Digital Resources for STEM Educators and Recommendations for Cyberlearning Initiatives

Results from the National Science Foundation Digital Library/Distributed Learning Program Evaluation

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Preface

The National Science Digital Library/Distributed Learning (NSDL) program was introduced in 2000 to support the development of resources, collections, and technical tools and services for teachers and learners in science, technology, engineering, and mathematics (STEM) education. NSDL’s mission was to assemble these elements into a distributed digital library that would be widely available to the public through websites. In 2011, the National Science Foundation (NSF) discontinued grant funding for projects in order to build on the results of the NSDL program and to establish the next generation of cyberlearning programs, including Cyberlearning: Transforming Education.

Like other NSF programs, the NSDL program sought to support individual projects that have strong scientific merit. Unlike other programs, however, the NSDL also sought to develop distributed, self-sustaining communities of users of and contributors to shared collections of digital teaching and learning resources and tools. NSF invested substantial resources in a technical and social infrastructure to realize these goals.

NSF has structured the evaluation of the NSDL program in a phased approach. Phase 1 of the evaluation, which focused on documenting program inputs, was conducted internally. Findings were made available to the RAND Corporation researchers who conducted the second and third phases of the evaluation.

The Phase 2 evaluation provided a preliminary assessment of the program, based largely on existing information resources and results of the initial evaluation effort; designed a robust formative evaluation for the subsequent phase; refined research questions and methods; and conducted limited field studies to pilot test instruments and procedures that could be used in Phase 3. Findings identified antecedents that were potentially supportive of the overall aim of the NSDL to facilitate improvements in teaching and learning in STEM disciplines.

This document reports on the Phase 3 evaluation of the NSDL program. The Phase 3 project was initiated as a formative evaluation under the assumption that the NSDL program would continue and that its output would chiefly serve to inform NSF decisionmakers about ways to strengthen and improve the program going forward. After the Phase 3 project was under way, NSF announced its decision to cease funding the NSDL program beyond the 2012 fiscal year. In light of that announcement, RAND, in consultation with Guardians of Honor, refocused the final phase of evaluation to emphasize lessons learned that could be useful to other programs, both within and outside NSF, and specifically to identify the attributes of sustainable digital initiatives and to assess the extent to which the NSDL program demonstrated these attributes. This report is based on research conducted between 2010 and 2013. The text was completed in July 2015.

This report will be of interest to other programs in NSF, other organizations that fund related research (e.g., programs within the U.S. Department of Education, private nonprofit institutions
that support education research and development, state departments of education seeking to implement new STEM standards), and the digital library community.

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RAND Science, Technology, and Policy

The research reported here was conducted in the RAND Science, Technology, and Policy program, which focuses primarily on the role of scientific development and technological innovation in human behavior, global and regional decisionmaking as it relates to science and technology, and the concurrent effects that science and technology have on policy analysis and policy choices. The program covers such topics as space exploration, information and telecommunication technologies, and nano- and biotechnologies. Program research is supported by government agencies, foundations, and the private sector.

This program is part of RAND Justice, Infrastructure, and Environment, a division of the RAND Corporation dedicated to improving policy- and decisionmaking in a wide range of policy domains, including civil and criminal justice, infrastructure protection and homeland security, transportation and energy policy, and environmental and natural resource policy.

Questions or comments about this report should be sent to the project leader, Susan G. Straus (Susan_Straus@rand.org). For more information about RAND Science, Technology, and Policy, see www.rand.org/jie/stp or contact the director at stp@rand.org.
Tora K. Bikson, RAND senior behavioral scientist from 1974 to 2013 and longtime chair of RAND’s institutional review board, the Human Subjects Protection Committee, served as the principal investigator on RAND’s Phase 2 and Phase 3 evaluations of NSDL. Her untimely death on February 1, 2013, left her colleagues with a profound loss, both personal and professional. Her vision, leadership, and drive in guiding the five-year study made it an easy decision for the project team to keep Tora as first author on this, her final report. Tora’s impact in the fields of organizational change, advancing information technologies, sociotechnical system theory, and research ethics involving human subjects is widely known and respected, both in the United States and internationally. Aside from a venerable list of career accomplishments in her 39 years at RAND, Tora was a joy to work with. She is sorely missed and fondly remembered as a pioneer, close collaborator, mentor, and friend. We would be remiss if we did not underscore the invaluable contribution she made to the research presented here.

A recollection of Tora’s life and career, written by RAND’s current president and chief executive officer, Michael Rich, can be found on RAND’s website: www.rand.org/t/CP721.
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Summary

The National Science Digital Library (NSDL) program began in 2000 in the Directorate of Education and Human Resources within the National Science Foundation (NSF). Between 2000 and 2011, NSDL awarded more than 250 grants to support the development of resources, collections, and technical tools and services for teachers and learners in science, technology, engineering, and mathematics (STEM) education. The projects funded over the 11 years of the NSDL program had diverse objectives—e.g., to create and use STEM education resources, to conduct research on innovative uses of digital content and services for distributed learning, and to promote community-based processes for digital library development and classroom implementation. NSDL’s mission was to assemble these elements into a distributed digital library that would be widely available to the public through websites. In 2011, NSF discontinued grant funding for projects in order to build on the results of the NSDL program and to establish the next generation of cyberlearning programs, including Cyberlearning: Transforming Education.

The term NSDL has come to refer to many things. The NSDL program was NSF’s funding mechanism to “establish a national network of learning environments and resources for science, technology, engineering, and mathematics (STEM) education at all levels” (NSF, 2010). By default, when we use the term NSDL in this report, we are referring to the program. The NSDL portal refers specifically to the website NSDL.org, which is a starting point for searching NSDL resources. We use the terms NSDL.org and NSDL portal interchangeably. The NSDL community consists of researchers and developers who received funding through the program, as well as STEM educators, librarians involved with digital initiatives, the education community at large, and users of NSDL. The NSDL brand includes the NSDL name, logo, and tagline. These brand elements may be used to indicate that a tool, project, or resource is affiliated with or recommended by the NSDL program.

This report documents the third and final phase in a series of evaluations of the NSDL program. The broad goal of the current evaluation is to assess the sustainability of developing and developed NSDL resources, tools, and services over time and across the changing technology landscape.

Conceptual Background

The NSDL logic model (McArthur, 2008b), shown in Figure S.1, was developed for the Phase 1 evaluation and provided the framework for both the Phase 2 and the Phase 3 evaluations. As described by Bikson et al. (2011), the logic model comprises a set of interconnecting components designed to foster a distributed initiative that is greater than the sum of its parts. The
logic model specifies underlying theory and assumptions of the program, resources and inputs, activities and processes, products and outputs, and outcomes and impacts, along with relationships among these components. We supplemented the logic model with concepts from sociotechnical systems theory, given that digital libraries, as well as the distributed teaching and learning environments they are intended to enable and support, have both social and technical components and that these are likely to be highly interdependent.

**Figure S.1. NSDL Logic Model**

![Figure S.1. NSDL Logic Model](image)

**SOURCE:** McArthur, 2008b.

**NOTE:** DL = digital library; CI = Core Integration.

The Phase 2 evaluation was a formative study that addressed the state of health of the resource collections, evidence regarding user activities to find and access those resources, and early signs of positive effects of using NSDL resources among science teachers or learners. In light of the discontinuation of the NSDL program, NSF requested a summative evaluation in Phase 3, focusing on the sustainability of digital learning enterprises. Unlike many NSF programs which fund relatively independent projects, the primary mission of the NSDL program was to develop and maintain a distributed library of digital learning resources and services. Understanding the sustainability of this enterprise was therefore an essential factor in assessing its success or failure and in providing lessons learned for future or similar enterprises. Lessons learned about the sustainability of digital initiatives for STEM education are relevant to a range of stakeholders, including NSF, the broader NSDL community of researchers and developers,
STEM educators, librarians involved with digital initiatives, and the education community at large.

Thus, in Phase 3, we identify the attributes of sustainable digital initiatives, and we assess the extent to which the NSDL program demonstrates these attributes. The evaluation focuses on four subordinate goals contributing to sustainability as reflected in the NSDL logic model; specifically, we assess the extent to which the NSDL program produced

1. high-quality and usable STEM educational collections
2. resources that are customized or customizable to a range of specific learning goals or standards
3. a diverse array of services that discover, organize, reuse, and mix resources for educational practice
4. a growing and vibrant community of educational digital library users, developers, and partners who support development of customizable collections, tools, and resources.

In addition, we begin to examine the extent to which NSDL collections, tools, and services, in combination with community development, lead to improved STEM teaching and learning.

Evaluation Design

Like other NSF programs, the NSDL program supported individual projects that had strong scientific merit. NSDL also sought to develop distributed, self-sustaining communities of users of and contributors to shared collections of digital teaching and learning resources and tools. Our evaluation therefore focused both on individual projects and on relationships among the envisioned program activities, processes, products, and outputs. NSDL program tracks include Pathways (begun in 2004), which sought to help the broad community of teachers and learners to locate and use extant digital resources and tools; Services, which consisted of projects that developed tools and provided outreach through user- and developer-oriented workshops; and Targeted Research, which was a relatively small track consisting of applied research projects that would have an immediate facilitative effect on activities done in other tracks.

Our evaluation focused on three levels. The main NSDL portal (NSDL.org) and pathways constitute one level in our evaluation. The next component focuses on tools and services, which were developed by projects in the Services and Targeted Research tracks and by the core NSDL portal and pathways. The final level focuses on users, who play a critical role in stimulating demand for and contributing to the creation of digital STEM resources, tools, and services and in deploying these assets to improve understanding and delivery of STEM teaching and learning. We targeted these levels using multiple methods, including a literature review, development and application of a framework for evaluating the health and sustainability of digital initiatives, a review of tools and services funded through the NSDL program, usability studies, and case studies of three full instantiations of the NSDL logic model.
A Framework for Evaluating the Health and Sustainability of Digital Collection Initiatives

Assessing the potential for the sustainability of the NSDL program and pathway portals first requires understanding the key elements of sustainability. We rely on the following definition of sustainability: “Sustainability is the ability to generate or gain access to the resources—financial or otherwise—needed to protect and increase the value of the content or service for those who use it” (Maron, Smith, and Loy, 2009). We drew on the literature from several fields to develop a framework for evaluating the health and sustainability of digital collections, including library sciences, digital communities, business, and learning object repositories and open educational resources. Our model identifies key concepts of sustainability and the important attributes associated with each concept (see Figure S.2).

**Figure S.2. Concepts and Attributes of a Sustainability Model for Digital Initiatives**

The model has three primary concepts:

- **Audience**: A digital initiative is sustainable to the extent that there is an audience that values the initiative’s collections and services, providing the purpose for it to exist.

- **Organization**: Sustainability requires a strong organization that can deliver the collections and services to meet the needs of the audience over time.

- **Collections**: A healthy collection is a prerequisite for sustainability because the collection provides value and is thus used by the audience.

These concepts point to activities and processes in the NSDL logic model. The concepts are interrelated, and a successful sustainability strategy will address all three.
Audience

Sustainable organizations acknowledge the primacy of the audience in shaping their mission and guiding their actions. Key attributes of sustainability pertaining to audience include audience identification, audience engagement, and accountability to the audience.

Audience Identification

Audience identification reflects internal decisions about who the audience is and how it will benefit from an organization’s products and services, and audience identification addresses external communication with the target audience once it is established. In identifying the audience, it is critical to distinguish between the client, who uses the service, and the customer, who often funds or pays for it; small enterprises often focus their attention on the client when the customer is more critical to their success (Rothschild, 2012). Communication with the target audience can be facilitated through mission, purpose, and value proposition statements.

Audience Engagement

Developers of digital collection initiatives must determine effective ways to engage users, which increasingly involve interactive forms of audience engagement. Many digital collections are developing communities of practice (Wenger-Trayner and Wenger-Trayner, 2015), which can enhance sustainability because the audience participates in the creation and management of the collections and feels more committed to ensuring its success.

Accountability to the Audience

A sustainable initiative must be accountable to all key audiences by identifying the audiences’ ongoing and changing needs and by demonstrating that those needs are being addressed. Some approaches include having a mission statement and goals and participating in regular measurement and reporting of outcomes of the organization’s efforts to achieve those goals. Accountability also includes providing notice of proposed or impending changes to the initiative and publishing policies pertaining to privacy protections, collection development practices, and safeguards for protecting copyright of resources.

Organization

Sustainability requires a strong organization that can deliver the collections and services to meet the needs of the audience over time. Our framework focuses on four components of organization: technical infrastructure, leadership and staffing, role of the parent institution, and sustainability funding.

Technical Infrastructure

Nonprofit digital organizations often excel in the technical aspects of sustainability. Technical infrastructure, including both hardware and software, should exist to serve identified
user needs. Grants are usually awarded for innovative, groundbreaking technologies, whereas the needs of the community are often for a simple, robust infrastructure that is very easy to use.

Leadership and Staffing

Dedicated and entrepreneurial leadership is an essential element of sustainability. Other critical staffing areas include operations, financial management, and marketing.

Role of the Parent Institution

The parent institution, or other sponsoring organizations, can offer significant resources in terms of both indirect support (e.g., office space, computing equipment, utilities) and direct support (e.g., staffing). It is important to document the value of the support provided by the parent institution in order to know the costs of indirect and direct support if the parent institution should decide not to continue its investment. Likewise, it is important to consider the value of the initiative to the parent institution to document the project’s contribution to advancing the parent institution’s mission. Another sustainability strategy is to look for natural alignments of the initiative across departments in the institution, such as the library, departments of education, and information technology.

Sustainability Funding

There are few successful models for how to finance nonprofit digital projects, and there is generally no mandate by granting agencies that support such projects to engage in financial planning for sustainability. (In contrast to contract funding, when providing grant funding—which was the mechanism used to support development of the NSDL program—agencies typically impose limited control so as to foster experimentation and innovation.) Recently, some experts have proposed innovative revenue-generating strategies for nonprofits, such as producing both profitable and non–revenue-generating activities (Young, Jung, and Aranson, 2010). Cost-reduction strategies are also important for enabling the sustainability of a not-for-profit organization.

Collections

The third component in our model is the health of collections. A growing body of literature acknowledges the importance of authoritativeness, usability, and copyright and rights for use.

Authoritativeness

A well-maintained collection earns the trust of users who believe that there is a guiding strategy and useful purpose behind the selection and organization of its resources. Resources should be selected by experts in a subject field or experts in working with a specific target audience. A published peer-review strategy and collection-development practices also help to
establish authoritativeness (Downes, 2007). Resources that can demonstrate high impact will help the portal be competitive for ongoing funding and stakeholder support.

Usability

In the digital collections space, usability involves the technical aspects of using a resource, especially related to the search strategies supported by the collections. An essential attribute of usability is responsiveness to a user need, which is facilitated by metadata. Metadata, or data about data, refers to structured descriptions of data content. For example, metadata for a digital resource might specify the contributor, date, subject, description, resource type, copyright, format, and key words. Effective metadata enable a user to locate all relevant resources in response to a query; to compare results to select the most appropriate resource; and to identify who created the resource, when it was created, how to obtain it, and required permissions for use. Thus, metadata is a primary tool for enabling a user to determine whether a resource is responsive to his or her workflow need, prior to actually using the resource.

Copyright and Rights for Use

Another issue is whether the appropriate rights have been secured to enable users to display, copy, download, or modify resources, as well as whether this information has been conveyed clearly. Ensuring an effective rights platform involves not only acknowledging and documenting the copyright of site content, digital resources, and metadata but also documenting the licensing that enables permitted uses of the resource by the audience.

Health and Sustainability of the NSDL Portal and Pathways

We used the framework just described to assess the health of NSDL collections, particularly the relationship of the NSDL portal and pathways and the resource collections they feature. The evaluation found that the prospect for sustainability and long-term impact of NSDL and pathways was mixed.

Audience

The NSDL portal and all pathways made progress in identifying target audiences, but there was room for improvement. For example, a majority of pathways identified the audience served, with improvement from Phase 2 to Phase 3 of the evaluation. However, audience identification on the portal and pathways was generally very broad, and we found only minimal or moderate efforts to customize the resources and experience to different workflows and expectations of each audience. All sites lacked a compelling rationale for users to select the portal over competing alternatives (the “value proposition”). With the exception of providing advisory boards, NSDL and the pathways provided little evidence of accountability to the audience.
Although somewhat uneven across sites, audience engagement was generally a strength of the NSDL portal in terms providing capabilities to organize, comment on, contribute, and share resources. Progress was mixed, however, in that no form of engagement was common across all pathways, and some types of engagement, such as audience portals and rating and reviewing resources, were provided by only a third of the sites. NSDL and most of the pathways were also at only the very early stages of offering higher levels of collaborative activity that characterize a true community of practice. Nonetheless, NSDL excelled in the development of paradata, which documents resource use in the aggregate (e.g., how many times a resource has been rated, recommended, tagged, viewed) and in the collection and harvesting of annotation metadata, which consist of users’ actual comments and ratings for individual resources.

Organization

The NSDL portal generally received high marks for a strong technical infrastructure. Our review revealed a flexible, extensible, largely Java-based platform that is robust and well suited to a metadata-based collections portal. The core infrastructure components of the portal were based on industry standards that have proven durable. The modular and extensible technical platform, along with use of technologies with a large user base and a significant web-service market share, could be viewed as sustainability strengths for NSDL. However, improvements were needed in integrated security beyond basic user identification and password protection and in support for users in terms of training and personalized services.

The NSDL portal and pathways scored well on visionary leadership, but evidence for staff in other roles was less clear. Evidence of staffing for other organizational roles, including technical leadership, operations, finance, and marketing functions, was less consistent or was absent, and there was no systematic evidence of funding for sustainability or strategic planning activities. This suggested that leadership was not changing in a way to support the transition from research project to a nonprofit business.

The NSDL portal and the pathways demonstrated a range of diversity in parent organizations and other stakeholders, and this broad base can be a potential asset when seeking to diversify revenue streams. However, it is also a potential risk if the portal does not invest in the expertise and staffing to understand the needs of each market segment, perform an environmental scan to identify competing alternatives for services for each segment, and tailor a quality portal experience for each market segment.

Collections

Overall, the NSDL portal and pathways made consistent improvements in the authoritativeness of their collections. Professional oversight of resource accessions remained strong, and peer review increased significantly. Most collection resources documented in metadata were available for use. In terms of usability, the NSDL portal and pathways provided
good basic search services, although pathways needed to ensure that they support searching
directly from the front page.

The most-dramatic usability improvements in the NSDL portal and pathways relate to
improvements in metadata quality. Many pathways provided accurate and complete metadata
that were consistent across records and, in some cases, across collections. Perhaps the most-
important metadata improvements, however, consisted of greatly enriched descriptions of
resources, such as the alignment of NSDL materials to educational standards and the growing
use of usage metadata (annotations and paradata).

