect its clients.
- Theories of change or logic models are useful organizational planning tools and guides for evaluation. They make it possible to build evaluation instrumentation into technology and ensure that project activities are aligned with the intended outcomes and impacts.
- Evaluation succeeds when using multiple approaches. Both qualitative and quantitative methods are necessary to examine impact from the perspective of multiple stakeholders involved in a large, collaborative project such as NSDL.

# Endnotes

## [1]NSDL Communication Methods and Tools

- The CI team supported asynchronous communication by hosting and maintaining listservs and wiki pages and by publishing the *Whiteboard Report*, an online bi-weekly newsletter, instituted early in NSDL's development to help keep NSDL community members (past and present) informed about the events and activities associated with the project. By 2010, the *Whiteboard Report* had been replaced by the *nsdlnetwork.org* community site, which contained the same types of information. The website was supplemented with monthly NSDL-wide updates and quarterly community teleconferences. The CI team also provided conference call support for ad hoc committees and working groups, which was crucial to early committee work across NSDL.

- Perhaps the most effective communication mechanism for the community of NSDL project members was the annual meeting of Principal Investigators, which became known as the *NSDL Annual Meeting*. Participants consistently rated this face-to-face meeting highly in terms of its effectiveness for learning about other projects' work and its value for networking with potential collaborators.

- In the early years of the NSDL program, when many new projects were being funded, the CI team devoted much effort to welcoming projects to the community. Orientation sessions for new projects were added to the Annual Meeting program, and a CI staff member conducted telephone interviews with individual PIs to advise them on how their project might link to the social and technical networks and the communities supported by NSDL.

- Smaller face-to-face meetings and workshops were also held at least once or twice a year and were also highly rated by participants. Some by-invitation workshops recruited attendees across the NSDL program and were structured around crosscutting topics immediately pertinent to NSDL development, such as participant involvement in building digital libraries. Other workshops focused on gathering the expertise of particular groups (e.g., publishers, program evaluators) to inform the direction of NSDL strategic plans and invited representatives from higher education institutions, publishing houses, and researchers, in addition to some NSDL projects.

- Finally, several committees had face-to-face meetings at other conferences, such as the *Joint Conference on Digital Libraries*, and also had regular phone meetings to support project PIs and staff members in conducting their work throughout the year. However, committee participation was voluntary, and attendance varied widely by committee and over time. Unfortunately, when the CI-supported wiki pages were transitioned to a new platform, the committee reports, white papers, meeting minutes and presentations, and other documents were not preserved in an easily accessible format.

# Library as Metaphor

## Summary

NSDL was conceived at a time when both the promise and the shortcomings of the World Wide Web for education were apparent. NSDL was rooted in the notion that values added by libraries were critically important to realizing the potential of the Web and addressing its shortcomings. The library metaphor allowed the NSDL community to achieve a level of agreement that helped catalyze the NSDL collaborative initiative. However, the term "library" is overloaded with meanings that have become both assets and liabilities. Comparison to a library, with its traditional role as selector and purveyor of published information, can perpetuate the view of library as distribution channel, perhaps overlooking or underestimating its place and potential in supporting users in the creation of new resources.

## Lessons Learned

- Use of a shared image or metaphor has a significant impact on a project's identity and expectations, and organizations should approach its adoption carefully.
- Any metaphor brings with it an associated understanding, but everyone may not always share the same interpretation.
- Whether well chosen or not, once a project associates with a metaphor, any change is likely to cause confusion among those who have adopted it.
- New programs with names that do not convey an easily understood model face a different challenge. For example, the name of the *NSF CyberLearning program* does not create a false image but, on the other hand, neither does it convey an immediate understanding of its goals.
- Use a metaphor only with abundant explanation.

# Library as Metaphor

## Essay

### Introduction

Metaphors are powerful mental models that help us make meaning of our world. Our use of metaphors is sometimes purposeful and sometimes almost accidental (Lakoff, 1980). Since virtual organizations such as digital libraries are difficult to visualize, employing the metaphor of a library was helpful to explain the ideas behind it (Gazendam, 1999). This metaphor became a driving concept that helped NSDL achieve the level of agreement necessary to initiate the NSDL collaborative.

As with many metaphors, however, the many interpretations of "library" became both assets and liabilities. In this essay we explore how the metaphor worked and did not work and how it fared during the various phases of this long-term project. The NSDL community held multiple definitions, often conflicting, of what a "digital library" was or should be. Some participants used the term strictly metaphorically, while others tried to build a digital representation of a more physical or "bricks and mortar" structure. (For more information, see Endnote 1: *Evolution of the National Science Digital Library as a Metaphor*.)[1]

### The Library Metaphor as an Asset

A library is a multi-faceted endeavor that adds value to the items in its collections. Vartan Gregorian, President of the Carnegie Corporation, in its 1998 Annual Report, articulated the grand tradition of what a library could embody:

> *A living institution, libraries contain the heritage of humanity: the record of its triumphs and failures, its intellectual, scientific, and artistic achievements, and its collective memory.... They provide tools for learning, understanding, and progress. They are the wellspring of action, a laboratory of human aspiration, a window to the future...they are a medium of progress, autonomy, empowerment, independence, and self-determination... the symbol of our universal community, of the unity of all knowledge, of the commonwealth of learning.... It represents and embodies the spirit of humanity in all ages* (p. 9).

NSDL was conceived at a time when both the promise and the shortcomings of the World Wide Web for education were becoming apparent. Many in the NSDL community were taken by the notion that the values of traditional libraries could be critically important both to realizing the potential of the Web and to addressing its shortcomings. These aspects of libraries informed the initial design of NSDL and eventually resulted in policies to support critical digital library functions. (For more information, see Endnote 2: *More about Library Metaphors.*)[2]

## The Library Metaphor as a Liability

For all its value in creating enthusiasm and painting a broad picture of NSDL potential, significant problems arose from the use of the library metaphor in creating a focused, coherent vision for the effort. These problems are outlined in the following subsections.

### Metaphors Mask Differences in Viewpoints

Metaphors can have somewhat plastic understandings, making the communication of vision, mission, audience, and expectations for experiences difficult at best. This diversity may stem from an individual's personal interactions with a library or its services, or conversely, from no personal experience at all, with both situations leading to the perpetuation of differing interpretations. The metaphor may be insufficient to create a congruent vision in the minds of all users or developers.

Because the utility of any metaphor depends on a shared understanding of its meaning, we must consider the case where the metaphor “library” does not conjure up a mental model of any kind. This possibility seemed unlikely at the onset of NSDL. However, in today's world, the widespread use of mobile technologies, the ubiquity of accessible information resources, and the emergence of generations that may never enter a physical library raise the possibility that the word "library" in the future may reference some untethered device rather than a building and its associated services.

Comparison to a library, with its traditional role as selector and purveyor of published information, can perpetuate the view of library as distribution channel, perhaps overlooking or underestimating its place and potential in supporting users in the creation of new resources.

### Metaphors can Perpetuate Misconceptions

The use of a metaphor can also lead to misconceptions about or lowered receptiveness to new ways of performing key functions. In the case of libraries, misconceptions and resistance include the following examples:

- **Libraries and their contents are free.** The relatively wide acceptance of libraries as a public good tends to hide their costs from most users. This fact exacerbates the challenges of identifying effective business models for a new enterprise such as NSDL.
- **Libraries are controlled centrally.** Brick and mortar libraries typically have clear lines of leadership, authority, and control that are largely invisible to most users and difficult to translate into community-oriented virtual libraries such as NSDL.

- **Librarians provide the path for finding materials.** Although search, browse, discovery, and other key library functions once were possible only by creating proxies such as catalog cards for each item in a library's collection, technology now makes direct access so straightforward that new mechanisms are constantly being invented. Legacy emphasis on the critical value of human cataloging can be an impediment to such advances in terms of attitudes or resource allocations.
- **Users are not creators.** The important potential of role reversals, where vast numbers of readers and content users are empowered to become the creators or authors of new content, is more difficult to envision in the context of traditional libraries where relatively few are authors.
- **Libraries are perceived as old fashioned.** Although the authors believe this perception is wildly inaccurate, many people think of libraries as old-fashioned or even obsolete institutions, and these perceptions impede branding, marketing, and other aspects of implementing a truly viable and sustainable business model.

## Lessons Learned

- Use of a shared image or metaphor has a significant impact on a project's identity and expectations, and organizations should approach its adoption carefully.
- Any metaphor brings with it an associated understanding, but everyone may not always share the same interpretation.
- Whether well chosen or not, once a project associates with a metaphor, any change is likely to cause confusion among those who have adopted it.
- New programs with names that do not convey an easily understood model face a different challenge. For example, the name of the *NSF CyberLearning program* does not create a false image but, on the other hand, neither does it convey an immediate understanding of its goals.
- Use a metaphor only with abundant explanation.

# Endnotes

## [1]Evolution of the of National Science Digital Library as a metaphor

The initial vision of what was to become NSDL grew, in part, from the comprehensive review of the state of undergraduate STEM education, *Shaping the Future, New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology (NSF 96-139)*. This report called for a digital clearinghouse to organize, validate, and disseminate the instructional resources produced through the NSF's Course and Curriculum Development Program (CCD), Instrumentation and Library Improvement Program (ILI), and later Course, Curriculum, and Laboratory Improvement (CCLI) projects funded by the Division of Undergraduate Education.