Most pathways had copyright and terms-of-use policies, although many failed to
provide sufficient guidance for users about the rights associated with a resource and the uses
they are permitted to make of a resource.

Digital Tools and Services

Tools and services facilitate or enrich the provision of, access to, or use of digital content but
are not themselves content. These might include wikis or application programming interfaces
(APIs) that enable developers to quickly find and deliver digital resources. We conducted a
broad review of tools and services that have been funded in the NSDL program and then selected
a few key tools and services for further analysis. It should be noted that our analysis of NSDL
services was limited; therefore, many of the conclusions discussed here should be considered
tentative.

We found a diverse range of themes in the technology awards funded. Many efforts
sought to advance basic knowledge about the kinds of tools and services that would benefit users
and to conduct preliminary studies on tool and service technology. Some awards were aimed at
developing tools to help users manipulate specific collections or resources in complex ways.
Others sought to develop stand-alone services for end users or developers, while others planned
to enhance the underlying NSDL infrastructure and improve search capabilities, metadata, and
other features.

Project abstracts indicated both redundancy and gaps in service provision. In spite of
the wide range of services and tools that were proposed by NSDL projects, some areas, such as
annotation services, might have been the focus of too many projects. Our review suggested that a
number of projects “rediscovered the wheel” rather than adopting an existing service and
building on it. Still other services important to NSDL program directors went unexplored.

In addition, a more in-depth review of a random sample of projects indicated that many
proposed tools and services were not completed. We found clear evidence that approximately
one-third of the projects in our subset successfully delivered tools and services that closely
resembled those described in the project abstracts; however, close to 60 percent showed no
evidence of a completed tool or service. The degree of integration of services with the NSDL
portal was also variable. Only about half of the proposed tools or services were intended to be
integrated into NSDL.org or one of the pathways sites. Moreover, fewer than half of those projects actually completed their implementation.

There were several key tools and services that were sustained for several years, and most were integrated with the NSDL portal—which, in most cases, was accomplished by using the underlying NSDL web platform. However, the most-enduring services were developed by teams that maintained the NSDL infrastructure and portal rather than by projects from the Services track. Ultimately, although we identified some successes, our cursory assessment of services suggested that the NSDL program’s driving vision of an ecosystem of self-sustaining tools and services had not yet been realized.

Usability Studies: Using NSDL for Lesson Planning

Information retrieval is critical for a collections portal. Our two usability studies produced key findings regarding the authoritativeness and relevance of search results for STEM education. In the first, we conducted a pilot study in which a library search expert evaluated the configuration and implementation of NSDL’s search service in comparison with a general search engine (Google) when seeking representative STEM content. In the second, we designed a usability experiment with preservice teachers and library science students to assess the relative effectiveness and usefulness of NSDL, two relevant pathways, and Google for middle-school earth and physical science lesson planning.

The authoritativeness of NSDL results was judged to be very high. In the expert analysis study, NSDL results consistently outscored Google’s results on this dimension of quality and reliability (although broken links somewhat diminished the trustworthiness of results found when searching NSDL). Results from the usability experiment converged with these findings. The number of unique host websites, coupled with whether the most frequently returned host websites were associated with NSDL, suggested that users retrieved higher-quality (vetted) resources and more-focused results from the NSDL portal and pathways as compared with Google, where the large number of host websites and the number of times each site was selected indicated much more variable quality (e.g., YouTube is at the top of the list).

However, participants in the usability experiment found more-relevant resources using Google compared with using the NSDL portal and pathways websites, a finding that was stronger for more-difficult search tasks. These results could indicate that STEM resources were more available or easier to find via Google or that greater familiarity with Google facilitated search and retrieval. In the expert analysis, the relevance of results also showed higher scores in Google than in NSDL. Using NSDL top-level filters led to some improvement, but relevance ratings remained lower than those from Google. NSDL did not take full advantage of the metadata to rank the relevance of search results, as is common in digital library initiatives.

Google also excelled over the NSDL portal in the presentation of search results. The way results are displayed plays an important role in the user’s ability to identify and select relevant
resources. This was particularly apparent in the expert analysis when searching for a graphical resource. Google excels in such searches, whereas NSDL produces only text descriptions of links to other sites. Google also returns results from social networking sites, whereas NSDL does not; access to a broad range of resources presents both advantages and disadvantages.

**Greater configuration of the search utility, particularly to leverage metadata, should improve the retrieval of results that are relevant and authoritative.** Metadata in NSDL are targeted to educator workflows and educational standards and are an important strength of the portal. Improving the relevance of search results by taking full advantage of the metadata to rank results, while maintaining authoritativeness, is likely to have a positive effect on the uptake of NSDL. Adding graphical displays to NSDL may also influence use of search results.

**Lessons from Case Studies**

We evaluated three full instantiations of the NSDL logic model using a replicated case study design. We relied on sociotechnical systems theory to develop classes of explanatory variables and outcome indicators. Explanatory variables consisted of characteristics of the antecedent organizational context into which the technology is introduced, properties of the technology itself, and implementation processes to integrate the technology into an existing user context. We sought evidence for three types of outcomes: teacher uptake, use, and satisfaction, plus improved STEM teaching; increased student engagement, plus improved STEM learning; and sustainability after the end of special research funding.

We looked for exemplary cases in which NSDL funding promoted use of high-quality online resources by teachers and learners in science classrooms.

- **The Curriculum Customization Service (CCS)** aims to provide teachers with high-quality interactive learning resources to help engage students of varied academic ability in mastering a science and to support new standards-based curricula for science instruction in Denver Public School (DPS).

- **The Noyce Scholars program** seeks to improve K–12 STEM education by encouraging undergraduate STEM majors to become K–12 math and science teachers and by increasing the number of strong STEM K–12 teachers in high-need school districts. We examined the Noyce Program within the California State University (CSU). At CSU, the Noyce program draws heavily on Multimedia Educational Resources for Learning and Online Teaching (MERLOT), a digital STEM repository that has been funded, in part, by NSF. The Noyce Commons is an interface to MERLOT and supports a community of practice around digital resources for Noyce scholars.

- **iCPALMS** (Individualize Collaborate Plan Align Learn Motivate Share) Pathway is a personalized portal that allows users to customize the content, applications, and look and feel of their “homepages” on the CPALMS (Collaborate Plan Align Learn Motivate Share) platform, which is the State of Florida’s online source for teaching standards, courses, and standards-based resources. The aims of iCPALMS are to create online tools and services to enable K–12 math and science teachers to integrate high-quality digital
resources into standards-based instructional planning, to expand NSDL collections with high-quality digital resources that are aligned with standards, to establish a collaborative network of users, and to build capacity for long-term sustainability.

Primary data source for the cases included site visits involving interviews with key stakeholders and group discussions with end users or “clients” (chiefly in-service or preservice science teachers).

All three cases showed evidence of success. In all cases, teachers were enthusiastic about the benefits of access to vetted, digital resources that are aligned with standards. They reported that the resources had positive impacts on student learning by engaging students. Teachers also reported benefits related to their own professional growth and development in terms of improved content knowledge.

The cases highlight distinct organizational contexts and implementation processes. In CCS, the initial focus of the project was earth sciences, and implementation was at the district level. The program used a process of demonstrating and then replicating the process in other districts. It fostered technology readiness by providing all earth science teachers in DPS with hardware and Internet connectivity prior to rollout. CCS tapped an advisory board and used a financial services professional to promote commercialization. It also pursued research on the cognitive role of digital media in advancing science mastery among teachers and learners. For Noyce Scholars using MERLOT, the focus of the implementation was on STEM teacher credentialing. Key implementation activities included embedding digital resource use in preservice and in-service programs and fostering a large and persistent user-developer community. Forums helped to foster community development among the Noyce Scholars. For iCPALMS, the focus of the implementation was a statewide system. The program used a modular but integrated approach to funding and development, used a strategically timed approach to roll out and market the system, and quickly established a critical mass of users and contributors.

Despite these differences, there were a number of commonalities in key activities, processes, and outputs contributing to success across cases, although some of these success factors played out in different ways. These factors included

• strong support from a host organization and key stakeholders that provided funding or other resources
• visionary leadership or champions who played a central role in marketing the system and fueling demand among users
• participatory design of the system beyond the project’s core development team
• free and direct access to highly usable digital collections and to services to support the customization of resources, which were linked to educational standards
• opportunities for users to create their own resources or personal collections
• development of a large community of user-developers who contributed and reviewed resources and fostered diffusion

• training and technical support for users.

Three of these factors were particularly important in fostering sustainability across all cases. These include strong support from a host institution, funding from multiple sources, and the development of large and persistent user-developer communities and partners. The communities and partners promote sustainability through their demand for resources and services and through the social capital they generate as they contribute back to the digital initiative.

Several of the activities and processes and outputs are interdependent and cumulative, as depicted by the logic model. For example, providing access to high-quality collections, coupled with training and outreach, fostered the development of user-developer communities. The growing social infrastructure helped fuel demand for resources, and community members’ contributions via creation, sharing, and vetting of resources, plus support from partners, further developed the collections, thereby fueling additional demand and expansion of the community.

The NSDL program played two distinct kinds of roles in these cases and in other projects it has supported over the years: It provided funding to enable projects to build or enhance digital collections or services. Through this funding, the program created a community and network of resources that enabled projects to grow and contribute back to the collective NSDL effort. In supporting the latter role, the NSDL portal has supported projects in a variety of ways—for example, providing access to high-quality digital resources for project or user collections, access to digital tools and services to develop project sites and systems, capabilities to customize resources or tools and services by project developers or users, repositories where projects can add new or revised digital materials, and sites where projects can add new or revised tools and services. The NSDL program not only provides materials and services to its projects but also encourages the sharing of new and improved resources and services back to NSDL.org and, as a result, to the broader NSDL community.

Conclusions and Recommendations

The conclusions and recommendations that follow from this evaluation are not intended for the NSDL program per se, since it has ended, but instead are directed at NSDL projects that may continue in the future—specifically, NSDL.org and the pathways projects and future cyberlearning programs, which likely will need to address some of the same challenges that confronted the NSDL program.
Trade-offs in Developing Sustainable Digital Initiatives

Results of the Phase 3 evaluation pointed to a number of trade-offs in developing and sustaining digital initiatives. We next describe these trade-offs and propose recommendations to resolve these tensions.

Innovation Versus Trust

As the web grows, digital library initiatives must continue to expand collections to provide access to innovative content and genres and to present resources in compelling and informative ways. On the one hand, NSDL projects focused on providing access to high-quality digital resources by vetting collections; on the other hand, this strategy excluded a good deal of dynamic and interesting content on the web, such as YouTube channels, Twitter feeds from prominent scientists, and open-source online textbooks. Likewise, when users can annotate, rate, and perhaps combine and repurpose digital materials and place them in personal collections, the users’ actions pose challenges to the authoritativeness of collections even while enriching them.

The tension between innovation and trust could be addressed, in part, by tagging content to indicate that it is not vetted or to have different collections for vetted and nonvetted content. In concert with this approach, a digital initiative could solicit reviews of new content from trusted (e.g., registered or trained) users to acquire new content while preserving its reputation for quality.

Innovation Versus Control

The vision of NSDL creating a complex digital library and community was very ambitious. In terms of services, for example, a critical challenge to this vision was to ensure that a complete and coherent set of tools was created and maintained—yet we identified redundancies and gaps in tools and services, as well as products that were not integrated with the NSDL portal. Whereas a single technical infrastructure and basic services might have been best built through contracts that articulated detailed requirements, in the early days of the NSDL program, it was unclear what the program would become. Under such circumstances, it was reasonable that the NSDL program used grant funding—which provides much less control by the funding agency—to support several different approaches, learn from the experiments about which services worked best, and then abandon most of them while funding the refinement of only a few. The importance of promoting research to foster innovation may also partly explain why projects in the Services track had varied relationships with the NSDL program and its portals, which ranged from tight couplings with the NSDL portal to very loose connections. Similarly, the program structure and funding mechanisms may explain shortcomings in sustainability, particularly with respect to organizational attributes, given that principal investigators who successfully competed for NSDL grants were primarily interested in conducting research and development in the area of digital libraries rather than in developing a sustained enterprise.
If sustainability is a goal of future digital learning initiatives, the tension between innovation and control can be addressed by (1) making it clear from the outset that projects seeking ongoing funding are expected to plan for sustainability and (2) supporting projects using a combination of grant and contract funding. In early stages of a program, grant funding can provide project teams with freedom to experiment and innovate. In later stages, projects that have produced promising results and have designed plans for sustainability can be funded under contract or cooperative agreement to implement such plans and transition their products to other sponsors. Likewise, contracts or cooperative agreements could be used to fund the development of tools and services to fill identified gaps. An important strategy to complement this approach is to ensure that projects are evaluated on criteria for sustainability in annual progress reports.

Collaboration Versus Efficiency

The previous sections noted several reasons why collaborative yet relatively independent and parallel processes to develop NSDL collections and services might lead to more-innovative results than highly controlled and tightly coordinated processes would yield. However, there are clearly areas where the efficiency of a central decision is preferable. It is easier to manage copyright and permitted uses, for example, when a collection is centrally controlled. Indeed, having a single usage policy across multiple NSDL collections and pathways, not just within each one, can greatly help users understand what they can do and cannot do with NSDL resources.

Community development can create synergistic results but also may engender coordination costs. Users who want to submit composite or repurposed materials to an NSDL collection, for example, may post compliance challenges for centralized copyright and terms-of-use policies. Privacy policies may also be challenged as users become more-active participants in digital library communities rather than mere consumers of digital resources—and thereby risk sharing more information than they want to about themselves. In general, NSDL, like many digital libraries, wants to encourage its users to become producers rather than just passive consumers of digital resources, but this will impose additional management and monitoring costs on the library operators—assuming that they want to maintain high levels of quality.

The tension between collaboration and efficiency in the evolving ecosystem of collections, tools, and services can be addressed, in part, by promoting mutual accountability among all the stakeholders engaged in developing the initiative. Improving accountability provides a means of getting stakeholders more involved while also providing a structure to guide their involvement and collaborative activities. Mutual accountability requires engaging partners in developing the program purpose and mission, clearly communicating goals and expectations for participation in the program, documenting mutually agreed-on requirements with each contributor, and evaluating compliance with requirements.
Recommendations for Improving Evaluation of Digital Initiatives

Although the project team sought to collect primary data from NSDL users (i.e., teachers) and students to evaluate program goals, NSF opted not to seek approval for data collection as required by the Paperwork Reduction Act of 1995 (Public Law 104-13), which mandates approval for systematic data collection from ten or more persons under federally funded contracts. This greatly limited the extent to which we could assess program outcomes and impacts. The evaluation team also did not have access to annual progress reports as a possible source of inputs for analysis of project activities and outcomes in the Phase 3 study. Recommendations for future evaluation efforts focus on methodological approaches and research questions using a broader range of data sources:

- Perhaps the most important recommendation for future evaluation is to assess the impact of the program on student engagement and learning, given that these are the principal aims of NSDL. Research resulting from individual projects—particularly using methods that allow for inferences about causality—is a critical component of a comprehensive evaluation. Experimental or quasi-experimental methods are needed to draw inferences about teaching and learning effects and other outcomes. Likewise, assessing teachers’ knowledge gain and performance as result of using NSDL resources should be investigated.

- Collecting data about related processes and outcomes from NSDL clients and customers is also important given the significant roles they play in the program’s logic model—and, presumably, in other digital enterprises, particularly those that rely on community-based, collaborative development. Such methods as focus groups, interviews, and surveys can be used to address a variety of elements in the logic model. A teacher survey, developed but not used for this evaluation, can be found in Appendix E. It can be used or modified for evaluating other digital initiatives.

- Data from program and project staff might be used to assess processes related to organizational sustainability, such as the development of strategic plans and funding for sustainability, and how the initiative contributes to the mission of the parent and sponsoring institutions (and vice versa).

- Secondary data can provide a variety of additional information about the health of digital initiatives’ inputs, processes, outputs, and outcomes. For example, web metrics can be used to monitor traffic flow usage patterns, sources, and destinations of users. Web metrics can also be used to examine the effect of program innovations on resource uptake. Annual progress reports can be reviewed to assess whether projects form alliances with other partners and successfully complete proposed products. Reviews of scholarly research products can be used to assess project outputs and to identify lessons learned at the project and program levels. New text mining and visualization tools can be used to uncover key themes and topics in these sources of secondary data.

- Finally, another critical recommendation is that cyberlearning initiatives, particularly multiyear, collaborative initiatives such as NSDL, need a much greater focus on sustainability from the outset to balance the emphasis that NSF has traditionally placed on innovation to demonstrate broader impact. Initiatives such as NSDL require years to
demonstrate impact, and thus the elements that contribute to impact need to be tracked over time.

Our sustainability model is the first attempt that we have discovered to identify the key entities and attributes of sustainability and to develop rubrics that assess the likelihood of sustainability for a complex multiyear initiative such as NSDL. We encourage NSF to build on our work to incorporate concrete sustainability requirements into solicitations and annual reporting requirements—in particular, to target funding directly to products that have been identified as sustainable and worthy of ongoing development and support.
Acknowledgments

We wish to thank numerous people who made this evaluation possible. We are grateful to Ellice Forman at the University of Pittsburgh and the students at University of Pittsburgh; University of North Carolina; and Rutgers, the State University of New Jersey, for taking part in the usability experiment.

We are indebted to many people who took part in our case studies, including staff and teachers from the Denver Public Schools, Curriculum Customization Service at the University of Colorado at Boulder’s Institute of Cognitive Science and Digital Learning Sciences in the University Corporation for Atmospheric Research (UCAR), the Robert Noyce Scholars Program at California State University, and the Individualize Collaborate Plan Align Learn Motivate Share (iCPALMS) Pathway at Florida State University. Special thanks to Holly Devaul, Kaye Howe, and Eileen McIlvain, from UCAR; Tammy Sumner from the University of Colorado at Boulder; Gerald Hanley from California State University; and Rabieh Razzouk from Florida State University for hosting our site visits and sharing their insights.

We acknowledge Lionel Galway from RAND and Priscilla Caplan from Florida State University for their thoughtful and insightful comments on an earlier version of this report.

We are grateful to Michael Woodward of RAND for outstanding administrative support, conscientious preparation of the final report, and endless good humor.

We thank Carl Mitchell, our program director from Guardians of Honor (GOH), who acted as contract, finance, and policy liaison between RAND and the National Science Foundation for the Phase 2 and Phase 3 evaluations.