Subsequent advisory reports reviewed the potential of information technology to transform STEM education and emphasized the role of instructional technology in supporting "access to world-wide resources, accumulation and presentation of data, and enabling communication, interaction and collaboration among students and instructors to improve the practice of teaching and the experience of learning" (NSF 98-182). The original outlines for a SMETE Library (Fortenberry, 1998) were presented in two reports:

- *Report of the NSF Science, Mathematics, Engineering, and Technology Education Library Workshop (NSF 99-112)*, which outlined the educational principles and impacts on education for a SMETE Library
- *Developing a Digital National Library for Undergraduate Science, Mathematics, Engineering and Technology Education; Report of A Workshop (NRC, 1998)*, which further explored the intersection of educational needs in STEM education and emerging information technologies

The concept of a digital library emerged from this discussion because it seemed to capture the need to share resources widely with a community, effectively organize resources, and support users with a strong set of library services. Early discussions added the notion of library as community center—the "intellectual commons" of a discipline—that integrates collections, services, and people in support of excellence in STEM education (Manduca and Mogk, 2000).

The technical advances that motivated the creation of NSDL were also rooted in the emerging world of digital libraries as much as in that of the Web in general. The concept of a central information or knowledge store had been explored previously by visionaries such as Vannevar Bush (1945) and J.C.R. Licklider (1965).

The bringing together of technical advances with the needs of the educational community were highlighted in two important guiding principles in an essay by Dr. Christine Borgman, "Social Aspects of Digital Libraries" (1996):

# Endnotes

- Digital libraries are a set of electronic resources and associated technical capabilities for creating, searching, and using information. In this sense, they are an extension and enhancement of information storage and retrieval systems that manipulate digital data in any medium (text, sounds, static or dynamic images) and exist in distributed networks.

- Digital libraries are constructed by a community of users, and their functional capabilities support the information needs and uses of that community. They are a component of communities in which individuals and groups interact with each other, using data, information, and knowledge resources and systems. In this sense, they are an extension, enhancement, and integration of a variety of information institutions as physical places where resources are selected, collected, organized, preserved, and accessed in support of a user community.

Thus, the concepts of what constitutes a library were deeply embedded into NSDL from the beginning. This approach required careful coordination of diverse educational needs and expectations with the technology that could make this vision a reality. The foundational document, *Pathways to Progress* (2000), provided an ambitious direction for NSDL:

> *The National Science, Mathematics, Engineering, and Technology (SMET) Education Digital Library (NSDL) was conceived and is being constructed to support excellence in SMET education for all Americans. The NSDL will be a comprehensive information system built as a distributed network and will develop and make accessible collections of high-quality resources for instruction at all levels and in all educational settings. It will also establish and maintain communication networks to facilitate interactions and collaborations among all SMET educators and learners, and will foster development of new communities of learners in SMET education. Multiple services will be available to help users effectively access and use NSDL resources.*

## [2]More about Library Metaphors

Libraries can be associated with many metaphors, including the following examples:

- **Library as Network.** Traditionally, libraries serve users through both centralized and distributed points of contact (e.g., main and branch libraries), often tailored to the needs of a smaller or more discrete group of users. Libraries also participate in collaborations with other library entities to share services and resources (e.g., OCLC, ARL). Digital libraries expand the possibilities inherent in networks, facilitating rich connections between online resources and users.

# Endnotes

- **Library as Place.** In the United States, a library is first and foremost a public good for anyone who cares to cross the threshold. It is a place where people meet, exchange ideas, and participate in serendipitous discovery. Mobile and tablet devices have changed our notion of place because people can now cross a virtual threshold to enter a library any place at anytime.

- **Library as Collection.** Unlike a bricks-and-mortar library, a digital library lets a single resource exist simultaneously in more than one collection. Linkages among digital objects also greatly expand the notion of "collection." At the same time, curation of digital collections provides a fresh context for old challenges while creating new issues and opportunities (e.g., crowd-sourcing some functions such as resource selection and cataloging).

- **Library as Contextualizer.** Traditional libraries provide context about their holdings, such as the descriptive information in catalog records or the conceptual associations of subject terms. Digital libraries extend the degree of context available about resources, such as nuanced recommendations for pedagogical use or usage data such as "likes" or "downloads." Digital libraries also provide an infrastructure that supports complex relationships among information objects, representing them in context rather than as an isolated resource found through a stand-alone Web search.

- **Library as Services.** Much of a traditional library's value is manifest in services provided to patrons. Digital libraries offer an opportunity to expand the notion of user services, some of which do not have good analogs in traditional libraries. Digital library services also can expand the idea of access, providing resource metadata in different contexts or creating personalized views into digital collections.

- **Library as Impact.** NSDL provides worldwide access to high-quality STEM materials for all users from “K to grey.” This inclusive mission fits very well within the library metaphor especially as supported by the *American Library Association’s Library Bill of Rights,* which stresses the important role of libraries in providing information for all.

- **Library as Community.** Libraries have traditionally been at the center of community life—a place where people come to learn about community events and to meet according to self-organizing principles. Libraries also aggregate a range of community resources beyond texts, such as maps, artworks or other visualizations, and tools. Digital libraries have expanded the possibilities for the creation of virtual communities.