We note that one of the report’s authors, David McArthur, began serving as a co-director of NSDL on a temporary basis, effective November 1, 2013. He conducted the Phase 1 evaluation of National Science Digital Library/Distributed Learning at GOH in 2008. He subsequently served as a consultant to GOH for the Phase 2 evaluation and as a consultant to GOH and RAND for the Phase 3 evaluation. His principal efforts on the Phase 3 evaluation concluded on September 6, 2013.
# Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AAAS</td>
<td>American Association for the Advancement of Science</td>
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<td>AMSER</td>
<td>Applied Math and Science: Community College</td>
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<td>API</td>
<td>application programming interface</td>
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<td>ASN</td>
<td>Achievement Standards Network</td>
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<tr>
<td>BEN</td>
<td>BiosciEdNet</td>
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<td>CCS</td>
<td>Curriculum Customization Service</td>
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<td>ChemEdDL</td>
<td>Chemical Education Digital Library</td>
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<td>CI</td>
<td>Core Integration</td>
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<td>CLEAN</td>
<td>Climate Literacy &amp; Energy Awareness Network</td>
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<tr>
<td>ComPADRE</td>
<td>Communities of Physics and Astronomy Digital Resources in Education</td>
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<tr>
<td>CPALMS</td>
<td>Collaborate Plan Align Learn Motivate Share</td>
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<tr>
<td>CREATE</td>
<td>Component Repository and Environment for Assembly of Teaching Environments</td>
</tr>
<tr>
<td>CSERD</td>
<td>Computational Science Education Reference Desk</td>
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<tr>
<td>CSU</td>
<td>California State University</td>
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<tr>
<td>CU</td>
<td>University of Colorado at Boulder</td>
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<td>DCS</td>
<td>Digital Collection System</td>
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<td>DDS</td>
<td>Digital Discovery System</td>
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<td>DL</td>
<td>digital library</td>
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<tr>
<td>DLESE</td>
<td>Digital Library for Earth System Education</td>
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<tr>
<td>DLI</td>
<td>Digital Libraries Initiative</td>
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<tr>
<td>DLSI</td>
<td>Digital Library Service Integration</td>
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<tr>
<td>DOE</td>
<td>Department of Education</td>
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<td>DPS</td>
<td>Denver Public Schools</td>
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<tr>
<td>ECG</td>
<td>Evaluation Consulting Group</td>
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<tr>
<td>Fedora</td>
<td>Flexible Extensible Digital Object Repository Architecture</td>
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<td>FSU</td>
<td>Florida State University</td>
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<td>FY</td>
<td>fiscal year</td>
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<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
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<tr>
<td>GRAM</td>
<td>Generally Recognized as Mature</td>
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<tr>
<td>HTTP</td>
<td>hypertext transfer protocol</td>
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<tr>
<td>IA</td>
<td>Instructional Architect</td>
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<tr>
<td>iCPALMS</td>
<td>Individualize Collaborate Plan Align Learn Motivate Share</td>
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<tr>
<td>IIS</td>
<td>Information and Intelligent Systems</td>
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<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>jOAI</td>
<td>Java-based Open Access Initiative</td>
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<td>LAR</td>
<td>Learning Activity Readiness</td>
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<td>MatDL</td>
<td>Materials Digital Library Pathway</td>
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<td>MathDL</td>
<td>Mathematical Association of America’s Mathematical Sciences Digital Library (the Math Gateway)</td>
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<td>MERLOT</td>
<td>Multimedia Educational Resource for Learning and Online Teaching</td>
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<td>MiNC</td>
<td>Middleware for Network- and Context-aware</td>
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<td>MSP2</td>
<td>Middle School Portal 2: Math and Sciences Pathway</td>
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<td>NCS</td>
<td>NSDL Collection System</td>
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<td>NISO</td>
<td>National Information Standards Organization</td>
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<td>NSDL</td>
<td>National Science Digital Library/Distributed Learning</td>
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<td>NSF</td>
<td>National Science Foundation</td>
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<td>OAI</td>
<td>Open Archives Initiative</td>
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<td>OAI-PMH</td>
<td>Open Archives Initiative Protocol for Metadata Harvesting</td>
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<td>OER</td>
<td>open educational resources</td>
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<td>OSMM</td>
<td>Open Software Maturity Model</td>
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<tr>
<td>PhET</td>
<td>Physics Education Technology (at the University of Colorado)</td>
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<td>PI</td>
<td>principal investigator</td>
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<td>RC</td>
<td>Resource Center</td>
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<td>REST</td>
<td>representational state transfer</td>
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<td>RPC</td>
<td>remote procedure call</td>
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<td>SLM</td>
<td>Science Literacy Maps</td>
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<td>SMART</td>
<td>Science and Mathematics Accessible Resource Tool</td>
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<tr>
<td>SMILE</td>
<td>Science and Math Informal Learning Educators</td>
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<tr>
<td>SMS</td>
<td>Strand Map Service</td>
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<tr>
<td>STEM</td>
<td>science, technology, engineering, and mathematics</td>
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<tr>
<td>TAB</td>
<td>Teacher Advisory Board</td>
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<tr>
<td>TD-ESC</td>
<td>Teacher Domain Educational Standards Correlation</td>
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<tr>
<td>TNS</td>
<td>Technical Network Services</td>
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<tr>
<td>UCAR</td>
<td>University Center for Atmospheric Research</td>
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<tr>
<td>UNESCO</td>
<td>United Nations Educational, Scientific and Cultural Organization</td>
</tr>
<tr>
<td>URL</td>
<td>uniform resource locator</td>
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<tr>
<td>XML</td>
<td>Extensible Markup Language</td>
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</tbody>
</table>
Glossary

**annotation metadata** Comments and ratings for individual resources (see metadata below for further information)

**authoritativeness** Reflects the accuracy, currency, objectivity, and reliability (e.g., availability) of resources in a collection, which in turn influence users’ trust in its value

**collection** Projects that aggregate and manage a subset of the digital library’s content; collections were often distinguished by their STEM subject area, but some addressed sectors, such as formal or informal education, or grade bands (e.g., middle school)

**Core Integration (CI)** A large, multi-institutional NSDL project whose main objectives were to coordinate a distributed group of resource collection and service providers and to ensure reliable access to the network of learning environments and resources

**federated digital libraries** Collections of separate information services that use common standards to support interoperability among those services

**metadata** Structured or standardized descriptions of the data content (data about data)—e.g., a digital resource may include metadata specifying information about the resource, such as the contributor, date, subject, description, resource type, copyright, format, key words, and other information about the resource

**metadata record** A set of metadata used to describe a resource—e.g., the Dublin Core standard specifies up to 22 metadata elements that compose a metadata record, including title, author, source, and format

**open educational resources (OER)** The “open provision of educational resources, enabled by information and communication technologies, for consultation, use, and adaptation by a community of users for non-commercial purposes” (UNESCO, 2002, p. 24)

**paradata** Aggregated documentation describing how resources have been used (e.g., number of downloads, favorites, or shares)
<table>
<thead>
<tr>
<th>Pathways</th>
<th>NSDL projects providing educational content to a broad community of learners; Pathway projects were also responsible for establishing methods and tools to identify, select, and annotate high-quality digital resources and to generate metadata for the resources that they managed (see definition of metadata)</th>
</tr>
</thead>
<tbody>
<tr>
<td>phase or stage</td>
<td>In this report, \textit{stage} refers to periods of development of the NSDL program, whereas \textit{phase} refers to the evaluation of the NSDL program</td>
</tr>
<tr>
<td>Selection Service</td>
<td>NSDL projects focused on increasing the amount of high-quality STEM educational content known to NSDL users through usage development workshops for various communities of learners</td>
</tr>
<tr>
<td>Services</td>
<td>NSDL projects that developed services or tools, such as search capabilities, website authoring, and blogging applications, to support users, collection providers, and the Core Integration project to enhance the usability, usefulness, and value of the digital library</td>
</tr>
<tr>
<td>Targeted Research</td>
<td>NSDL projects that explored specific topics related to the creation, use, and educational impact of digital libraries and digital resources</td>
</tr>
<tr>
<td>web metrics</td>
<td>Statistics about how a website or web page is used, including the number of visitors, number of unique users, time spent on the site, and other sites from which users arrived at the web page</td>
</tr>
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</table>
Chapter One. Introduction

The National Science Digital Library/Distributed Learning (NSDL) program began in 2000 to support the development of resources, collections, and technical tools and services for teachers and learners in science, technology, engineering, and mathematics (STEM) education.\(^1\) NSDL’s mission was to assemble these elements into a distributed digital library that that would be widely available to the public through websites. In 2011, the National Science Foundation (NSF) discontinued grant funding for projects to build on the results of the NSDL program and to establish the next generation of cyberlearning programs, including Cyberlearning: Transforming Education.

The term NSDL refers to many things. The NSDL program was NSF’s funding mechanism to “establish a national network of learning environments and resources for science, technology, engineering, and mathematics (STEM) education at all levels” (NSF, 2010). By default, when we use the term NSDL in this report, we are referring to the program. The NSDL portal refers specifically to the website NSDL.org, which is a starting point for searching NSDL resources. We use the terms NSDL.org and NSDL portal interchangeably. The NSDL community consists of researchers and developers who received funding through the program, as well as STEM educators, librarians involved with digital initiatives, the education community at large, and users of NSDL. The NSDL brand includes the NSDL name, logo, and tagline. These brand elements may be used to indicate that a tool, project, or resource is affiliated with or recommended by the NSDL program.

This report documents the third and final phase in a series of evaluations of the NSDL program. In Phase 1, McArthur (2008b) conducted a review of the NSDL program, documenting program inputs, processes, outputs, and results from 2000 to 2007 and producing an inventory of projects’ products, services, collaborations, and scholarly publications. In Phase 2, a research team from the RAND Corporation conducted a preliminary assessment of program inputs and outcomes using primary and secondary data and developed a plan for a larger-scale Phase 3 assessment (Bikson et al., 2011). Phase 3 was originally intended as the final phase of a formative evaluation of NSDL, based on the assumption that the program would continue for several years. However, because the program was discontinued, NSF requested a shift in focus of

\(^1\) As noted in Bikson et al. (2011), in FY 2000, the NSDL program came into being with the name National Science, Mathematics, Engineering, and Technology Education Digital Library, with the abbreviation NSDL (in which S itself stood for another abbreviation, SMET). Several years later, the order of terms in the full name was changed to Science, Technology, Engineering, and Mathematics (STEM), but the NSDL abbreviation was retained. In FY 2009, NSDL became an abbreviation for National STEM Digital Library/Distributed Learning program, concurrent with an increased emphasis on the link to science learning.
the Phase 3 evaluation from formative to summative, with a particular emphasis on the sustainability of digital initiatives for STEM education. Unlike many NSF programs, which fund relatively independent projects, the primary mission of the NSDL program was to develop and maintain a distributed library of digital learning resources and services. Understanding the sustainability of this enterprise was therefore an essential factor in assessing its success or failure and in providing lessons learned for future or similar enterprises.

Thus, the broad goal of this evaluation is to assess the sustainability of developing and developed NSDL collections, tools, and services over time and across the changing technology landscape. Drawing on diverse literatures, we identify the attributes of sustainable digital initiatives, and we assess the extent to which the NSDL program demonstrates these attributes. Our evaluation focuses on four subordinate goals contributing to sustainability; specifically, we assess the extent to which the NSDL program produced

1. high-quality and usable STEM educational collections
2. resources that are customized to a range of specific learning goals or standards
3. a diverse array of services that discover, organize, reuse, and mix resources for educational practice
4. a growing and vibrant community of educational digital library users, developers, and partners who supported development of customizable collections, tools, and resources.

In addition, we begin to examine the extent to which NSDL collections, tools, and services, in combination with community development, lead to improved STEM teaching and learning.

These goals are interdependent in several ways, as shown in the NSDL logic model in Figure 1.1. The effective use of customizable NSDL materials in educational contexts presupposes that they are not only high quality but also accessible and persistently available on the web. And the growth of continuously available digital resources and services, in turn, relies on a vibrant community of developers and users who can create innovative content and tools and improve them on an ongoing basis.

The results of the Phase 3 evaluation of NSDL are intended to benefit the Directorate of Education and Human Resources within NSF and to inform the design and evaluation of similar programs in NSF and in other organizations. Lessons learned about the sustainability of digital initiatives for STEM education are relevant to a range of stakeholders, including NSF, the broader NSDL community of researchers and developers, STEM educators, librarians involved with digital initiatives, and the education community at large.

NSDL Logic Model

The NSDL logic model, originally developed for the Phase 1 evaluation (McArthur, 2008b), provided a foundation for both the Phase 2 and the Phase 3 evaluations. As described by Bikson et al. (2011), the logic model comprises a set of interconnecting components designed to foster a
distributed initiative that is greater than the sum of its parts (see Figure 1.1). The logic model specifies underlying theory and assumptions of the program, resources and inputs, activities and processes, products and outputs, and, finally, outcomes and impacts. As with other NSF programs, the NSDL program supported individual projects with strong scientific merit. Unlike other programs, however, the NSDL program also sought to develop distributed, self-sustaining communities of users of and contributors to shared collections of digital teaching and learning resources and tools. Relationships among the envisioned activities, processes, products, and outputs are depicted in the program model. Substantial resources have been invested in a technical and social infrastructure to realize these linked aims. Thus, the program’s logic model provides an important guide for an evaluation of the NSDL program and was used as a framework for both the Phase 2 and the Phase 3 evaluations. Consistency of methodologies and foci from the Phase 2 evaluation to the Phase 3 evaluation also provides an opportunity to demonstrate improvement or change across the life of the NSDL program.
Figure 1.1: NSDL Logic Model

A digital library can be integral to improvements in teaching and learning if it:
- provides easy access to many diverse high-quality resources,
- can customize them to specific learning needs, and
- can be integrated into the workflow of educational practice.

The community-based, collaborative, distributed development of digital libraries can be productive and lead to the creation of high-quality content and services customized to specific educational needs.


NOTE: DL = digital library; CI = Core Integration.
The Phase 2 evaluation targeted the intermediate components of the logic model: (1) activities and processes and (2) products and outputs. As we describe below, these components of the model were also targeted in Phase 3 of the evaluation. A summative evaluation would ideally examine outcomes more extensively, but several constraints on our program evaluation, noted throughout this report, limited opportunities to examine classroom learning and teaching outcomes. In particular, the Paperwork Reduction Act of 1995 (Public Law 104-13) mandates approval for systematic data collection from ten or more persons under federally funded contracts; NSF opted not to seek such approval, which greatly limited the extent and nature of primary data that we could collect to address program outcomes and impacts. The evaluation team also was not provided with annual progress reports as a possible source of inputs for analysis of project activities and outcomes for the Phase 3 evaluation. In Chapter Eight, we provide recommendations for methodological approaches and research questions using a broader range of data sources to inform future evaluation efforts for other cyberlearning programs.

Sociotechnical Systems Foundation

It is clear throughout the NSDL logic model that digital libraries, as well as the distributed teaching and learning environments they are intended to enable and support, have both social and technical components and that these are taken to be highly interdependent. Therefore, we supplemented the logic model by using a sociotechnical systems-theoretic foundation as a basis for the Phase 2 and Phase 3 evaluations.

Sociotechnical systems theory is well suited to account for the ways in which the social and technical sides of a complex system can be effectively integrated to yield complementary outcomes. Research carried out at RAND and elsewhere suggests the usefulness of a sociotechnical systems perspective for understanding how new technologies can be introduced into existing contexts of use to achieve particular aims (Ericshen et al., 2013; Cresswell, Worth, and Sheikh, 2012; Ackerman et al., 2012; Bikson and Eveland, 1991; Bikson and Eveland, 1998; Mankin, Cohen, and Bikson, 1997). In these ways, sociotechnical systems theory can help explain how and why these two major constituents of the NSDL logic model should lead to reciprocally influential effects.

Our Phase 3 evaluation, accordingly, looked for evidence that NSDL digital resources are being customized for use in educational contexts. In particular, the evaluation sought indicators of constructive user involvement with developers to adapt resources to suit the needs of varied educational contexts.

Background on the NSDL Program and Evaluation Approach

Over its 11-year history, the NSDL program funded projects with a diverse array of objectives—e.g., to create and use STEM education resources, to conduct research on innovative uses of digital content and services for distributed learning, and to promote community-based
processes for digital library development and classroom implementation. Bikson et al. (2011) described five initial program tracks:

- **Core Integration (CI)** provided the central functionality for the NSDL program, which was construed both as an organization uniting a community of projects within the program and as a technical infrastructure (including NSDL.org, the main portal) supporting the network of collections, services, and other digital resources.

- **Collections** sought to develop, organize, and manage sets of digital content related to STEM learning within a coherent theme (e.g., subject area or grade level) (this track was discontinued in 2004).

- **Pathways**, which replaced the Collections track in 2004, was intended to provide stewardship for STEM education content and services needed by a broad community of teachers and learners, helping them to locate and use extant digital resources and tools.

- **Services** consisted of services and tools to facilitate or enrich the reach, value, and impact of digital library materials, but these services and tools were not themselves content (e.g., wikis that enable users to repurpose and combine resources and application programming interfaces that enable developers to quickly find and deliver digital resources).

- **Targeted Research** was a relatively small track consisting of applied-research projects that would have an immediate facilitative effect on activities done in other tracks.

The NSDL program tracks changed considerably in the later years of the program; Chapter Two discusses the evolution of the program in more detail.

**Summary of Phase 2 Results**

Before describing the focus of the current Phase 3 evaluation, we summarize key findings from the Phase 2 report. As described by Bikson et al. (2011), the Phase 2 study focused on three key areas: the digital resources developed, avenues for accessing them, and expected outcomes of their use. Key findings from the Phase 2 study addressed the health of the resource collections, evidence regarding user activities to find and access those resources, and early signs of positive effects of using NSDL resources among science teachers or learners.

**Collections**

The stability of collections was noteworthy: 95 percent of records we sampled were available. However, we found that the authoritativeness of collections was questionable. Fourteen of the 50 collections reviewed were not current, although 13 of the 14 were still available for search and retrieval via the NSDL portal. Many of the pathways and collections did not have published peer-review practices. Sample searches revealed a number of problems with metadata, including search-result lists of heterogeneous resources that were difficult to identify and compare, a lack of information about what could be done with resources once they were identified, inconsistent and unclear copyright guidance, and missing privacy policies in many of
the collections.\footnote{In digital libraries, metadata are standardized or structured descriptions of the data content, or “data about data.” For example, a digital resource may include metadata specifying information about the resource, such as the contributor, date, subject, description, resource type, copyright, format, keywords, and other information about the resource. Metadata are discussed in detail beginning in Chapter Three.} Our analysis also revealed that the NSDL portal (which, as described in Chapter Two, is a federated portal of collections provided by the pathways) was not an integrated one-stop shop. With a collection overlap of only 55 percent, there was considerable disparity between the resources that could be found in individual pathways compared with those available at NSDL.org. There was no real evidence of collaboration and no common elements of look and feel across pathways. These findings suggest that NSDL.org did not appear to be substantially greater than the sum of its parts.