# Developing and Sustaining Communities across NSDL

## Summary

NSDL has created and sustained several communities organized around STEM education that are primarily advanced through Internet technologies. However, the NSDL community learned that face-to-face and other forms of personal communication were critical to support the effort. Most members of the developer communities have extensive experience in scientific and educational associations and bring the traditions and cultures of those organizations with them. NSDL also attracted a large population of users who expressed interest in learning about and often actively engaging in STEM activities.

## Lessons Learned

- Large projects such as NSDL need to anticipate and provide support to multiple communities organized around their functional needs.
- Communities in large projects are most likely to be self-organizing and will emerge at different stages of the project's life cycle.
- Even in projects that are primarily based on electronic resources and communication, face-to-face opportunities play an important role in sharing and benefiting from the work of communities.
- Large projects should anticipate the need to support multiple communities of practice in content and functional areas.

# Developing and Sustaining Communities across NSDL

## Essay

### Introduction

The idea of creating a community was a basic principle of NSDL. However, "community" is a broad term with many different connotations, depending on its context. Like "library," the word "community" can cause misunderstanding because of its variable meanings. Communities comprise individual members who join and participate for their own reasons; individuals create their own perceptions of the benefits the community brings to them personally and professionally.

Throughout NSDL's development, the question continually recurred: "What is the NSDL community?" Is it the group of technical developers and users working to improve the *NSDL.org* website interface; (2) the Principal Investigators and project staff funded through the NSF's NSDL program; or (3) all teachers and students involved in STEM education? The particular challenge for NSDL, as well as its strength, was that the vision of an interdisciplinary effort blurred the boundaries between previously disparate communities. NSDL development required technical, library, and education experts to work together across varied STEM disciplines and at all levels of the research and educational communities. At the same time, moving ideas and resources across the similar breadth spanned by the user community was a key library goal.

Ultimately, NSDL created and sustained several communities organized around STEM education that were advanced primarily by Internet technologies. However, the NSDL community learned that face-to-face and other forms of personal communication also were critical to the effort.

### Types of NSDL Communities

NSDL communities were large and small, divergent and convergent, and motivated by varied goals. Most were focused around specific tasks or projects, and many will continue to exist beyond the tenure of the NSDL program. Further study of these communities may provide fruitful advice for large-scale collaborations.

To describe NSDL's experiences in developing and supporting communities, it is important to clarify the characteristics of the communities involved. One important aspect is the level of engagement of their members.

These communities tend to fit into one of three types:

- **Resource Users (interested in content).** In the context of NSDL, this group includes faculty and teachers wanting to find resources and methods that can benefit their students and classes. It may also include self-motivated students. Group members identify themselves as consumers rather than education developers. They visit NSDL websites to learn about excellent resources and may have some connections to other resource users and members of communities of practice.

- **Communities of Practice (ties through collaboration).** This group includes those involved in the development, assessment, and improvement of the community educational activities and resources. Within NSDL, it includes curriculum developers and those engaged in the scholarship of teaching and learning. They may contribute directly to NSDL projects or have close ties to Central Participant group members.

- **Central Participants (consortium).** This group includes individuals or organizations that are providing funding or are actively engaged in building and maintaining the infrastructure that supports the community. In the context of NSDL, this is the community of NSDL participants and infrastructure developers. They consider NSDL (or a specific collection) to be an important part of their research and development activities. Many are also tied to disciplinary or other community activities.

Many educators using NSDL services did so only as "clients" of *NSDL.org* or one or more of the distributed NSDL resource libraries. However, some NSDL users moved beyond the role of library users to participate as members of affiliated Networked Communities. (For more information see Endnote 1: *Levels of Engagement in Networked Communities.*)[1]

**Examples: Engagement in Networked Communities**

- Since 2006, the *Biosciences Education Network (BEN)* has been building and coordinating a community of 75 biological sciences faculty Scholars who promote the use of digital library resources and student-centered teaching and learning and engage in projects and activities to transform undergraduate biological sciences education. Outreach activities are aimed at biological sciences faculty, postdoctoral fellows, and middle and high school teachers. Activities are carried out locally within departments on campuses throughout the region and nationally through professional societies.

- Members of MSP2 have formed teacher networks around subjects such as, math, science, integrating technology, literacy in the content areas, and research to practice. Members come to these groups from across the country to share resources and knowledge, ask questions, and discuss issues they encounter in their teaching.
- The *NSDL Developmental Mathematics Collection* provided the impetus for regional networks of math faculty in California community colleges to aggregate exemplary resources across campuses. Out of this sense of shared purpose, other collective activities have since developed, and a social infrastructure was created to foster connections across regions so that the most widely used resources could be promoted from regional prominence to national visibility.

## Supporting Multiple Communities of Practice in NSDL

This section looks at some of the lessons that can be learned from examining NSDL as an organization that included multiple communities of practice. In addition to being members of a general NSDL community, the project's developers and designers can also be thought of as members of different communities of practice and networks of practice.

Communities of practice typically share a common interest and interact on a regular basis to improve their knowledge or abilities (Wenger, 2006). Although networks of practice have some similarities, they tend to be broader and more loosely organized. (For more information, see Endnote 2: *Communities of Practice and Networks of Practice Defined.*)[2]

Because of their separate worldviews, integrating communities and networks of practice into organizational work can be a challenge. In distributed organizations such as NSDL and the widely distributed, interdisciplinary, and collaborative network it involves, participants of these various networks and communities of practice need to establish common ground. In the NSDL experience, this work has not always been easy, particularly at the program level.

**Examples: Integrating Communities of Practice and Networks of Practice**

- Lagoze et al (2005) describe the early years of NSDL's experience with automatically harvesting Dublin Core metadata through OAI-PMH. Despite the provision of “low barrier” tools and extensive technical support, the harvesting process was slow. The authors' expectation (unfounded in retrospect) was "that Dublin Core and OAI-PMH were relatively simple and that surely every collection provider would be able to implement them."

However, it turned out that "very few NSDL collections had a single person, let alone a team, with these three skill sets." The "'automatic" harvesting actually consisted in transferring and coordinating knowledge among different communities of practice associated with technical infrastructure, metadata and cataloging, and domain and pedagogical expertise, in a highly distributed and often part-time organizational environment. Rather than an NSDL "community" with the skills to implement OAI-PMH, Lagoze et al encountered multiple disparate communities of practice in specific organizational contexts.

- Work with the *Digital Water Education Library (DWEL)* involved computer scientists and educators in its collection development The project experienced some issues at the start, particularly with getting these educators to complete their cataloging tasks in a timely fashion. Despite having spent several days in face-to-face training workshops, the project PIs and the educators, who were from different communities of practice, had different tacit understandings and technological frames (Orlikowski & Gash, 1994) of what digital libraries were. These differences were unrecognized by the participants at the time, and they impeded the project's organizational communication and workflow. In order for the project to move forward, the differences had to be identified, analyzed, and subsequently addressed and mediated through the design and development of online tools that acted as boundary objects between the PIs and the educators (Khoo, 2005).

In general, a trade-off existed between the depth of knowledge available in individual communities of practice and the ease with which this knowledge could be shared and integrated across NSDL as an organization. Discussions of an "NSDL developer community" appropriately refer to an external perspective on an organization that shares a general, broad set of visions and goals. However, implementation of these visions and goals requires paying attention to the existence of the many disparate communities of practice within NSDL and the need for wider and substantial communication among them and the different organizational settings in which they are found.

Many NSDL projects were managed or carried out by faculty whose participation was, by necessity, part time. This circumstance meant that communication across the program was highly distributed, relatively sparse, and asynchronous. In many cases, it was not sufficient to support rich discussions among the different communities of practice. Thus, while there was strong evidence of an overall vibrant NSDL developer "community," there was also a risk of accepting at face value the implication that the NSDL community was homogeneous. Instead, significant effort was needed to maintain and sustain adequate and substantial communication.

## Lessons Learned

- ◻ Large projects such as NSDL need to anticipate and provide support to multiple communities organized around their functional needs.
- ◻ Communities in large projects are most likely to be self-organizing and will emerge at different stages of the project's life cycle.
- ◻ Even in projects that are primarily based on electronic resources and communication, the need for face-to-face opportunities are an important element in benefiting from the work of communities.
- ◻ Large projects should anticipate the need to support multiple communities of practice in content and functional areas.

## Endnotes

### [1]Levels of Engagement in Networked Communities

Participation of some educators in an NSDL networked community engaged them as members of a network of teaching practice—a set of relationships, personal interactions, and connections among participants that support learning, such as information flows, helpful linkages, and joint problem solving and knowledge creation (Wenger et al, 2011, p. 9). At a deeper level, participation in an NSDL networked community engaged some educators in an extended community of teaching practice, contributing to a shared identity around the roles, relationships and practices of teaching (Wenger, 2011; p. 9). Engagement with the development and support of NSDL collections helped enable groups of educators interested in a particular teaching area to form a community of purpose around improving teaching by drawing on the collection and its affiliated network of educators. In other cases, the NSDL experience helped build on an existing community of purpose formed around improving teaching practice to expand and deepen its activities and impacts, through new and extended uses of online resource collections and networked communities. For some individuals, this expansion of shared professional identity extended beyond their own teaching practice so that the NSDL experience provided the catalyst for developing a larger, collective intention to steward the domain of teaching knowledge and its affiliated resources and networked communities (Wenger et al, 2011, p. 9). The impact of the community of practice on professional identity is what distinguishes this level of engagement from a team or community of purpose that forms around a shorter-term goal (e.g., collection building) and is likely to disperse once that task concludes.

# Endnotes

## [2]Communities of Practice and Networks of Practice Defined

**Communities of practice** are "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger, 2006), which helps groups to share knowledge in organizations (Lave & Wenger, 1991, 1999). Newcomers become members of a community of practice over time by learning what that community does. Experienced members of the community show the less experienced members of the community what it means to be a community member and guide them through the community's practices. As newer members can become more experienced, they can, in turn, induct newer members into the community. In NSDL, communities of practice could be based, for example, on various professional backgrounds and project responsibilities, such as educators, catalogers, web developers, and database and metadata developers.