\textbf{Evidence of User Activities to Find and Access Resources}

The NSDL portal and the pathways used web metrics to monitor overall traffic and to modify the site and design. NSDL.org and pathways personnel had little knowledge of the demographic characteristics of their user communities and conducted limited assessment of site usage. We also found little communication between pathways and NSDL.org personnel and no mandated reporting of web statistics to the organizations responsible for the central functionality and technical infrastructure of the NSDL portal.

\textbf{Evidence of Teaching or Learning Effects}

The Phase 2 study found that these outcomes were addressed by only a small number of studies resulting from NSDL-funded projects, and variations among studies precluded categorizing project features or approaches to produce more-general results. In addition, assessments relied on teachers’ self-reported behavior or intentions to change. Experimental or quasi-experimental methods were largely absent from this body of research.

\textbf{Recommendations}

Bikson et al. (2011) proposed a number of suggestions to improve collection health, access, and evidence of teaching and learning outcomes. Key recommendations included

- regular review of resource collections
- encouragement of policies and practices that provide evidence of collection authoritativeness
- development of common metadata elements and vocabularies across the NSDL portal and pathways
- adoption of a social networking service model for NSDL.org
- selection and promulgation of standardized web metrics and mandated reporting
- allocation of more funding for targeted research, particularly to assess longer-term outcomes and broader impacts.
**Phase 3 Tiered Design and Methods**

The technical approach we used in the Phase 3 evaluation relies on a three-tier design (see Figure 1.2). The tiers are hierarchical in the sense that they are not independent and are progressively narrower in scope.

**Figure 1.2. Tiers of the NSDL Program Examined in Phase 3**

<table>
<thead>
<tr>
<th>Tier 1: NSDL.org &amp; Pathways</th>
<th>The main NSDL portal ((N = 1)) and an exhaustive sample of pathways ((N = 18))^a and their collections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 2: Tools &amp; Services</td>
<td>Extensive sample of tools and services developed by individual Services and Targeted Research projects, as well as by the core NSDL portal and pathways</td>
</tr>
<tr>
<td>Tier 3: Users</td>
<td>Teachers who participate in the community of developers and users; prospective teachers using resources for STEM lesson planning</td>
</tr>
</tbody>
</table>

^a Two projects are now considered pathways but were not funded under the Pathways track.

As shown in Figure 1.2, NSDL.org (the main NSDL portal) and pathways constitute one tier in our evaluation. Because the NSDL portal and pathways are tightly associated with the collections they represent, we assessed them jointly. NSDL.org and pathways are expected to help users find their way to appropriate collections and to locate resources of interest, thus forming a critical part of the infrastructure. NSDL.org and the pathways play complementary and focused roles by targeting reasonably delimited user populations.

The second tier of the evaluation focuses on tools and services, which have less clear roles in the overall structure of NSDL. Tools and services belong at the same design level as NSDL.org and the pathways because they too are intended to be useful across collections. For instance, the Curriculum Customization Service (CCS) drew on the Digital Library for Earth System Education (DLESE), as well as the EduPak tool and the Strand Map Service, in implementing improved digital earth science education materials in collaboration with Denver Public Schools (DPS). (However, from a practical perspective, the tools and services developed by NSDL projects were narrower in scope than NSDL.org and pathways because most of them were used within a single project rather than across collections.) At this level of the design, key research questions had to do with the roles played by the tools and services in facilitating interconnectivity, vitality, use, and growth.

Users compose the third tier of the design. They play a critical role in stimulating demand for and contributing to the creation of digital STEM resources, tools, and services and in deploying these assets to improve understanding and delivery of STEM teaching and learning, a vital step in the transition from digital libraries to distributed learning. In the process, users will likely
engender communities of practice that disseminate the use and support the sustainability of NSDL as a sociotechnical enterprise.

We targeted these tiers using multiple methods in the Phase 3 evaluation.

Literature Review

We began by reviewing the literature to understand the factors contributing to sustainability of digital initiatives.

Assessment of Sustainability of NSDL Portal and Pathways

Next, we applied this framework to assess the sustainability of the NSDL portal and its pathways by reviewing their websites and publicly available documents. The Phase 2 evaluation (Bikson et al., 2011) provided relatively comprehensive results regarding the state of health of the collections. Therefore, in Phase 3, we focused more narrowly on dimensions of collections noted in the Phase 2 evaluation related to authoritativeness (e.g., evidence of peer review and professional oversight), clearly articulated user policies, and quality of metadata. We also assessed the NSDL portal and pathways on other important attributes of sustainability related to audience (e.g., identification, engagement) and organization (e.g., leadership, strategic planning), as identified in our review of literature.

Assessment of Tools and Services

We then assessed tools and services projects based on a review of abstracts and websites, interviews with developers of selected projects, and analysis of usage of selected tools and services. Our intention was to document the kinds of tools and services developed, their usage and sustainability, and whether the tools and services showed evidence of collaborative development.

Usability Studies

Next, we conducted usability studies aimed at assessing how users find and identify resources for routine tasks in STEM teaching. We conducted a pilot study, with search experts’ judgments, to assess the authoritativeness and relevance of the results of representative STEM teaching search tasks using NSDL and Google. We also conducted a larger usability study examining the information-seeking behavior of prospective teachers to assess factors affecting the usability of NSDL digital resources and to understand how these resources meet STEM teachers’ instructional needs.

Case Studies

Finally, we conducted case studies of three full instantiations of the NSDL logic model that used diverse approaches to its realization—CCS, the Noyce Scholars Program/MERLOT (Multimedia Educational Resource for Learning and Online Teaching), and iCPALMS (Individualize Collaborate Plan Align Learn Motivate Share).
Project Oversight

An advisory group, the Evaluation Consulting Group (ECG), advised on the design and execution of the Phase 3 evaluation, with a focus on reviewing the research design. The ECG consisted of five researchers and educators with expertise in different areas, including the development of social and technical infrastructures, cyber-infrastructures for teaching and learning, and educational evaluation.

How to Read This Report

Following an introduction to the NSDL program in Chapter Two, there are five chapters about results and a concluding chapter. Each chapter has its own rationale and methods section, as well as an independent discussion of the conclusions that its findings support. Chapter Three describes a framework for evaluating the health and sustainability of digital initiatives, and Chapter Four applies the framework to NSDL. We then present the results of some focused studies of NSDL tools and services (Chapter Five), user experiences (Chapter Six), and case studies (Chapter Seven). Chapter Eight summarizes our results and presents recommendations.

The chapters are not necessarily stand-alone—i.e., understanding the content of some of the chapters requires a general understanding of the NSDL program. Therefore, we recommend that all readers read Chapter Two, and, in some cases, we suggest other prerequisite reading, as described below. In addition, where relevant, the chapters refer to appendixes that provide supporting material.

The layout of the remaining chapters is as follows:

- Chapter Two provides a brief history of NSDL and reports statistics regarding the scope of the program. The chapter discusses the NSDL tracks and reviews changes made by NSF in later years of the program to refine program goals and to help projects achieve those goals.
- Chapter Three describes the results of the literature review of factors that contribute to the sustainability of digital collection initiatives. It develops a sustainability model and proposes a framework for evaluating the health and sustainability of digital initiatives.
- Chapter Four applies the sustainability framework described in the previous chapter to assess the health and sustainability of NSDL.org and the NSDL pathways sites. This chapter should be read in combination with Chapter Three.
- Chapter Five presents the results of the analysis of tools and services based on a review of project documents and websites. This analysis looks at tools and services that have been developed and maintained by the NSDL portal and pathways and at others that were planned and built by projects in other NSDL tracks, including Services and Targeted Research.
- Chapter Six presents the results of studies at the user level of our design, including the study based on search experts’ judgments and the usability study of preservice teachers.
- Chapter Seven presents results of the case studies. We review three cases and discuss the varied ways in which they implemented the full NSDL logic model.
• Chapter Eight summarizes our findings and presents recommendations for sustaining digital libraries and for future evaluation of digital library initiatives.
In this chapter, we provide an overview of the NSDL program, including statistics on the number of programs funded and the level of funding over time.

Prior Programs and Influences

NSF began the NSDL program in fiscal year (FY) 2000. NSDL was one in a sequence of digital research activities undertaken by NSF, including the Digital Libraries Research Initiative (later called the Digital Libraries Initiative [DLI]), which was launched by NSF’s Division of Information and Intelligent Systems (IIS) in 1994. The goal of DLI was to address challenging questions regarding the organization, discovery, and use of digital content (Griffin, 1998; Zia, 2008). DLI ran from 1994 through 1998; based on its impressive achievements—which included the original development of Google’s search technology—DLI-2 began in the spring of 1998 (Griffin, 2005). DLI-2 enjoyed support from a broader set of federal agencies.3

DLI and the work leading up to the launch of NSDL occurred when the Internet was young. Although millions of web pages existed at the time of the NSDL’s launch (26 million in 1998), searching the web was difficult. AltaVista, InfoSeek, Yahoo, and Lycos were popular search engines. Netscape and Internet Explorer 1.0 were among the popular web browsers. Google had just been created: The domain google.com was registered in 1997 and became prominent only in 2000. There was a clear need for research on how web pages on the Internet could be better made available for STEM education.

Interest in digital libraries for learning and teaching was also growing within the Education and Human Resources Directorate of NSF. In 1999, the Division of Undergraduate Education conducted a modest funding effort under DLI-2, which supported several prototype projects targeting undergraduate education. Based on the positive response to this effort from the community, NSF initiated the NSDL program in FY 2000.

From the outset, the NSDL program had a more collaborative orientation that the traditional NSF programs. Most NSF programs fund relatively small, separate projects that focus mainly on their own individual research-and-development activities. In contrast, although the NSDL program also funded its projects through independent grants, its primary goal was distinctly collective—as depicted in the second assumption of the logic model in Figure 1.1. NSDL’s central mission was not to “let 1000 flowers bloom” (McArther, 2008a) but rather to create,

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3 These include NSF, the Defense Advanced Research Projects Agency (DARPA), NASA, the National Institutes of Health and the National Library of Medicine, the National Endowment for the Humanities, and partners from the Institute of Museum and Library Services, Smithsonian and National Archives and Records Administration.
develop, and sustain a national digital library supporting STEM education at all levels, from prekindergarten to elementary grades, through undergraduate, graduate, and lifelong learning (Zia, 2008).

NSDL Program Overview

The NSDL program’s unique mission challenged NSF program directors to foster high levels of coordination and synergy across projects. Changes in the program’s structure over time can be seen as one of NSF’s responses to these challenges. Table 2.1 describes the initial program tracks in use in Stage 1 of NSDL (2000–2003). NSDL’s first stage of development funded projects in four tracks: CI, Collections, Services, and Targeted Research. (Note that we use the term stage to refer to periods of development of the NSDL program, whereas we use the term phase to refer to the evaluation of the NSDL program.)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description and Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Integration (CI)</td>
<td>A large, multi-institutional project whose main objectives were to coordinate a distributed group of resource collection and service providers and to ensure reliable access to the network of learning environments and resources</td>
</tr>
<tr>
<td>Collections</td>
<td>Projects that aggregated and managed a subset of the digital library's content; collections were often distinguished by their STEM subject area, but some addressed sectors, such as formal or informal education, or grade bands, such as middle school</td>
</tr>
<tr>
<td>Services</td>
<td>Projects that developed services or tools, such as search capabilities, website authoring, and blogging applications to support users, collection providers, and the CI project to enhance the usability, usefulness, and value of the digital library</td>
</tr>
<tr>
<td>Targeted Research</td>
<td>Projects that explored specific topics related to the creation, use, and educational impact of digital libraries and digital resources; the results of these projects were expected to be relevant to the activities supported by the other program tracks</td>
</tr>
</tbody>
</table>

From 2000 through 2002, several pilot CI projects were funded, but by FY 2002, a single CI team emerged, composed of partners from the University Center for Atmospheric Research (UCAR), Cornell University, and Columbia University. This team was supported by a five-year cooperative agreement with NSF. The CI awards were renewed in FY 2007, and the track was recompeted, with some organizational changes in FY 2008 (see Table A.1 for details).

The CI’s central purpose was to manage the NSDL program’s primary portal, the NSDL.org website. It is important to note that NSDL.org is not a single digital repository of resources but a highly distributed, or federated, library of resources and collections provided by other projects, including ones from the Collections track (later replaced by the Pathways track). From a practical perspective, this means that when users find a resource on NSDL.org, they typically are
viewing descriptive information about the resource together with a link to the collection or website where the resource resides. NSDL.org typically acquires its federated collections by harvesting metadata from its distributed partner sites.

The second stage of the NSDL began in 2004, with several changes and additions to the program’s tracks. The Collections track was dropped, while Pathways and Selection Services tracks were added. Table 2.2 describes the new program tracks added in 2004. These first years of the program can be thought of as NSDL 1.0. In this framing, the NSDL technical infrastructure was designed as a basic metadata repository, and collections were intended to aggregate a very large number of online resources (Howe et al., 2011).

Table 2.2. New NSDL Program Tracks, Stage 2 (2004–2008)

<table>
<thead>
<tr>
<th>Name</th>
<th>Description and Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways</td>
<td>Pathways replaced the Collections track. These projects were larger than typical Collections projects and assumed a stewardship role on behalf of NSDL for the educational content needed by a broad community of learners. The projects were also responsible for establishing methods and tools to identify, select, and annotate high-quality digital resources and to generate metadata for the resources that they managed.</td>
</tr>
<tr>
<td>Selection Services</td>
<td>These projects focused on increasing the amount of high-quality STEM educational content known to NSDL users. Usage-development workshops promoted the use of NSDL and its resources by various communities of learners. These refinements to the Services track increased the prescriptiveness of the program. In FY 2006, the Services track was further extended to include Integrated Services projects that would build their services using the digital content and technical infrastructure provided by the emerging NSDL data repository, rather than using a different platform or tool set.</td>
</tr>
</tbody>
</table>

Viewed broadly, these program-track changes were concerted attempts to increase coordination across NSDL projects. The need for improved coordination became apparent to NSDL program directors within a few years of the program’s inception. First, it was apparent that many projects were proposing similar sorts of services, often related to search and discovery; at the same time, several important service areas were not being addressed. The specific service subtracks were an attempt to call researchers’ attention to these areas. The Integrated Services subtrack also tried to encourage the reuse of services and inclusion of new services within the main NSDL portal. In addition, beginning in FY 2008, the program required projects to allocate 15 percent of their budgets to support the emerging shared technical network infrastructure.

Second, program directors quickly saw that the NSDL program did not need to stimulate the creation of new digital collections; these were occurring at an accelerated pace on the web. Thus, instead of seeding many collections, the program decided to support a few larger projects to organize existing materials by discipline or education-related topic area. These projects were expected to include resources from the earlier Collections projects and also high-quality content...
from other websites. The Pathways track also simplified the coordination of projects. The CI project could then collaborate with a small number of large pathways instead of hundreds of small collections providers. The Pathways track continued to fund new projects until the end of the NSDL program (see Table 2.3 for details).
<table>
<thead>
<tr>
<th>FYs Funded</th>
<th>Pathways I</th>
<th>Pathways II</th>
<th>Pathway Name</th>
<th>URL</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005–2008</td>
<td>2009–2011</td>
<td>2009–2011</td>
<td>NSDL Physics and Astronomy Pathway (Communities of Physics and Astronomy Digital Resources in Education [ComPADRE])</td>
<td>ComPADRE.org</td>
<td>Physics for high school to graduate level</td>
</tr>
<tr>
<td>2008–2011</td>
<td>—</td>
<td>—</td>
<td>Ensemble: Enriching Communities and Collections to Support Education in Computing</td>
<td>computingportal.org</td>
<td>Computing for K–12 to graduate level</td>
</tr>
<tr>
<td>FYs Funded</td>
<td>Pathways I</td>
<td>Pathways II</td>
<td>Pathway Name</td>
<td>URL</td>
<td>Description</td>
</tr>
<tr>
<td>------------</td>
<td>------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-----</td>
<td>-------------</td>
</tr>
<tr>
<td>2008–2011</td>
<td>—</td>
<td>Middle School Portal 2: Math and Science Pathways</td>
<td>msteacher2.org</td>
<td>Math and science for middle school</td>
<td></td>
</tr>
<tr>
<td>2008–2011</td>
<td>—</td>
<td>Teach with Data: Quantitative Social Science Digital Library Pathway</td>
<td>teachingwithdata.org</td>
<td>Quantitative literacy in the social sciences for high school to graduate level</td>
<td></td>
</tr>
<tr>
<td>2009–2012</td>
<td>—</td>
<td>Math Landing</td>
<td>mathlanding.org</td>
<td>Mathematics for elementary school</td>
<td></td>
</tr>
<tr>
<td>2009–2012</td>
<td>—</td>
<td>CLEAN: Climate Literacy &amp; Energy Awareness Network</td>
<td>cleanet.org</td>
<td>Climate literacy and energy awareness for middle school to undergraduate level</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: The first FY range shows initial Pathways funding; a second date range indicates Pathways II funding. In FY 2004 and FY 2005, Pathways projects could be up to 48 months in length; subsequently, they had a maximum length of 36 months. Pathways II were up to 24 months. Years funded may show greater length because many projects took no-cost extensions or received supplementary support.
As these changes were taking place within the Services and Pathways tracks, the CI project was overhauling the technical infrastructure of NSDL.org in ways that would support the needs of the new projects. The main change was to move from a metadata-centric approach, which supported the harvesting of records and basic search and discovery services, to a resource-centric approach, which promised to provide a much richer platform for the generation of new Web 2.0 and social networking–related services. The new platform, called the NSDL data repository, was built using Fedora (Flexible Extensible Digital Object Repository Architecture), and it quickly led to the development of several key NSDL services, including the *Expert Voices* blog, and the NSDL wiki (McArthur, 2008b). These services were not contributed by projects in the Integrated Services track but rather were authored by the CI itself.

The third stage of the NSDL ran from 2008 to 2011, when the program ended. This stage was ushered in by two new program refinements, as shown in Table 2.4. In general, the period from 2008 to 2011 reflected an evolution to NSDL 2.0, in which the technical infrastructure was aimed at mapping relationships between resources, collections were curated to include high-quality resources, and new tools were developed to help increase user creation of resources (Howe et al., 2011).

### Table 2.4. NSDL Program Refinements, Stage 3 (2008–2011)

<table>
<thead>
<tr>
<th>Program</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways II</td>
<td>The first cohorts of Pathways projects were nearing the end of their funding. Pathways II provided support to expand and maintain these original efforts.</td>
</tr>
<tr>
<td>Core Integration (CI)</td>
<td>The original CI project was split into two complementary pieces: an NSDL Resource Center project to coordinate the organizational and community building efforts of NSDL projects, and the NSDL Technical Network Services project that would manage the technical infrastructure issues; host the primary NSDL portal NSDL.org; and continue the development and maintenance of the NSDL data repository containing digital objects, associated metadata, and related digital information.</td>
</tr>
</tbody>
</table>

The program changes in Stage 2 attempted to improve coordination across many diverse NSDL projects. The changes that distinguished Stage 3 tried to address an equally important challenge to the NSDL program as it matured: how to ensure the sustainability of the NSDL community (developers and users of the NSDL) and its primary portal, NSDL.org, as the NSDL program wound down.