**Networks of practice** have some similar characteristics to communities of practice (Brown & Duguid, 2001), but "the term network...suggests that relations among network members are significantly looser than those within a community of practice.... Unlike in communities of practice, most of the people within such a network will never know, know of, or come across one another. And yet they are capable of sharing a great deal of knowledge." Examples of networks of practice include including occupations, professional associations, and academic disciplines. Brown and Duguid use networks of practice partly to analyze how knowledge can be hard to share among the different groups in an organization. There are different ways for organizations to prompt knowledge sharing. Hierarchical managerial control can be used but may inhibit innovation. Instead, Brown and Duguid suggest intercommunal negotiation and the translation of perspectives between networks of practice, for instance by boundary spanners—organizational members with backgrounds in multiple domains who can translate among those domains.

# Concluding Remarks

Ten years ago, NSF's Division of Undergraduate Education launched a remarkably ambitious program to build an openly accessible digital library, dubbed the *National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL)*, whose content would support STEM teaching and learning at every level of education, in both formal and informal settings. This report—the outcome of a three-day retrospective workshop on the effort—concludes that NSDL, as it evolved over the years (to the point where it is now titled the *National STEM Education Distributed Learning* program), was judged to be successful by some attendees and less than successful by others at the April 2012 meeting.

NSDL design and development was both a technical and social enterprise, and participants recognized its success to the degree that its technical infrastructure and services enabled the aggregation, organization, archiving, and distribution of assets held by the library and that NSDL supported and transformed teaching and learning in the STEM disciplines at all levels. NSDL-funded projects made significant contributions in both of these focus areas, and NSDL.org offers global access to digital STEM education resources. Many individual projects succeeded in supporting the expectations and needs of specific communities (defined by discipline, audience, and geography) that were empowered to contribute and use resources and services in new ways to support STEM education. However, as a program, NSDL fell short of the grand vision of an integrated portal that served the diverse interests and needs of STEM education for all audiences.

Reflecting on their individual perspectives on NSDL, workshop participants sought to discover the central messages from their experiences and to understand and articulate the tensions inherent in working on such a diverse, distributed, and collaborative effort. This section summarizes the lessons learned both while building NSDL and reflecting on the building process during the April 2012 meeting. Three central messages emerged through the workshop effort: (1) large, collaborative, interdisciplinary projects require organizational structures to support the efforts of the whole; (2) an organization's vision and goals must actively guide management and planning; and (3) keeping collaborative projects collaborative requires strong communication networks.

## Large, collaborative, interdisciplinary projects require organizational structures to support the efforts of the whole.

As noted elsewhere in this report, NSDL was unique within the broad scope of NSF programs. Hundreds of small projects were funded, along with a central organization that was charged with building infrastructure and organizing the community. (For more information, see the

NSDL history authored by NSF Program Officer Lee Zia.) The entire body of projects—each bounded by different funding levels and durations and focused on developing specific elements of infrastructure, services, or content to be integrated into NSDL—formed a loose, geographically and intellectually distributed federation that worked to realize a vision of NSDL as articulated in the NSF RFP for the program.

**Grant-funded projects need organizational models that balance centralized and distributed management structures.**

At the inception of the NSDL program, NSF funded a centralized organization to develop key pieces of infrastructure and coordinate the eventual integration of individual projects with this framework. At the same time, community-based governance was created to represent the needs and views of individual project leaders to the central organization. Each of these groups was deemed important, but no clear organizational structure or accountability mechanism connected the central organization to the individual projects.

The lack of coordination between these two groups set the stage for increased tension and uncertainty among the project participants about NSDL goals, objectives, and decision-making authority. This lack of agreement made it difficult to establish an organizational structure that could truly meet the diverse needs of NSDL participants, develop bridges among the differing opinions, and establish an open or transparent decision-making process. Lack of agreement on such fundamental factors also made it difficult to evaluate NSDL's success, as one is forced to ask, "Which NSDL?"—the NSF program, the central organization, or the individual projects.

The workshop organizers were struck by the fact that workshop participants, 12 years into the program, continued to debate the origins, merits, failures, and accomplishments of the community governance model and the central organization. The fact that this debate continues to define the experiences and perspectives of NSDL project leaders and participants produced this critical recommendation: Early on, large, collaborative, interdisciplinary projects should establish an organizational and governance model around which participants can form at least a rough agreement in order to move the project forward.

A community governance model such as that envisioned for NSDL might have been more successful if two important facets had been in place: (1) clear lines of authority in both the central organization and the community; and (2) project accountability across both groups The sometimes-competing leadership structures significantly hindered decision making and led to a leadership vacuum (real or perceived). These factors, combined with the lack of authority or power on the part of both structures to hold individual projects accountable to the collective enterprise of NSDL, exacerbated the diffuse nature of the project, making coordination even more difficult.