Technical Network Services (TNS) and Resource Center (RC) projects were funded for four years each, but the level of support was larger in the first two years and ramped down for years 3 and 4, reflecting NSF’s expectation that core NSDL activities would become self-sufficient over the grant period. Similarly, the Pathways II grants were much smaller than the original awards and required the projects to implement a sustainability plan. The final award to UCAR in 2011 (see Table A.1) was intended to support the reorganization and business planning that would be
necessary to launch NSDL as a nonprofit by 2014. This award sought to lay the groundwork for NSDL 3.0, intended as “a responsive tool for the next generation of digital learning” (Howe et al., 2011). NSDL 3.0 would include a flexible collaborative infrastructure; resources that would be easy to discover, use, and reuse; and a community that would promote spontaneous collaboration (Howe et al., 2011).

In sum, the NSDL program’s mission to develop a digital library from the products of individual projects posed coordination and sustainability challenges for NSDL program officers, and they responded by changing the program’s structure several times during the program’s history. The themes of coordination and sustainability are addressed in detail in Chapters Three through Seven.

NSDL Program Statistics

The previous sections reviewed the evolving structure of the NSDL program and touched on some of the reasons behind its structural changes. This section concludes the overview of the program and its history by summarizing the scope of the program in terms of the number of projects supported in the NSDL tracks and their levels of funding over time.

Figure 2.1 shows a chart of the number of awards in each track for each FY of the NSDL program. Roughly 330 awards were granted, but some projects involved several awards (for example, a collaborative project might include awards to several partners, or a single institution could get several awards for a single project). Thus, the number of distinct NSDL projects was probably no more than 250. Nevertheless, the figure shows several clear trends.

The largest number of projects was awarded during FYs 2001, 2002, and 2003, when the Collections track was still operating. The total number of awards per year dropped dramatically when Pathways replaced the Collections track in FY 2004. The Services track received a relatively constant flow of awards from the beginning to end of the NSDL program; although, as noted, the track evolved from a general focus on all services to more-targeted selection, user workshops, and integrated services. Targeted Research was a relatively stable track, but it was smaller than Services. An increase in the relative number of Targeted Research projects in later years of the program may have indicated growing interest in getting NSDL program resources into classrooms and other educational settings.
The pattern of awards looks different when viewed in terms of funding levels rather than project counts, as shown in Figure 2.2. In comparison to Collections, far fewer Pathway projects were funded, although the level of funding for Pathways projects by the end of the program (approximately $43.4M) approached that of Collections (approximately $51.4M overall). For CI, RC, and TNS projects, there were also never more than a few awards in this track in any given year, but, in some years, the CI consumed a high percentage of the NSDL program’s funding.
Figures 2.1 and 2.2 illustrate only part of the story, since they count projects only in their award years, and most projects were active for several years and spent only a fraction of the award total in the first year. In addition, project lengths differed across tracks; for example, Collections projects were usually two or three years in length, whereas Pathways projects often lasted four years. Figure 2.3 shows counts of projects that were active in each FY rather than just in the start year and shows award spending distributed throughout the active years of projects.
Overall, Figure 2.3 shows a much smoother flow of projects and resources than was seen in Figures 2.1 and 2.2. Although the number of new projects funded each year was relatively small and variable, Figure 2.3 shows that the number of projects active in any given year was much larger and relatively constant (excluding the beginning and ending years of the NSDL program). Clearly, for most of its existence, the NSDL program supported a substantial community of projects.

In terms of funding, Figure 2.4 shows that CI, RC, and TNS enjoyed relatively stable support across all years of the NSDL program, although their awards came in a few large allocations. In FY 2008, they were awarded more than 50 percent of the NSDL funding that year, but their annual average spending generally ranged from 20 percent to 40 percent of the total NSDL budget, except in FY 2012 and FY 2013, when all other tracks were almost depleted. Perhaps more interesting, even though the Collections track ended in FY 2003, this track spent more than any other in FY 2004 and FY 2005; many of the Collections awards were active until FY 2007 and even FY 2008. Changes in the NSDL program solicitation thus influenced the projects that were supported—but the changes took many years to substantially affect the program’s portfolio and transform the NSDL community.
Beyond the NSDL Program Numbers

The previous sections reviewed the structure and funding levels of the NSDL program over time. However, this analysis is only part of the story, and later chapters fill in many details. Although the projects fell into several program tracks, the tracks alone say very little about what specific projects aimed to do or actually accomplished. As noted, NSDL program officers refined track descriptions to influence the kinds of proposals that were submitted. But NSDL, like most other NSF programs, funded projects as grants rather than as contracts; thus, it was not possible for the program to tightly dictate the details of project directions.

Just as the details of what happened within tracks were not apparent from their program names, the track groupings also offer limited insights into cross-track similarities and differences. Projects in the same track often did different things and those in different tracks did similar things. For example, most Services projects developed and deployed services, but a cursory inspection shows that many NSDL services actually came from other tracks, such as Targeted Research and CI, RC, and TNS. The growth and use of NSDL services, within and outside the Services track, will be discussed in more depth in Chapter Five.
Chapter Three. Sustainability of Digital Collection Initiatives: A Literature Review

Geneva Henry, in her study *Core Infrastructure Considerations for Large Digital Libraries* (2012), argued that sustainability is an important factor in users’ trust of a digital system: The users need to be assured that the resources that they retrieve and reference will be available over time. Achieving sustainability is complex, and, after more than 20 years of digital collections development, there are few examples of successful strategies for sustainability. The ongoing viability and impact of the NSDL portal and its pathways are of vital concern. However, assessing the potential for sustainability of the NSDL portal and pathways first requires understanding the key elements of sustainability.

Although the literature on sustaining digital collections and communities is growing, few studies have attempted to develop a framework to delineate the elements of sustainability for digital initiatives that develop collections or curate collections assembled from other sources. In this chapter, we review and synthesize the relevant literature to develop a comprehensive model for assessing the sustainability of digital collection initiatives. In Chapter Four, we apply the model to analyze the NSDL portal and the NSDL pathways. We also intend for the model to be used by others in evaluating ongoing digital initiatives that are similar to NSDL, as well as future cyberlearning programs and projects funded by NSF and other agencies and foundations.

We draw on literature from several fields for this review. First, we examine research that emerged primarily from the library sciences. Libraries were pioneers in online collection development, beginning in the mid to late 1990s. As collections moved from innovative test beds to portals, digital library researchers have addressed how to manage and sustain digital collections and service portals over time (Bishoff and Allen, 2004; Greenstein and Thorin, 2002; Guthrie, Griffiths, and Maron, 2008; Henry, 2012; Maron and Loy, 2011b; Maron, Smith, and Loy, 2009; Smith, 2001).

Second, we draw on the rapidly expanding literature on digital communities. Although the NSDL program started as an online repository initiative, the NSDL portal and pathways are beginning to evolve from collections of resources into interactive communities. Community-based development and collaboration can occur through such activities as developing new resources, including services and tools, which are then shared with the NSDL community; revising existing resources and tools and integrating them back into the NSDL portal or pathways; or using a common technical platform to facilitate the sharing of interoperable resources among NSDL projects. However, a true community develops when members interact with the portal and with each other to collectively influence the direction and outcomes that the portal achieves—for example, when community participants interact online to review or rate resources. These activities are reflected in the assumptions and outputs of the NSDL logic model.
(see Figure 1.1): Sustainability is measured in terms of community development and engagement, not just in terms of the quality and usability of the contents and services provided. Indeed, experts note the importance of interaction with the community to be served (Borgman et al., 2008; De Souza and Preece, 2004; Margarian, Milligan, and Douglas, 2007; Sánchez-Alonso et al., 2011).

Third, because research on the sustainability of digital collections is still an emerging area of study, we have included in our review research from the business literature, particularly from the not-for-profit arena. As with other entities that must sustain themselves, digital initiatives must be able to attract customers in a competitive marketplace where they have many options, even in the nonprofit space.

Finally, we have included findings from the learning object repository and open educational resources (OER) literatures. OER is defined as the “open provision of educational resources, enabled by information and communication technologies, for consultation, use, and adaptation by a community of users for noncommercial purposes” (UNESCO, 2002). NSDL is moving toward providing OER to educational communities. The OER community advocates free access to digital resources for its users, which presents unique opportunities and unique challenges with such issues as cost recovery and sustainability.

Definition of Sustainability

For this review, we rely on a definition of sustainability from a well-known study on sustaining digital resources: “Sustainability is the ability to generate or gain access to the resources—financial or otherwise—needed to protect and increase the value of the content or service for those who use it” (Maron, Smith, and Loy, 2009, p. 9). This definition focuses on the need to sustain the resource at the point that start-up funding ends and to adapt the resource to meet the changing needs of users.

Model of Sustainability

Our sustainability model identifies key concepts of sustainability and the important attributes associated with each concept (see Figure 3.1).
The model has three primary concepts, which address both the enterprise that develops or curates a collection and the collection itself:

- **Audience**: A digital initiative is sustainable to the extent that there is an audience that values its collections and services, providing the purpose for the initiative to exist.
- **Organization**: Sustainability requires a strong organization that can deliver the collections and services to meet the needs of the audience over time.
- **Collections**: A healthy collection is a prerequisite for sustainability because the collection provides value and is thus used by the audience.

In terms of the NSDL logic model, these concepts point to *activities and processes* that are key to creating sustainable initiatives. In addition, the concepts are interrelated, and a successful sustainability strategy will address all three. We address each of these concepts and their key attributes in the following sections.\(^4\)

**Audience**

While all concepts in the model are important, the organization, collections, and services will be sustained only if there is an audience that values the products the organization provides. Sustainable organizations acknowledge the primacy of the audience in shaping their mission and guiding their actions. Key attributes of sustainability pertaining to audience include:

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\(^4\) In assessing the health of collections and the organizations that manage them, we will discuss search services that are specific to the collections, since these affect the usability, and hence the sustainability, of the collections. However, the broader range of digital library tools and services, as noted in Chapter One, are discussed in Chapter Five.
• the identification of a target audience or audiences to which services will be provided
• audience engagement, both to identify the needs of users and to enable users to contribute to the value of the services
• accountability to the audience, through which the initiative can demonstrate to the audience how well its needs are being met.

Audience Identification

Audience identification serves two related functions: It reflects internal decisions about who the audience is and how it will benefit from the organization’s products and services, and it addresses external communication with the target audience once the product and services are established. As discussed in our Phase 2 evaluation (Bikson et al., 2011), identifying the audience is a key element of a collection development plan, since digital resources must be responsive to the target audience. Acknowledging the audience (e.g., via the name of the initiative or prominent display on a website) enables potential users to know at a glance whether the portal will provide collections and services that meet their needs.

Mission, purpose, and value proposition are statements that also help an organization communicate to its target audience. Mission, according to Rothschild (2012), operationalizes an organization’s purpose, clarifying what it does—and what it does not do. A mission statement articulates how the organization creates value; purpose, on the other hand, speaks to what that value is. The value proposition focuses more directly on the targeted audience and includes three critical features: (1) a brief definition of what the initiative is or strives to accomplish; (2) a statement of the value the user gains from investing time, effort, or money in engaging with the initiative; and (3) an explanation of why the initiative is either unique or competitive in providing that value (Bart, 1997; Bishoff and Allen, 2004; Bradley, 2007; Maron, Smith, and Loy, 2009).

It is often difficult for organizations to articulate mission, purpose, and value propositions because audience identification can be complex. Digital collection initiatives generally speak of users, who use the resources in the collection to meet their information needs, and other stakeholders, such as funders, collection contributors, and parent organizations, who have varied interests in the collection and its success. However, a more nuanced view of the organization’s audience is critical when considering the sustainability of a digital collection initiative. Rothschild (2012) distinguishes between the client, who uses the service, and the customer, who often funds or pays for it, generally because the service enables the customer to meet its own mission and purpose. Rothschild argued that many small enterprises fail to distinguish between the two or focus their attention on the client when the customer is more critical to their success. For example, learning object repositories generally contain resources intended to be used by teachers (e.g., to prepare lessons, display in class, or assign as homework). In this case, the teachers are the clients. The customer, however, is critical to a repository’s economic viability.
and organizational sustainability but is often harder to define. Is the customer the schools or school districts that incorporate the e-learning repository as an essential feature of the curriculum? Or is it the granting agency or foundation that funds the organization to accomplish specific goals? The customer is often directly related to the client, perhaps even serving or representing the client, but, unlike the client, the customer is the entity whose support is most critical to the ongoing viability of the organization (Rothschild, 2012). As an example, Rothschild described the nonprofit organization Playworks, which aims to enable every child to play every day. To realize this purpose, Playworks organizes supervised, constructive recess activities for school children, which the organization markets to schools. School principals and other administrators are Playtime’s customers, while the children are the direct receivers of service, or clients. Playtime staff mold their services to clients to achieve the outcomes their customers need, which, in this case, involve “recaptured teaching time,” or the time teachers can spend teaching instead of solving problems that originated on the playground (Rothschild, 2012). Thus, the resources of Playworks are dedicated to recapturing teaching time, which is a service it can effectively market to the schools (customers) that fund the purpose of giving each child in the program (client) a daily period of play (Rothschild, 2012).

Distinctions among audience constituencies are becoming increasingly blurry with the evolution of user-centered tools and services to create digital resources, thus making it possible for consumers of digital content to also be content creators, and for customers to also be competitors and vendors (Webster, 1992). This point is acknowledged in the blueprint for NSDL 3.0, which stated that “the network of interactive partners is, in fact, the platform of NSDL” (Howe et al., 2011, p. 1), and “NSDL’s ability innovate and achieve educational impact is depend[e]nt upon a diverse ecosystem of large and small entities whose interleaved efforts produce, consume, process, aggregate, reorganize, embellish and tinker with digital content” (Howe et al., 2011, p. 4). Identifying and differentiating among the audiences who are most critical to success and designing products that offer demonstrable value to those audiences are not easy tasks to accomplish in the digital space but are essential to developing a sustainable collection.

**Audience Engagement**

Once the audience is identified, developers of a digital collection initiative must determine effective ways to engage users.

**First, the audience needs to be aware of the initiative.** The UNESCO OER community of practice identified awareness raising and promotion as the top priority for OER initiatives (D’Antoni, 2008). However, a number of researchers have argued that engagement entails more than informing the audience about the digital collection initiative. One of the biggest threats to effective audience engagement is a focus on supply rather than demand (Guthrie, Griffiths, and Maron, 2008). That is, initiatives often create collections and broadcast the value of the content or innovative technology, rather than beginning with a demand-driven desire to address a need.
that is not being met. As a result, many not-for-profit and academic projects get little user input in design and even less user feedback after implementation (Guthrie, Griffiths, and Maron, 2008). The sustainability of such projects can be threatened because they fundamentally misread the needs of their users (Harley, Henke, and Nasatir, 2006).

As more and more digital repositories transform themselves into digital communities, they are increasingly adopting interactive forms of audience engagement that go beyond one-way communication. Users can engage with web-based collections and services to communicate and exchange ideas—between users at the site and between users and the site. They can also contribute to the site as creators in their own right, by sharing comments and evaluations of resources in the collection, by submitting resources they have created or modified, or by offering strategies for effective resource use. The NSF Task Force on Cyberlearning argued that e-learning initiatives should reach out to their users to co-design and build tools at the start, not as an afterthought (Borgman et al., 2008). Marlino et al. (2008) described early and ongoing audience engagement as one of the founding principles for DLESE, one of the NSDL pathways. A portal that actively engages its audience is going to be more sustainable not only because the audience is participating in the ongoing creation of the portal but because the user feels more strongly connected to the portal and to its ongoing success.

An initiative that functions in this way has come to be known in the literature as a community of practice. Etienne and Beverly Wenger-Trayner defined a community of practice as “people who engage in a process of collective learning in a shared domain of human endeavor” (Wenger-Trayner and Wenger-Trayner, 2015). The concept of community is critical to both the identity and the ongoing viability of a learning object repository and is a key assumption in the NSDL logic model. The community becomes a reason to visit the portal, and the communication and learning that take place within the portal become a compelling service or value that the portal offers, in addition to its digital collections and tools.

These functions of a community of practice reflect the idea from sociotechnical systems theory that both technical and social factors are important in fostering technology adoption. De Souza and Preece (2004) identified sociability, the social interactions in the online community, as one of the key qualitative factors of success for an online community. Whereas reliable technology is necessary for digital collections, De Souza and Preece encouraged designers to first address the social needs of users and then adopt and adapt technology to meet those needs.

Well-planned digital collections focus on user needs. One way to do this is to adopt a user-centered approach, in which the developers try to understand the needs of the user, often based on a generalized needs assessment and usability studies. A more recent approach adopts a user point-of-view strategy. While the user-centered approach views services and collections as something to be marketed to “the other,” the user point-of-view approach attempts to organize and make available its services and collections as users would do for themselves. Repositories that attempt to reflect the user point of view must be highly attuned to changes in the community.
culture. Recent studies have explored how community cultures can be identified through automated and scalable methods, such as models that identify communities of practice from searching and other usage patterns (Sánchez-Alonso et al., 2011), or the capture and analysis of paradata (e.g., aggregated documentation of uses, such as downloads, favoriting, and sharing), which NSDL has recently championed (Howe et al., 2011).

The user point-of-view approach is complicated by the fact that the audience, or customer, is not the only critical stakeholder for the learning object repository. Funders often set conditions for funding or have expectations for the use of funds that developers must meet. Developers and content creators have needs for personal impact and recognition that must be addressed. Kiker and Gay (1998) noted that digital libraries are embedded in complex social systems, which include librarians, engineers, funders, and users. The idea that the “user knows best” also may not work well with emerging technologies, such as digital libraries, where users may not conceive of ways that technology can dramatically improve and transform their work processes.

Accountability to the Audience

A sustainable initiative must be accountable to all key audiences by identifying the audiences’ ongoing and changing needs and by demonstrating that those needs are being addressed. Accountability flows from the organization’s purpose and mission in the form of measurable and achievable goals that should be developed in collaboration with stakeholder groups. Establishing and publishing a mission statement and goals (particularly concrete, measurable goals), along with regular measurement and reporting of outcomes of the organization’s efforts to achieve those goals, can help ensure that the organization is accountable to its stakeholders, including funders, supporters (such as collection contributors), and the portal users.

Margaryan, Milligan, and Douglas (2007) note that it is important to identify at an early stage the criteria for success of a learning object repository. In measuring success, collection initiatives tend to measure outputs (e.g., the number of resources accumulated or downloaded) rather than outcomes, as outputs are easy to capture and demonstrate that activity is taking place (Rothschild, 2012). It is much more difficult to document outcomes, for example, that a learning object repository is transforming the practices of a community or increasing the learning and understanding of the student clients it ultimately serves. In addition to identifying meaningful criteria for success, clear communication about the criteria and the initiative’s performance in meeting them are essential aspects of accountability.