**Finding the "right" organizational structure requires time and testing.**

Future efforts should consider balancing centralized and distributed management structures as well as "top down" and "bottom up" approaches to research and innovation. In this regard, timescales for progress are often longer than anticipated. In particular, an iterative process for community building and goal refinement must be allowed to play out. It also is important to recognize emergent outcomes that cannot be determined through a proposal process.

Building NSDL through individually funded projects also created structural issues. Individual awards did not necessarily comprise the whole of the resources and services needed to build NSDL. This funding structure resulted in uneven development that could not be rectified through ad-hoc proposal submissions. PIs were primarily responsible for the successful completion of their own project's work plan and only secondarily responsible for the success of NSDL as a whole. Organizations must carefully consider the issue of centralized versus decentralized development to ensure that critical services are established for the good of the whole while allowing enough flexibility for individual projects to creatively develop additional systems that can meet unique needs or produce unexpected outcomes.

One way to mitigate the confusion inherent in a distributed, collaborative project is to create an independent position that serves both the central organization and individual projects. In NSDL's case, such a position could be invested with the authority to make decisions, establish workflow processes, and coordinate among the many projects to resolve collaboration and communication issues. Some workshop participants felt this role should focus on achieving consensus and supporting collaboration rather than directing activities. They also noted the tension between the need to have a directive manager to achieve integration and the desire of projects to work in a more loosely coordinated network.

Numerous challenges result from trying to align distributed, collaborative projects with the goals of NSF and the federal government and the desire to build a financially self-sustaining facility. These goals can come into conflict as needs and expectations change in relation to different timescales, research questions, and levels of project maturity. Workshop participants keenly felt shifts in project direction related to changes in government priorities for the NSDL program and its impact on STEM education. The proposal process resulted in projects with different foci, goals, activities, and products that did not always add up to the larger NSDL vision.

## An organization's vision and goals must actively guide its management and planning.

In addition to factors that affect organizational structure, it is also important to consider how an organization's success can depend on arriving at a broad, functional level of buy-in to a clearly articulated vision and goals.

### Choose the words used to describe a vision and goals carefully.

From the outset, a multiplicity of meanings and values were attached to the words behind the acronym of NSDL (see *Library as Metaphor*). The program name and initial RFP became strong indicators of the project's overall direction. However, individual projects established separate proposal goals that did not necessarily represent or align with the broader vision, goals, or values of the larger group. A tension grew between the desire of individual projects to participate in the larger endeavor while also being evaluated on their own goals. It was difficult for projects to acknowledge such divergences from the larger effort and then either realign their own goals or create a path that allowed these differing goals to be accomplished successfully.

### Use goals as guideposts to ensure alignment of project activities in a distributed organization.

An organization's goals must guide its planning, project management, and evaluation efforts. Following this rule requires spending at least as much effort in managing the evolution of goals as was invested in their initial definition. All too often, organizations create and record goals and then rarely reference them again, especially in day-to-day practices. In such cases, it becomes difficult to manage the expectations associated with those goals and perhaps even impossible to determine the appropriateness and effectiveness of specific projects and activities.

As NSDL matured, goals of the central organization and individual projects evolved to reflect changes in technology and education. Such evolution can affect any assessment that uses these goals to gauge an organization's successes and failures. Factors that can cause goals to evolve include advances in research and commercial markets and changes in project expectations. Such influences can become powerful forces, requiring careful monitoring to keep an organization true to its vision and goals. Projects should remain flexible to respond to changes in objectives, organizational demands, and external environmental conditions.

### For effective collaboration, value the success of individual parts as highly as that of the whole.

From the outset, projects need to establish processes to ensure holistic, continual assessment of their project goals and to disseminate their evaluation results. As in any research effort, expected project outcomes such as functionalities, services, and populations served had to be addressed. At the same time, the creativity of the independent projects also allowed some surprising and serendipitous results that should be counted as positive credits for NSDL. Evaluation of such complex organizations requires an evolving evaluation process with widespread participation.

Sometimes a tension can develop in sharing the results and aggregating the outcomes of an individual project with those of the central organization. Although workshop participants indicated that it is easier to conduct evaluations and report results at the project level, the same can be said for the larger central organization. Projects must take care that the success of one group does not outweigh that of the other, as the success of each individual effort is integral to the success of the entire distributed organization at all levels.

## Keeping collaborative projects collaborative requires strong communication networks

**Communication in a large, distributed, collaborative project is a daunting challenge.**

In a distributed environment, information communications technology is both necessary and helpful, but it did not fully support the communicative actions needed to establish common ground across NSDL. The communication required to facilitate NSDL's ongoing successful development was dispersed across multiple projects, timescales, communities, developer groups, networks of practice, and geographic and virtual locations.

Addressing many of the issues identified in this report required additional intensive and reflective communication efforts. For example, challenges included facilitating communication between the central organization and individual projects, defining the role of the committees between annual meetings, and supporting the ongoing management of technical development among designers, developers, catalogers, and others. At the same time, NSDL's widely distributed structure and the inability of many PIs to commit to more than a part-time effort meant that this communication was very difficult to achieve. This finding has important, practical implications for future projects.