Another aspect of accountability is providing notice of proposed or impending changes to the initiative. These might include modifications to the look and feel of the portal, along with opportunities for users to provide feedback (George, 2005; Norberg et al., 2005; Chou, 2002). Similarly, organizations should inform users about future plans if an initiative terminates its services. As Borgman et al. (2008, p. 30) notes, “after too many experiences with educational
innovations emerging from NSF becoming unusable after a few years, when the original developers have lost funding or moved on to other projects, teachers have become reluctant to implement these innovations.”

**Adhering to and communicating policy is another way to demonstrate accountability and foster trust in digital collection initiatives.** Privacy protections safeguard the personal identity of a user and keep confidential the information practices of a user—both the nature of the information the user accesses and how he or she uses it (Agnew, 2008). A published collection development policy and safeguards for protecting copyright of resources (particularly for repositories that encourage user contributions) are other important policies that are relevant for accountability to the audience and are related to the usability of collections (Agnew, 2008; Borgman et al., 2008; De Souza and Preece, 2004; Johnson et al., 2012; NISO Framework Working Group, 2007). We address these attributes in more detail in the section on collections.

**Organization**

Sustainability requires a strong organization that can deliver the collections and services to meet the needs of the audience over time. This section describes some of the key requirements of a sustainable digital collections project, including

- a **technical infrastructure**, which comprises the hardware and software that provide a platform for digital collections and community services
- **leadership and staffing** to run the enterprise on a day-to-day basis and also to establish policies and execute strategic planning
- a **parent or other sponsoring organization(s)** to support the start-up enterprise that may also use the project to further its own mission
- **sustainability funding**, which includes strategies to grow revenues and reduce costs so that the project can gain financial stability.

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5 Agnew (2008) identified four principles for designing and maintaining a privacy policy:

- conformance to relevant law and organizational policy (the policy should reference, and reflect, national law and the privacy policy and practices of the host organization)
- public availability and dissemination (the privacy policy should be prominently referenced on the home page but also on any page where a person might submit personal information, such as the site registration page)
- support for fair information practice principles (which relate to notice about personal information collection; choice and consent concerning how personal information may be used; access to one’s personal information on a site; integrity and security to ensure that information is accurate and protected; and enforcement and redress, establishing steps users can take if they feel that information privacy has been violated)
- disclaimers for information the portal cannot control (particularly third-party sites to which the user may be directed through a link).
Technical Infrastructure

Nonprofit digital organizations often excel in the technical aspects of sustainability, particularly since they are often funded by NSF and similar organizations that value and expect a robust, standards-based technical infrastructure. Like NSDL, many are staffed with leaders who have extensive experience in computer science, information science, or library science.

Technical infrastructure, including both hardware and software, should exist to serve identified user needs. Different expectations for technical infrastructure among developers and users can pose a significant risk to the sustainability of grant-funded projects. Grants are usually awarded for innovative, groundbreaking technologies, whereas the needs of the community are often for a simple, robust infrastructure that is very easy to use. Technology-savvy researchers often want to build the most cutting-edge tools into their digital enterprises, but these tools can remain prototypes for a long while—and prototypes are usually complex and unstable. This is usually just the opposite of what most users want, which is a website that is “very, very, very easy to use; always, always, always up” (Wilkins-Diehr and Lawrence, 2010, p. 6).

Leadership and Staffing

Dedicated and entrepreneurial leadership is an essential element of sustainability (Guthrie, Griffiths, and Maron, 2008; Maron and Loy, 2011a; Maron, Smith, and Loy, 2009). In research-based, grant-funded initiatives, the principal investigator (PI) usually serves such a leadership role. PIs of projects of this nature typically expect to get many grants over the course of their professional careers. Thus, a significant risk is the failure of project leadership to change from primarily research and development in the initial stages of the project to more-operational needs as the project matures (Guthrie, Griffiths, and Maron, 2008). Borgman et al. (2008) concurred and noted that often the original researchers are not the appropriate people to lead these later stages of a digital enterprise. Guthrie, Griffiths, and Maron (2008) emphasized the importance of an operational leader who is fully dedicated to the project and whose job security is based on achieving both operational and financial goals. Entrepreneurial and operational leadership may be provided in tandem by co-leaders, as the digital initiative transitions from research-focused to a mature, enduring endeavor. The technical leader will ensure that the project’s technical infrastructure and website are stable and always available to users.

Another staffing area critical for organizational sustainability is financial management, responsible not only for managing the budget but for financial planning, including banking and investing resources for future growth, monitoring the success of different revenue streams, and controlling operational costs (Guthrie, Griffiths, and Maron, 2008). It is particularly important to identify strategic financial leadership to assist the project in detailed cost analysis to determine what is needed for both operations and development to sustain the project over the succeeding three to five years (Bishoff and Allen, 2004).
A final key leadership area is **marketing**, which entails a variety of activities, in addition to advertising the availability of the portal and its collections and services. Webster (1992) described the focus of marketing as relationship management. Madhusudhan (2008) echoed this view and delineated a number of marketing activities, including customer relationships, branding and corporate identity, marketing communications, price and pricing policy, marketing data collection, and marketing strategy and planning.

**Role of the Parent Institution**

**An important stakeholder, particularly for grant-funded initiatives, is the parent institution** (Bishoff and Allen, 2004; Bradley, 2007; D’Antoni, 2008; Downes, 2007; Friesen, 2009; Greenstein and Thorin, 2002; Guthrie, Griffiths, and Maron, 2008; Marlino et al., 2008; Maron, Smith, and Loy, 2009). Parent institutions, particularly universities, can offer significant resources in terms of indirect support (office space, computing equipment, utilities, etc.). They can also provide significant direct support, such as staffing. However, Maron, Smith, and Loy (2009) noted that few projects have attempted to quantify the monetary value of parent-institution contributions, and few have developed a plan to for what to do if this support ends. They recommend that project leaders document the value of the support provided by the parent institution, noting that tough-to-quantify, in-kind contributions can hide the full cost of running a project. It is important to know what will be lost in terms of indirect and direct support if the parent institution should decide not to continue its investment.

**Likewise, it is important to consider the value of the initiative to the parent institution.** Sustainability experts recommend documenting the project’s contribution to advancing the parent institution’s mission and meeting periodically with relevant administrators to discuss how the project is providing a return on investment and advancing the institution’s mission (Friesen, 2009; Greenstein and Thorin, 2002; Guthrie, Griffiths, and Maron, 2008; Maron, Smith, and Loy, 2009). Particularly in difficult economic times, projects and initiatives that lack strong external funding are candidates for elimination in parent institutions’ operational budgets. External activities that pull faculty and staff away from the core organizational mission can be difficult to justify if the case for their mission-critical nature has not already been established.
An important sustainability strategy for some digital initiatives is to look for natural alignments of the initiative across departments in the institution. In one example in the Ithaka S+R sustainability study, the Voltaire Foundation, a not-for-profit center at the University of Oxford, obtained ongoing support for its subscription-based electronic resource by contracting with Oxford University Press for marketing and subscription management and with the University of Oxford’s Bodleian Library for supporting the technical infrastructure and maintaining the digital collection. In this case, the project leader argued successfully that the technology developed for the project would be useful to the library for its own digital publishing initiatives, and the project fit well with the library’s information-sharing mission. This transfer to a new, permanent home proved critical to the project’s sustainability (Maron, Smith, and Loy, 2009). Greenstein and Thorin (2002) also noted that the information technology department is a natural collaborator for digital libraries. The education department is another potential partner; education researchers can study the use and impact of digital resources, and future educators can learn to use digital resources with students. For example, the NSF-funded Video Mosaic Collaborative, a digital collection portal hosted by the Rutgers University Libraries, is in active use for four graduate courses in the Rutgers Graduate School of Education and is heavily used for research by education faculty and graduate students (Hmelo-Silver et al., 2012; Maher, Landis, and Palius, 2010).

In some situations, a different sponsoring organization, rather than the parent institution, may offer opportunities for fruitful collaboration. In particular, in the case of learning object repositories, statewide initiatives can cluster resources around state standards and reflect statewide educational practices and goals, and they may garner financial or in-kind support from the state’s education department. Two notable NSDL examples are the iCPALMS portal, part of a larger CPALMS (Collaborate Plan Align Learn Motivate Share) initiative, which is a collaboration of the Florida Department of Education and Florida State University, and the Teacher’s Domain state portals, which align resources to state educational standards. See Chapter Seven for a detailed description of iCPALMS, which is one of the case studies in the Phase 3 evaluation.

Sustainability Funding

Without a well-defined audience, strong leadership, and measurable goals, it is difficult, if not impossible, to obtain funding for digital initiatives. Even if projects demonstrate these attributes of sustainability, funding to sustain digital collection initiatives remains a vexing concern for many reasons, not least of which is the expectation that resources with a primary purpose of contributing to the public good should be available at no cost to the user. In the not-for-profit digital collections arena, there is a legitimate concern about charging for a service that is clearly a social good. This concern centers around the digital divide and creating the “haves,” who can afford to pay for the service, and the “have-nots,” who cannot and who are often most in need of the service because they have less access to resources (Longhorn
and Blakemore, 2004). However, there are real costs behind the provision of information. Therefore, even an enterprise that wants to provide free access to information and services will need to plan financially if it expects to sustain itself.

**There are few successful models for how to finance nonprofit digital projects and generally no mandate by granting agencies that support such projects to engage in financial planning for sustainability.** When providing grant funding—which was the mechanism used to support development of NSDL—funding agencies typically impose limited control so as to foster experimentation and innovation. Consequently, financial planning in grant-funded projects tends to be weak, with business decisions often based on wishful thinking rather than on careful studies of the market and the competition (Bishoff and Allen, 2004). Bishoff and Allen (2004) identified many aspects of business planning strategy for digital information projects, including both revenue and expenses elements (see the box). Most nonprofit digital projects address very few of them.

Firms in the commercial digital environment grapple with these issues to innovate, maintain market share, and turn a profit—and very often do not succeed. Nonprofit businesses that serve the public good face even steeper challenges. Smith (2001) argued that users and service providers have opposing expectations: users expect unrestricted access to data, and service providers expect to be able to recover costs through controlled access. Similarly, Young, Jung, and Aranson (2010) noted that nonprofits seem to be under pressure to address social missions while breaking even financially, which is often referred to as having a double bottom line.

**Recently, some experts proposed innovative revenue-generating strategies.** Young, Jung, and Aranson (2010) advised nonprofit organizations to consider producing two kinds of services—ones that are profitable and help sustain the organization and ones that directly affect its mission and may need to be subsidized. Rothschild (2012) offered a similar approach in which organizations develop innovative resources that can be sold for profit, supporting the nonprofit arm of the enterprise. Minnesota Public Radio, for example, has many successful product spin-offs from its very popular *Prairie Home Companion* program, which are produced and marketed by other companies but return a share of the profits to Minnesota Public Radio (Rothschild, 2012).

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### The Many Elements of Business Planning

**Revenue streams:**
- consulting or training
- software services
- licensing resources
- grants and donations

**Expenses:**
- salaries, fringe benefits
- equipment, facilities
- legal and accounting services production costs
- promotion costs, including website development and management
- sales costs and exhibit costs
- training costs, content creation costs

**General constraints:**
- build in inflation and price increases
- base estimates on real market research
- support replacement and innovation through excess revenue over expenses
Revenue-generating strategies can also be tried in combination. As Maron, Smith, and Loy (2009) noted, case studies of the sustainability strategies of digital projects (including the NSDL pathway Middle School Portal) revealed that projects used several strategies to earn revenue, including subscriptions, content licensing, pay per use, custom services and consulting, and corporate sponsorships or advertising. Downes (2007) identified nine funding models or sources: endowment, membership, donations, conversion, contributor pays, sponsorship, institutional, government support, and partnerships and exchanges. These models are not mutually exclusive and may be implemented in tandem or at different points along the continuum of the repository’s development. However, making the right choices at the right times can be difficult, and finding the right business model and pricing strategy may take multiple attempts (Guthrie et al., 2008).

Finally, cost-reduction strategies are as important as raising revenue in enabling the sustainability of a not-for-profit organization, such as NSDL and its pathways. Lavoie (2011) argued that, in calculating the total cost of ownership involved in curating digital assets, data curators must determine the costs of maintaining the collection in a usable condition for an extended period. Stepanyan, Littlejohn, and Margaryan (2010) noted, citing several e-learning scholars, that cost-effectiveness can often be achieved through economies of scale—for example, by sharing and reusing educational resources. Consequently, because digital resources are easier to share and reuse than books or other print materials, the higher fixed costs associated with the design and development of these educational resources may be defrayed by offering them to a wider array of users. Finding such opportunities for cost-savings and factoring them into a business plan, however, can be complex (Bishoff and Allen, 2004).

**Collections**

We end our sustainability literature review with a discussion of the health of collections. A growing body of literature (Agnew, 2008; Ardito et al., 2006; Bishoff and Allen, 2004; Blandford and Buchanan, 2003; Clements and Pawlowski, 2012; Hall, Naughton, and Lin, 2009; Kimbrough, Padmanabhan, and Zheng, 2000; Lim and Ko, 2005; Nicholson, 2003; NISO Framework Working Group, 2007; Saracevic, 2005; Xie, 2006; Xie, 2008) acknowledges the importance of the following:

- **authoritativeness**, which reflects the accuracy, currency, objectivity, and reliability (e.g., availability) of resources in a collection, which in turn influence users’ trust in its value
- **usability**, which is the integration of the collections and the tools, such as the search and browse capabilities and user interactivity features, that contribute to a positive and empowering user experience
- **copyright and rights for use** and **privacy** policies of collections, which protect both creators and users to support the responsible and confidential use of resources.

Although we present authoritativeness and usability as separate, the discussion below indicates that they are interdependent in several ways. Both authoritativeness and usability are
critical to building a brand and maintaining a reputation that encourages busy educators and learners to return to collections again and again (Shapiro and Varian, 1999).

Authoritativeness

Sustainability is very much the marriage of a good product with the management, or stewardship, of that product. Stewardship involves selection and management of resources to sustain impact over time, and the nature of these processes influences the authoritativeness of the collection (see box). An authoritative collection earns the trust of users, who believe that there is a guiding strategy and useful purpose behind the selection and organization of its resources.

To achieve these goals, resources should be selected by experts in a subject field or by working with a specific target audience. Sponsoring organizations that represent this expertise writ large, along with advisory boards, can ensure that solid collection development practices are followed. A published peer-review strategy, particularly when those reviews can accompany the resources, also helps to establish authoritativeness for a digital collection (Downes, 2007). Collection development practices should include the evaluation of the resources in terms of the collection’s mission, scope, and audience. These criteria are important features of a collection development policy (Bergen County Cooperative Library System, n.d.; Biblarz et al., 2001; Johnson, 2009; Mannon, 2001–2002; NISO Framework Working Group, 2007; School Library Media Services, 2005). Resources that do not support the mission, do not conform to collection scope, or are not intended for the primary and secondary audiences can often be eliminated. However, elimination can be interpreted broadly to mean finding a new home for the resources, such as a portal with a mission, scope, and audience more appropriate to the resources in question. One value of a collaborative endeavor such as NSDL is the ability to shift collections and metadata across portals to align portal collections more closely to the audience and scope without ultimately affecting access to those collections for users.
A collection development policy should be part of a broader set of collection management practices that address the processes of selecting and weeding, or deaccessioning, resources. A collection development policy driven by the collection’s mission, goals, and scope will guide selection of resources with appropriate levels of depth and breadth (Biblarz et al., 2001). In the K–12 arena, collections are selected less for depth and breadth and more for appropriateness to educational level and to the curriculum, accuracy, currency, support for student learning, and readability and usability, as well as whether they are reflective of a diverse society and present a range of viewpoints for controversial issues (Baltimore County Public Schools, 2006; Chicago Public Schools, 2006).

In the digital environment, usability is a key factor for weeding resources. Is the resource unavailable or too difficult to download and use? Does it require outmoded tools, such as earlier editions of a file viewer, which are no longer generally available? Does it have broken links that remain unavailable for an extended time? Although all usability factors are important, **impact is the primary criterion for weeding resources**. Resources that can demonstrate high impact will help the portal be competitive for ongoing funding and stakeholder support, whereas resources with little impact do not help users and other stakeholders. Impact can be measured in various ways, including standard web metrics, such as downloads and views. This information can be shared with the user audience, as proposed by the NSDL 3.0 team, through the publishing of paradata (e.g., aggregated documentation of uses, such as downloads, favoriting, and sharing).

An organization needs to communicate changes in its digital collections to its audiences. Many repositories, including NSDL, provide access to resources or collections but may not own or manage them. Consequently, if the portal removes access to those resources, it may have a significant impact on further use of those resources and thus may hasten their elimination from the digital collection space altogether. Therefore, an important aspect of deaccessioning, or removing resources from a portal, is to alert stakeholders, such as a collection owner or contributor, that the metadata for their collection are being removed from the repository. This action may motivate the collection owner to update or terminate the collection. In either case, the collection owner may be a future contributor to the repository or other stakeholder, so good communication about the repository’s intentions can help to maintain this ongoing relationship. Collection development for distributed learning object repositories is as much about managing collaborations and people as it is about managing resources.

---

6 Using the Conspectus model, the International Federation of Library Associations and Institutions described a number of criteria to evaluate the strength and depth of collections. Conducting these assessments typically requires judgments made by professionals (librarians or subject-matter experts) or by end users (Biblarz et al., 2001) and was beyond the scope of our evaluation.
Usability

The International Organization for Standardization’s ISO 9241 standard defines *usability* as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use” (International Organization for Standardization, 1998). In the digital collections space, usability involves the technical aspects of using a resource, especially related to the *search strategies supported* by the collections. *Can I easily search for, and discover, resources? When I select a resource, can I readily obtain it by clicking on a link?* These aspects of usability are important for ensuring a uniformly good experience and building trust in the repository by its user base. However, an *essential attribute of usability is responsiveness to a user need.* In the e-learning space, usability requires resources to be appropriate for the intended learning task (Ardito et al., 2006).

Metadata are a primary tool for enabling users to determine whether a resource is responsive to their workflow needs, prior to actually using the resource. Metadata, which can be loosely defined as the description of a resource, are critical for the effective use of a digital collection or repository. Well-designed, high-quality metadata connect users to resources that meet a described need in an intuitive, largely transparent manner. Metadata accomplish this task by means of a structured approach for creating resource descriptions, which are then used to pull together helpful resources from collections in response to the query. An example of a rich NSDL metadata record is shown in Figure 3.2. It includes the title, URL, and brief description of the data (green arrow), which is typical of most resources; pedagogical information, such as education level and standards to which the resource is aligned (purple arrows); paradata on how the resource has been used and annotated by users (red arrow); copyright information (blue arrow); and related resources (orange arrow).