**In distributed contexts, communication needs to be both rich and nurtured.**

Even in a highly technical project with access to high-quality information, communication technologies, and face-to-face communication—such as that in the NSDL Annual Meetings —was highly prized. Communication tools and processes need to bridge the timescale and geographic gap among distributed projects.

**Projects should not underestimate the amount of communication management or the cost (i.e., fiscal and time) that a distributed program requires.**

Communication management brings new members into a project and connects them more strongly to its vision, goals, and participants. The type of face-to-face communication necessary to keep communication lines open and transparent requires significant resources. It can cost as much to build an organization’s social network as to develop the actual product.

One of the challenges encountered by the federated NSDL was balancing the promotion of individual projects with that of the broader NSDL organization. Although there were large efforts to build brand recognition and use for NSDL collections and services, we were not successful in building a mechanism that allowed users to hold dual allegiances to their disciplinary or specialized libraries and to NSDL as a whole. Given the breadth of roles that NSDL attempted to play in STEM education, it also proved difficult to build a stable and sustained community of users.

## Final Thoughts

As this report has demonstrated, NSDL has made tremendous strides in developing STEM educational digital libraries. It has developed high-quality collections and innovative tools and has created and sustained a broad and lively intellectual community, all in a distributed setting. NSDL's vision served as a catalyst for interdisciplinary research (1) on the transformative role of technology in the classroom; (2) the pedagogies and information literacy skills used by STEM teachers and learners; and (3) on digital libraries in general.

NSDL efforts enhanced learning opportunities for teachers and students by offering pathways for them to explore STEM content, methods, data, visualizations, pedagogies, assessments, and related supporting services. NSDL has opened new possibilities that can transform what and how we teach across the STEM disciplines.

The NSDL program and projects provided a platform for examining the impact of digital STEM resources on teaching and learning. Early on, interdisciplinary perspectives provided models for involving users in the design of digital libraries. Although 10 years of evaluation efforts did not yield measures of impact, they did result in a nuanced understanding of the difficulties of such measurement, concluding that teachers are a reasonable audience to study and that changing teacher practice requires a sustained effort (see essay in this report on *Transforming Teaching and Learning*).

NSDL served as a catalyst for digital library research and was one of several large research initiatives undertaken about the same time around the world (see the *Scaling Technology* essay). As a result, the U.S. research community participated and learned from this broader conversation.

Again, what made NSDL unique among these other initiatives was its interdisciplinary approach to developing a STEM education digital library. Going forward, digital libraries are increasingly both components and examples of wider information infrastructures, including cyberinfrastructure and cyberlearning, which are "used to facilitate the distributed, collaborative use of content over time and distance" (Borgman, 2007). NSDL can continue to serve as a catalyst and model by functioning as a working platform for cyberlearning implementations and innovative cyberinfrastructure experiments.

The NSDL program and its component projects have demonstrated the power of digital libraries to improve the quality of STEM education and widen the reach of the very best resources it has to offer. At the same time, NSDL has been a grand socio-technical experiment, resulting in important lessons learned in both the social and the technical dimensions. As with any experiment, negative results can be as valuable as positive ones. Viewed through that lens, NSDL has been successful at the program, project, and personal levels, although the divergent perspectives on the definition and scope of NSDL may mask the synergistic outcomes achieved at each one. Almost every workshop participant noted that one of the reasons they valued working on NSDL projects and being part of its community was the opportunity to exchange ideas and collaborate with colleagues from other disciplines. Indeed, many attendees noted that the connections they made while working to realize the vision of NSDL have had a lasting impact on the direction of their work, and indeed, their lives.

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# Appendix:

## Workshop Participants

## Conveners

- Flora McMartin, Broad-based Knowledge, LLC
- Cathy Manduca, Science Education Resource Center at Carleton College
- David Mogk, Montana State University, Bozeman
- Sarah Holsted, Broad-based Knowledge, LLC

## Participants

- Alice Agogino, University of California at Berkeley
- Tom Carey, San Diego State University
- Lillian Cassel, Villanova University
- Anne Diekema, Utah State University
- Sam Donovan, University of Pittsburgh
- Dave Fulker, OPeNDAP
- Yolanda George, American Association for the Advancement of Science
- Jack Hehn, American Institute of Physics
- Kaye Howe, UCAR
- Karon Kelly, University Corporation for Atmospheric Research
- Mick Khoo, Drexel University
- Dean Krafft, Cornell University
- Kim Lightle, The Ohio State University
- Marcia Mardis, Florida State University
- Bruce Mason, University of Oklahoma
- Dave McArthur, University of North Carolina at Chapel Hill
- Lois McLean, McLean Media
- Mimi Recker, Utah State University
- Robby Robson, Eduworks
- Len Simutis, ENC Learning, Inc.
- Frank Wattenberg, US Military Academy
- David Yaron, Carnegie Mellon University