Metadata quality is determined, in part, by how well the data describe learning resources using standard terms. In addition, *innovation is essential to ensure that educational metadata continue to get ever richer, meeting the learning and teaching needs of students and educators in new ways.* As discussed below, NSDL has emerged as a leader in the past few years in developing new metadata extensions, including the integration of educational standards to align resources to learning, as well as the addition of paradata to demonstrate resource value through use, which is discussed in more detail in Chapter Four.

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7 For purposes of this report, *workflow* is defined as sequences of possible activities or operations required to use inputs and tools to achieve work-related tasks. Applied to teaching, workflow could address how a teacher plans and delivers lessons.

8 *Record* refers to a fixed set of data elements. *Metadata record* refers to a set of elements used to describe a resource.
There has been considerable effort in the digital library community in recent years to identify attributes of quality metadata and to associate measurement rubrics with those attributes. A summary of attributes presented in Table 3.1 shows that different groups have arrived at broadly similar criteria for judging the quality of metadata in digital libraries. However, assessing quality in a federated metadata repository, such as the NSDL portal, has an added layer of complexity. In their study of metadata in federated repositories, Shrees et al. (2005) noted that metadata may be of high quality within a local database but can lose its relevance when moved to another site.
Table 3.1. Some Attributes of Quality Metadata

<table>
<thead>
<tr>
<th>Source</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruce and Hillmann (2004)(^a)</td>
<td>• Completeness</td>
</tr>
<tr>
<td></td>
<td>• Accuracy</td>
</tr>
<tr>
<td></td>
<td>• Provenance</td>
</tr>
<tr>
<td></td>
<td>• Conformance to expectations</td>
</tr>
<tr>
<td></td>
<td>• Logical consistency and coherence</td>
</tr>
<tr>
<td></td>
<td>• Timeliness</td>
</tr>
<tr>
<td></td>
<td>• Accessibility</td>
</tr>
<tr>
<td>Zeng, Subrahmanyam, and Shreve (2004)</td>
<td>• Completeness</td>
</tr>
<tr>
<td></td>
<td>• Correctness</td>
</tr>
<tr>
<td></td>
<td>• Consistency</td>
</tr>
<tr>
<td></td>
<td>• Duplications (inter- and intracollection)</td>
</tr>
<tr>
<td>Margaritopoulos et al. (2008)</td>
<td>• Completeness</td>
</tr>
<tr>
<td></td>
<td>• Correctness</td>
</tr>
<tr>
<td></td>
<td>• Relevance</td>
</tr>
<tr>
<td>Stvilia et al. (2007)</td>
<td>• Intrinsic information quality</td>
</tr>
<tr>
<td></td>
<td>• Relational/contextual information quality</td>
</tr>
<tr>
<td></td>
<td>• Reputational information quality</td>
</tr>
</tbody>
</table>

\(^a\) Based on the Quality Assurance Framework for statistical data developed by Statistics Canada (Statistics Canada, 2002), as adapted for metadata by Johanis (2002).

A different approach to judging the quality of metadata is to assess metadata against the core tasks that users engage in when finding and using information. Common core tasks were identified by the International Federation of Library Associations and Institutions. The core tasks are collectively known as FISO (find resources, identify them, select appropriate ones, and obtain them). Zhang and Li (2008) used the FISO tasks to evaluate the metadata schema designed for the Moving Image Collections project, an early NSDL collection project. In the Phase 2 evaluation of NSDL and pathways, we assessed fitness to purpose for metadata records using the four core user FISO tasks (Bikson et al., 2011).

Copyright and Rights for Use

Another critical area for sustaining resources, which cuts across both authoritativeness and usability, is whether the appropriate rights have been secured to enable users to display, copy, download, or modify resources, as well as whether this information has been conveyed clearly. Many experts document the critical importance of copyright and use permissions for the sustainability of resources and resource collections (Agnew, 2008; Bishoff and Allen, 2004; Blue Ribbon Task Force on Sustainable Digital Preservation and Access, 2010; Borgman et al., 2008; D’Antoni, 2008; Downes, 2007; NISO Framework Working Group, 2007; Smith, 2001). Lack of clear copyright guidance is a significant threat to long-term sustainability for copyright-protected resources, as well as for their continued reuse in educational settings.
Effective rights management begins with a portal-wide *copyright statement or policy*, which may be incorporated within a site’s terms of use but will also provide general information about access and reuse rights at the resource level. Creators of resources own the rights to the further exploitation and use of the works of their creation, unless they transfer those rights to another person or organization. Copyright confers the right to control use of the resource, such as copying, modifying, or disseminating the work, for the term of copyright assigned to the resource.

**Permitted uses are those allowed to other users by a copyright holder, generally through a formal or informal license.** In the case of digital collections, such as NSDL and pathways, that do not own the rights to many of the resources that they make accessible via metadata, the copyright policy can explain that the rights to reuse of the resource belong to the rights holder, who should be contacted for information about permitted uses of the resource. Permitted uses for a resource should also be documented in resource metadata (Agnew, 2008). The ability to modify, localize, and repurpose educational resources is already an important part of educators’ work processes and is an important aspect of user engagement. In the context of OER, Downes (2007) argued that these processes are evolving into a co-producer model, in which the users of resources take an active hand in their production. Such a model, where the repository content is constantly refreshed through modification and repurposing, can best thrive when licenses provide permissions for reproduction, distribution, and modification that are unconditional and permanent (Agnew, 2008). The availability of copyright and permitted use information is also an important criterion in selecting those resources to be included via metadata surrogate in a collection, since copyright can greatly limit what users can do with resources. At a minimum, resources included in any information portal should be available for display and use within an education workflow (e.g., classroom use, homework).

**Metadata are themselves resources and subject to copyright permissions and restrictions.** Portals that encourage others to submit metadata should include a license checkbox, or opt in, providing a nonexclusive license for use of the metadata to the portal and its administrators. This is a very important consideration, because transfer of metadata from one repository to another requires permission from the metadata rights holder for each record unless a blanket license is in effect. For example, when DLESE was preparing for the transfer of DLESE to UCAR, the portal administrators discovered that only 45 percent of the metadata were owned by UCAR. An important lesson learned was that obtaining licenses or permissions related to transfer of intellectual property rights between institutions can be a protracted process (Marlino et al., 2008).

Ensuring an effective rights platform thus involves not only acknowledging and documenting the copyright of site content, digital resources, and metadata but also **documenting the licensing that enables permitted uses of the resource by the audience.** A sustainable repository will invest considerable time and effort in a rights management strategy that enables the fullest,
broadest, and most flexible use of its metadata and resources, even when those resources are not
actually managed by the repository Borgman et al. (2008, p. 41) recommended that NSF should
require clear intellectual property and sustainability plans as part of grant
proposals for educational materials it supports. The default expectation around
intellectual property is that the materials should be released on the Web as open
educational resources under a license provided by Creative Commons, where
appropriate (perhaps with attribution only), at some identified point within the
term of the grant.

Chapter Conclusion

Now that each of the constructs and attributes of the sustainability model have been
examined, it is clear that they are highly interrelated and iterative. A collection that is not useful
is not sustainable, and often the reason for lack of usefulness is a failure to identify the
appropriate target audience and its information needs. A sustainable organization is one that
provides unique and compelling value to its audience, which can be accomplished only if
the organization has identified its audience, knows what the audience values and needs, and
is capable of providing that value and can fully recover the cost of doing so. As Margaryan,
Milligan, and Douglas (2007, p. 6) noted, the sustainability of a learning object repository
ultimately boils down to two questions:

What is the problem to which the repository is a solution? And who identifies
this as a problem? If your repository is mismatched with your users’ needs,
misaligned with institutional strategies and policies, ignores cultural, pedagogic
and organizational context of your users, it is inevitable that its uptake will be
poor.

Adding to the difficulty in answering these questions, it is no longer sufficient to regard
enterprises like NSDL as digital repositories. The NSDL portal and pathways are evolving
from collections of resources to interactive communities, whereby users’ application and
recommendations of resources can demonstrate relevance and usability; users interact through
online community blogs; and they contribute to the collections by developing, sharing, and
vetting resources. A community differs from a repository in its inherent collaboration, to the
point of co-ownership in the development, use, and ultimate sustainability of the initiative.
Consequently, it is important to measure sustainability in terms of social activities and outputs
and not just the quality of the contents and services provided.
Chapter Four. Health and Sustainability of Collected Resources

In the previous chapter, we reviewed the sustainability literatures on digital collections, learning object repositories, and nonprofit businesses to develop a general model for assessing the health and sustainability of digital initiatives (see Figure 3.1). This chapter applies the model to the NSDL portal and the individual NSDL pathways (see Table 2.3 for a summary of the pathways) to document the extent to which the portal and pathways have addressed the key sustainability concepts. The assessment examines each concept in the model—audience, organization, and collections—and derives rubrics to measure their attributes with some degree of comparability across the NSDL portal and the pathways.

Our analyses of the sustainability of the NSDL portal and pathways are based on a review of information available on project websites and in other publicly available documents, rather than on the results of surveys or interviews with project managers and NSDL stakeholders, such as students and teachers. Because of these constraints, we were unable to assess all the attributes in our sustainability model to the same extent that they are discussed in the literature review. For example, we addressed the diversity of stakeholder groups as evidence of a sustainable organization, but we do not analyze the roles of each stakeholder group in our evaluation.

Unless noted, we made binary judgments about whether NSDL and the pathways had evidence of each attribute in the model. Our ratings are relatively liberal; for example, if the website had a statement about the audience, no matter how broad, we gave it credit for having an identified audience. As an example, we inferred that the audience was biological science teachers and students from the following statement on the BEN portal, “The BEN Collaborative overall mission is not only to provide seamless access to e-resources but to serve as a catalyst for strengthening teaching and learning in the biological sciences.” We also gave credit to the portal or pathways for particular attributes even when they were labeled differently or combined—for example, when the audience was described only in a series of goal statements, as was the case for MathDL (Mathematical Association of America’s Mathematical Sciences Digital Library [the Math Gateway]).

Table 4.1 presents the three main concepts of our sustainability model and the attributes within each concept. Prior to discussing the attributes associated with each concept, we present a table that summarizes questions we asked to assess the attributes. Collectively, they provide our assessment rubrics for the sustainability model as applied to the NSDL portal and pathways. Many of our analyses compare results for Phase 2, conducted in 2010 for 14 to 17 pathways, and
Phase 3, conducted in 2012 and 2013 for 18 pathways. At the conclusion of this chapter, we describe other ways to assess attributes of the model.

### Table 4.1. Sustainability Model Concepts and Attributes for Digital Library Initiatives

<table>
<thead>
<tr>
<th>Audience</th>
<th>Organization</th>
<th>Collections</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Identification</td>
<td>• Technical infrastructure</td>
<td>• Authoritativeness</td>
</tr>
<tr>
<td>– Mission, purpose, and value proposition</td>
<td>– Hardware</td>
<td>– Collection development policy</td>
</tr>
<tr>
<td>– Clients and customers</td>
<td>– Software</td>
<td>– Collection management practices</td>
</tr>
<tr>
<td>• Engagement</td>
<td>• Leadership and staffing</td>
<td>– Availability of resources</td>
</tr>
<tr>
<td>– Communities of practice</td>
<td>– Entrepreneurial leadership</td>
<td>• Usability</td>
</tr>
<tr>
<td>– User-centered and user point-of-view design</td>
<td>– Operational leadership</td>
<td>– Search strategies supported</td>
</tr>
<tr>
<td>– Resource annotations and paradata</td>
<td>– Technical leadership</td>
<td>– Metadata quality</td>
</tr>
<tr>
<td>• Accountability to audience</td>
<td>• Role of parent institution</td>
<td>• Copyright and rights for use</td>
</tr>
<tr>
<td>– Mission and goals (establish and report)</td>
<td>– Value of parent institution to initiative</td>
<td>– Copyright statements or policies</td>
</tr>
<tr>
<td>– Collection development, copyright, and privacy policies</td>
<td>– Value of initiative to parent institution</td>
<td>– Permitted uses</td>
</tr>
<tr>
<td></td>
<td>– Natural alignments of initiative across</td>
<td></td>
</tr>
<tr>
<td></td>
<td>departments of parent institution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Sustainability funding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Stakeholder diversity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Revenue generation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Cost reduction</td>
<td></td>
</tr>
</tbody>
</table>

Beyond providing an assessment of the sustainability strengths and weaknesses of the current NSDL program, our analyses offer practical guidance for NSDL projects transitioning from development to ongoing operations, as well as assistance for those projects seeking a graceful termination. The lessons should apply not only to NSDL projects but also to future cyberlearning programs, such as NSF’s Cyberlearning Transforming Education, and digital initiatives at NSF and other federal agencies.

### Audience

Our digital sustainability model includes three concepts (see Table 4.1), but, arguably, if one concept is most important, it is audience. The audience provides the purpose for the digital collection initiative. At this point in the maturation of the NSDL portal and pathways, if there is not a committed audience for the initiative, it is unlikely to be sustainable.

---

9 As mentioned in Chapter One, two projects considered as pathways at the time of our analysis were not funded under the Pathways track.
We developed rubrics to measure all three attributes related to audience: **audience identification, audience engagement, and accountability to the audience**. Whenever possible, measures of audience were similar to or extend those used in Phase 2 (Bikson et al., 2011). The use of common measures allowed us to compare the NSDL portal and the pathways over time and to infer areas of progress or decline.

**Audience Identification**

An identified audience gives scope to the collections and services of the portal, since these should be aligned to the needs of the audience. Prominently advertising the identified audience also tells potential users that the portal has collections and services suited to their particular needs. Questions for audience identification are shown in Table 4.2.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statement of audience</td>
<td>Does the site provide information on the specific educational audience served by the portal or pathway?</td>
</tr>
<tr>
<td>Statement of mission or purpose</td>
<td>Does the site provide information to prospective users about what the enterprise does and does not do?</td>
</tr>
<tr>
<td>Statement of value proposition</td>
<td>Does the site explain how it creates value for users and how it is unique in creating this value?</td>
</tr>
<tr>
<td>Identification of clients and customers</td>
<td>Does the site clearly differentiate end users (clients) from customers (those providing the ongoing support to sustain the initiative) and other stakeholders, such as supporters and funders of the enterprise?</td>
</tr>
</tbody>
</table>

**We found improvement in audience identification from Phase 2 to Phase 3, although most sites identified their audiences and missions in both phases.** For Phase 2, 11 of 14 pathways (79 percent) included audience statements, while all 14 included purpose or mission statements. For Phase 3, all 18 pathways had both audience statements and purpose or mission statements.

Audience identification was very broad and general for the NSDL portal and for most of the pathways. For example, the NSDL portal had an all-encompassing audience description, defined on the portal’s “About NSDL” page:

*The National Science Digital Library provides high quality online educational resources for teaching and learning, with current emphasis on the sciences, technology, engineering, and mathematics (STEM) disciplines—both formal and informal, institutional and individual, in local, state, national, and international educational settings. (NSDL, n.d.-a)*

Whereas all the pathways identified a target audience, five of the portals identified their audience only by subject and stated that they address the educational needs of the range of students from kindergarten to graduate school and beyond. For example, the engineering
pathway was described as a comprehensive education pathway for “K to Gray.” We verified that each portal had resources and tools specific to the identified audience and found that pathways were generally supportive of the audience they defined.

Mission statements were usually factual statements of purpose rather than audience-centered or aspirational. An example of a factual statement of purpose is, “The ComPADRE Digital Library is a network of free online resource collections supporting faculty, students, and teachers in Physics and Astronomy Education.” An example of an aspirational statement is, “BEN resources can help you engage student interest, shorten lesson preparation time, provide concept updates, and develop curricula that are in line with national standards for content, use of animals and humans, and student safety.”

The NSDL portal and all the pathways lack discoverable value propositions. Such statements bring together the organization’s audience (who), the organization’s mission (what) and the unique or compelling value (why) that explains why the audience would select this organization among competitors.

Our analysis of the NSDL portal suggests that current thinking about customers is still at a preliminary stage. As described in Chapter Three, Rothschild (2012) argued for differentiating among the several stakeholder groups of a digital collection initiative, and specifically for distinguishing clients from customers. Information about customers was evident only in planning documents formerly available on the now-archived NSDL Network website.

The 2011 sustainability proposal to the NSDL program (Howe et al., 2011) was more specific about its stakeholders. The proposal identified a number of potential customers, including government agencies developing registries, collection developers needing a technical platform and organizational structure to enable them to cost-effectively market their collections, and school systems seeking collections to offer to their teachers or to populate their learning content management systems. However, while the different stakeholders were identified, they were not differentiated as customers (those providing primary support for sustaining the organization) or clients (users), nor did the proposal address how they would be engaged or identify the unique value that the NSDL portal could provide to each. There was also no evidence that these stakeholders were involved in identifying or prioritizing the innovations proposed in the NSDL 3.0 proposal to NSF.

Audience Engagement

Audience engagement demonstrates that the portal provides collections and services to support the information needs of an audience and that the audience supports the portal through active use of collections and tools. Moreover, as described in Chapter Three, digital collection initiatives engage their audiences by adopting user-centered or user point-of-view perspectives and by establishing communities of practice in which members develop shared capital. Measures of sustainability and related questions for audience engagement are shown in Table 4.3.
Table 4.3. Questions for Audience Engagement

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audience-specific portals</td>
<td>Does the site provide portals—which are customized views of the site, intended to make the site more useful to particular audiences by including collections and other services, guidance on resource use, and search functions, such as filtering terms—specific to that audience?</td>
</tr>
<tr>
<td>Resource organization</td>
<td>Does the site provide private workspaces, where users can organize and save resources in personal folders and share resources with others?</td>
</tr>
<tr>
<td>Audience participation</td>
<td>Does the site solicit or encourage participation through such activities as contributing or recommending resources, peer-reviewing resources, sharing resources with others, or providing comments or ratings for individual resources?</td>
</tr>
<tr>
<td>Communities</td>
<td>Does the site provide the opportunity for audience members to participate in specific communities of practice, such as online discussions forums and the capability to organize resources into collections specifically for the community?</td>
</tr>
<tr>
<td>Annotation metadata and paradata</td>
<td>Do metadata for resources describe the use that educators have already made of the resource (e.g., number favorited, shared), as well as providing comments and suggestions for use or resource ratings?</td>
</tr>
</tbody>
</table>

Table 4.4 shows measures of the first four engagement indicators for the pathways. For the most part, we would not expect the NSDL portal to provide some of the engagement opportunities described above, given its role as an integrator and federator of collections provided by other projects, rather than a direct provider of collections. Nonetheless, the NSDL portal did offer opportunities to share, contribute, and recommend resources. At the time of our evaluation, the NSDL network site (which was archived in June 2013) also supported other community activities for network participants (primarily for pathways managers, although they were open to anyone), such as training opportunities and the opportunity to learn about and comment on new initiatives, such as paradata.

Table 4.4. Audience Engagement in Pathways

<table>
<thead>
<tr>
<th>Pathways with Audience Portals</th>
<th>Pathways with Resource Organization</th>
<th>Pathways with Audience Participation</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 (33%)</td>
<td>11 (61%)</td>
<td>11 (61%) Share Resources 15 (83%) Contribute/Recommend Resources 7 (39%) Review Resources 12 (67%) Comment on Resources 7 (39%) Rate Resources 9 (50%) Pathways with Communities</td>
</tr>
</tbody>
</table>

Only six pathways offer portals geared to specific audiences, such as educators or students, with resources and collections tailored to the needs of those audiences. Of those six, only Teachers’ Domain and ComPADRE have portals that represent an audience-specific view of their site—i.e., that reorganize or classify site resources based on audience. Teachers’ Domain offers portals associated with state-specific educational standards and resource metadata referencing the state standards that the resources address. ComPADRE offers specialized
collections for students, teachers, faculty in general, and faculty teaching particular courses. Portals offered by other pathways were either external to the site, such as Ensemble, which takes the user to third-party sites for students and faculty, or sites designed and implemented separately from the primary portal, such as the Middle School Portal, SMART (Science and Mathematics Accessible Resource Tool), which provides resources created by students for other students that are separate from the Middle School Portal’s collection.

More than half of the pathways allow users to organize materials in their own workspaces, and many offer one or more opportunities for audience participation. More than half of the pathways permit users to share resources, and 83 percent provide opportunities to contribute or recommend resources. One-third of the pathways provide the opportunity to comment on individual resources, and 39 percent enable users to rate or review resources.

Finally, half of the pathways support communities whereby audience members can contribute to discussions and share resources within a specific interest area. An example is the Research to Practice group in the Middle School Portal, where educators explore applying new research discoveries to their teaching practice.

There was some improvement from Phase 2 to Phase 3. Our Phase 2 evaluation assessed a subset of the engagement measures described above. Table 4.5 shows comparisons between Phase 2 and Phase 3 results. In Phase 3, pathways show improvement in capabilities supporting resource organization, but a slightly smaller percentage of pathways enabled users to comment on individual resources.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pathways in Which Users Can Save/Organize Resources</th>
<th>Pathways in Which Users Can Share Resources</th>
<th>Pathways in Which Users Can Comment on Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathways Phase 2</td>
<td>7 (50%)</td>
<td>7 (50%)</td>
<td>11 (79%)</td>
</tr>
<tr>
<td>Pathways Phase 3</td>
<td>11 (61%)</td>
<td>11 (61%)</td>
<td>12 (67%)</td>
</tr>
</tbody>
</table>

As was the case in the Phase 2 evaluation, many pathways continued to provide valuable services to engage users that we did not measure in detail. These services included professional development resources, online courses, and awards or scholarships, such as the BEN scholars and the Mathematical Association of America writing awards. Middle School Portal and SMILE have continued to recognize active participation with badges and leader boards.

Although we did not find improvement in commenting and ratings functions among the pathways, pathways have increased opportunities to compile and share paradata with the NSDL portal for documenting and federating user contributions in the aggregate, as well as annotation metadata, which consist of the actual comments and ratings for individual resources. NSDL has supported annotation metadata through a schema (called anno) in its NCS (NSDL Collection System). Paradata are a new digital library service that complements metadata and is being rolled
out in the NSDL portal with selected pathways as part of the development of NSDL 3.0 (Howe et al., 2011). Paradata consist of “dynamic information about digital learning objects that is generated as they are used, reused, adapted, contextualized, favorited, tweeted, retweeted, shared, and all the other social media style ways in which educational users interact with resources” (NSDL Network, 2012b). For example, paradata might document the number of times a resource has been rated, recommended to others, tagged, viewed, favorited, or downloaded.

We reviewed a sample of ten metadata records from each pathway that had been incorporated into NSDL.org and counted the number that had paradata. As part of this review, we also recorded the availability of user comments and ratings on these resources from the pathways that provided them as a measure of whether users were taking advantage of the opportunity to contribute to the site. Results are shown in Table 4.6.

<table>
<thead>
<tr>
<th>Source and Number of Resources</th>
<th>Paradata</th>
<th>User Comments</th>
<th>User Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL.org (n = 180)</td>
<td>47 (26%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pathways (n = 120)</td>
<td></td>
<td>22 (18%)</td>
<td></td>
</tr>
<tr>
<td>Pathways (n = 70)</td>
<td></td>
<td></td>
<td>10 (14%)</td>
</tr>
</tbody>
</table>

*a We sampled ten records from each source for our analysis. The number of records sample—ten—was arbitrary. Ten records from each of 18 pathways were sampled for paradata; ten records for each of the 12 pathways that recorded comments were sampled; and ten records for each of the seven pathways that recorded user ratings were sampled. It should be noted that we were not certain which pathways were supplying paradata, so we checked all metadata records in our sample to see how much traction paradata had in the NSDL portal at the time of our analysis. In the pathways portals, by contrast, we looked for comments and ratings only in those portals that provide those opportunities to users, for a more accurate measure of user interaction with resources.

As Table 4.6 indicates, a relatively small number of the resources sampled included comments or user ratings. However, in some cases, a resource had annotation metadata providing comments or ratings in the NSDL portal that did not appear in the pathways site where the resource originated. This shows that NSDL.org is effectively creating composite records from other portals that show use of a resource from multiple entry points.

**Accountability to the Audience**

Central attributes of accountability to the audience include aligning digital products and services with identified audience needs through measurable goals and publishing the portal’s success in achieving those goals. To assess accountability, we examined documentation on the websites to look for evidence of the indicators shown in Table 4.7.
Table 4.7. Questions for Accountability to the Audience

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurable goals</td>
<td>Are goals stated explicitly on a pathway or NSDL portal website?</td>
</tr>
<tr>
<td>Internal assessment</td>
<td>Has an internal assessment been conducted, as indicated by pop-up surveys when the portal or pathway site was visited, or information about staff dedicated to evaluation of the portal?</td>
</tr>
<tr>
<td>External assessment</td>
<td>Has an external assessment been conducted by an independent group for the NSDL portal or a pathway and acknowledged on its website?</td>
</tr>
<tr>
<td>Professional oversight</td>
<td>Does the site describe an advisory board or board of directors (these external governing bodies frequently perform the role of assessing the success of the portal on an annual or semiannual basis)?</td>
</tr>
<tr>
<td>User privacy</td>
<td>Does the site have a clearly articulated privacy policy, particularly if the site allows or requires registration?</td>
</tr>
</tbody>
</table>

**NSDL addressed the first four accountability indicators**, providing some evidence of goals and the use of feedback from internal and external sources to assess progress in achieving goals. However, while this information is documented in the transition proposal to NSDL 3.0 (Howe et al., 2011), it is not evident to portal users, and it was difficult or impossible to locate in the no-longer-accessible NSDL network community site.

**Among the pathways, we found evidence for only one (MathDL), that specified its goals.** However, even in this case, we could not determine whether the goals are measured, because assessment indicators were not provided. Few pathways showed evidence of either internal assessment or external assessment, although most pathways had advisory boards, and it is possible that they played assessment roles. In brief, our review identified the numbers and percentages of pathways that met these criteria:

- Pathways with measurable goals: 1 (5%)
- Pathways with internal assessment: 7 (39%)
- Pathways with external assessment: 5 (28%)
- Pathways with professional oversight: 16 (89%).

**Most pathways have user registration options, although fewer have privacy policies.** The Phase 2 assessment looked at whether pathways providing the opportunity to register also published a privacy policy (Bikson et al., 2011). If sites collect information about users and can track or monitor their resource use, it is critical to publish privacy practices that explain how that information is being used and how the privacy of information use is maintained. As Table 4.8 indicates, in the Phase 2 assessment, all 14 pathways provided the option to register to allow users to interact with the portal or take advantage of special services, but only 64 percent had published privacy policies. In the Phase 3 evaluation, the situation improved slightly: 17 of 18 pathways had the option to register while 14, or 78 percent, had published privacy policies.
Table 4.8. Registration and Privacy Policy

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pathways with Registration</th>
<th>Pathways with Privacy Policy Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 2</td>
<td>14 (100%)</td>
<td>9 (64%)</td>
</tr>
<tr>
<td>Phase 3</td>
<td>17 (94%)</td>
<td>14 (78%)</td>
</tr>
</tbody>
</table>

Conclusions About Audience

The NSDL portal and all the pathways have made progress in identifying target audiences, although there are opportunities for improvement:

- While NSDL.org and the pathways identify their audiences, in many cases, the audience is very broad, such as K–12 or K–gray, and we found only minimal or moderate efforts to customize the resources and experience to different workflows and expectations of each audience.

- Each site lacks a compelling rationale for users to select it over competing alternatives (the value proposition), which poses a risk for ongoing sustainability.

NSDL.org could better support educator workflows by, for example, providing grade- or education-level (e.g., elementary, middle school) portals within subject-focused pathways. Whatever approach the NSDL takes toward integration of resources in the future, the literature is clear that a tighter and stronger audience focus is conducive to sustainability.

Although somewhat uneven across sites, audience engagement is generally a strength of the NSDL portal in terms of providing capabilities to organize, comment on, contribute to, and share resources. Overall, the NSDL portal and pathways support a broad range of opportunities for audience engagement, from individual to collective services that can foster communities of practice. Progress was mixed, however, in developing audience-engagement activities in the NSDL portal and pathways. No form of engagement was common across all pathways, and some types of engagement, such as audience portals and rating and reviewing resources, were provided by only one-third of the sites. It was surprising that more pathways did not offer audience-specific portals, such as grade level or audience role (e.g., educator, student).

NSDL.org and most of the pathways are also at only the very early stages of offering higher levels of collaborative activity that characterize a true community of practice, such as the selection and management of resources by the community. NSDL and the pathways could strengthen collaboration among users, which is an underlying assumption of the logic model (see Figure 1.1), by supporting a higher level of interactivity consistent with virtual communities of practice.

Innovations of the NSDL include the collection and harvesting of annotation metadata from pathways in a standardized manner and the development of paradata that aggregate measures of use for each resource at a pathway site. These services place an equal emphasis on discovery and use that are more reflective of a user-oriented and user point-of-view perspective that has recently been championed in the literature. Nevertheless, research on
paradata and shared workspaces is still in its early stages. It would be useful to apply other methods, such as user surveys and ethnographic methods, to examine how and why users share resources in private and communal workspaces within digital initiatives. This research could demonstrate how paradata influence or reflect user workflows and could validate the usefulness of different types of paradata to support teachers’ decisions about which resources to select and use.

With the exception of providing advisory boards, NSDL and the pathways provided little evidence of accountability to the audience. A question for future research is the extent to which demonstrating accountability to the audience contributes to the sustainability of digital initiatives. This question is particularly important in light of the transition or discontinuation of NSDL and many of the pathways. As described in Chapter Three, providing notice of impending changes is an aspect of accountability. Thus, when faced with possible discontinuation, part of accountability would include communicating intentions for sustainment. When portals are to be discontinued, they should make every effort to transfer their collections and services to a continuing portal and to communicate the transition so that users have continuous access to valued resources.

Organization

As digital initiatives mature, organizational supports need not only to grow but to change from a research start-up team to a business enterprise. As we describe in more detail below, the sources available for our analysis—project websites and available project documents—provide only a limited picture of the attributes of organizational sustainability. Our analysis focuses on three categories: leadership and strategic staffing, parent institutions, and sustainability funding (the last two categories are discussed together).

A comprehensive evaluation of technical infrastructure is provided in Appendix B of this report. In brief, we note that NSDL generally receives high marks for a flexible, extensible, largely Java-based platform that is robust and well suited to a metadata-based collection portal. The core infrastructure components of the portal are industry standard, based on common metadata schemata and protocols for metadata harvesting and search. Given use of technologies with a large user base and significant web services market share, there is little worry that the applications will become obsolete quickly or will be reliant on technologies with diminishing support. Primary concerns with NSDL’s technical infrastructure are the lack of integrated security beyond basic user identification and password protection and lack of application support for users in terms of training and personalized services.
Leadership and Strategic Staffing

Guthrie, Griffiths, and Maron (2008) noted that a significant risk to the sustainability of digital initiatives is the ability of project leadership to change course from primarily research and development in the initial stages of the project to more-operational needs as the project matures. We used several measures to assess evidence of sustainable organizations on projects’ websites. In particular, we looked for the staffing roles (described in Chapter Three), as shown in Table 4.9.

Table 4.9. Questions for Leadership and Strategic Staffing

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entrepreneurial leader</td>
<td>Does the initiative have a leader who provides the vision and spirit needed by the enterprise?</td>
</tr>
<tr>
<td>Operations leader</td>
<td>Does the initiative have a leader who guides day-to-day activities and ensures that measurable goals are met?</td>
</tr>
<tr>
<td>Technical leader</td>
<td>Does the initiative have a leader who ensures the development and maintenance of a robust and user-friendly service platform?</td>
</tr>
<tr>
<td>Financial manager</td>
<td>Does the initiative have a manager who provides financial planning, seeks sources of income, sets prices for services provided for a fee, and implements cost-saving measures?</td>
</tr>
<tr>
<td>Marketing/outreach manager</td>
<td>Does the initiative have a manager who ensures that the needs of the audience are continuously assessed and that potential customers are aware of the enterprise and its services?</td>
</tr>
</tbody>
</table>

The NSDL portal and most of the pathways had entrepreneurial leaders who provided the project vision and led marketing efforts, although evidence for the staffing of other organizational roles was less consistent (Table 4.10). Entrepreneurial leaders focused largely on the primary customer (NSF) and on key education and research stakeholder groups through conference presentations and scholarly papers. There was less evidence of staffing for other organizational roles, with technical leadership available only for NSDL and just over half of the pathways. The pathways showed little evidence of having operations management or staff who were responsible for marketing and outreach beyond those activities conducted by the PI or entrepreneurial leader.

Table 4.10. Key Staffing Roles

<table>
<thead>
<tr>
<th></th>
<th>Number in Leader Role</th>
<th>Number in Operations Role</th>
<th>Number in Technical Role</th>
<th>Number in Financial Role</th>
<th>Number in Marketing/Outreach Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Pathways</td>
<td>13 (72%)</td>
<td>4 (22%)</td>
<td>10 (56%)</td>
<td>1 (6%)</td>
<td>5 (28%)</td>
</tr>
</tbody>
</table>
Perhaps the biggest gap in staffing was the lack of a financial manager to foster sustainability through revenue generation and cost control. The apparent lack of emphasis on financial planning in most of the projects was also seen in their incomplete strategic planning efforts, described in more detail below. This gap is not surprising given that, initially, NSF did not fund the pathways to become start-up enterprises, although later funding was intended to encourage sustainability planning. Nonetheless, if the project leaders aim to create sustainable enterprises, staff are needed to fulfill this role.

**Role of the Parent Institution and Sustainability Funding**

Without opportunities to collect primary data (e.g., through interviews of key stakeholders), there was limited information we could obtain about other aspects of organization, such as the role of the parent organization and opportunities for alignment of the initiative across departments in the parent institution. Likewise, without access to the financial strategies of each organization, there was little direct information available about sustainability funding. Instead, we examined NSDL.org and the pathways for evidence of stakeholder diversity as an indicator of financial sustainability. A diverse array of stakeholders can provide critical in-kind and financial resources, as well as other types of support, such as assistance with planning and marketing, endorsement for the mission and services of the organization (e.g., backing by a respected professional organization), and other important tasks. The parent organization, in particular, provides a physical and financial base for the initiative and can be a source of continued funding and infrastructure after start-up grants have ended. Parent institutions are often the home organization for the principal investigator but may be professional societies or other organizations that are supplying critical support, such as technical infrastructure or staffing, to the initiative. We also looked for evidence of the role of the pathways in supporting the parent institution’s goals, because a parent organization may be more likely to sustain an initiative that advances the parent institution’s mission. Finally, we looked for sustainability funding by searching for published strategic plans or evidence of strategic planning activity. Strategic plans identify the development trajectory of the organization and help the organization determine the level of staffing and funding it will need for sustainability. Published plans also provide an opportunity for users to comment on, and perhaps, influence, the strategic direction of the organization. Table 4.11 lists the key questions about stakeholder and funding.

**Table 4.11. Questions About Parent Institutions and Stakeholders and Funding**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent organization/diverse stakeholders</td>
<td>Does the initiative have a diverse range of stakeholders, including a parent organization that is prominently identified? Does the pathway support the parent organization’s goals?</td>
</tr>
<tr>
<td>Sustainability funding/strategic planning</td>
<td>Does the initiative have ongoing funding or a strategic plan or other evidence of strategic planning?</td>
</tr>
</tbody>
</table>
NSDL.org and all pathways demonstrated a range of diversity in parent organizations and other stakeholders. Stakeholders included academic institutions, professional societies, government agencies, and museums. Several pathways had commitments of support from parent institutions or sponsoring societies. The diversified stakeholder base is a significant strength for NSDL and the pathways.

Some pathways strongly manifest the educational outreach missions of their parent institutions. One example is SMILE, which is a portal for informal education, reflecting the key mission of its lead organization, the University of California at Berkeley’s Lawrence Hall of Science and its partner museums. Teachers’ Domain is another pathway that is a strong avenue for the educational mission of its parent institution, the public radio station WGBH, and, by extension, public broadcasting. A more comprehensive analysis is encouraged and would document not only the ways in which parent organizations can support digital initiatives but the benefits of the initiative in advancing the parent organization’s mission.

The limited data we found show little or no evidence of strategic planning and sustainability funding for the NSDL portal and pathways. In the proposal for NSDL 3.0, Howe et al. (2011, p. 13) noted, “UCAR has established a small group of advisors from corporate, government, and philanthropic institutions to accelerate business planning and the pursuit of viable sustainability models.” This appears to be a start that may eventually guide strategic planning, but, by itself, it is not a strategic plan. For some pathways, the strategic plan may have been proprietary: as noted earlier, several of them are associated with strong parent organizations that presumably would determine the future of the project once NSF funding ended. Thus, it is possible that some of the pathways and the NSDL portal team have developed plans that we have not found.

Conclusions About Organization

When NSDL projects were initially funded, their original proposals did not include support for a financial or marketing manager, nor was this expected by NSF. But in later years of the program, NSDL program officers made it clear to NSDL portal and pathway leaders that funding would soon be coming to an end. As a condition for continuation funding for the pathways from 2006 onward, NSF asked the projects to develop business plans that would ensure their future viability. The last grant to UCAR and Cornell University to support the NSDL portal required projects to have a viable business plan with the participating pathways within the first year.

Our data show that the NSDL portal and pathways score well in terms of strong visionary leadership. However, evidence of staffing for other organizational roles, including technical leadership, operations, finance, and marketing functions, was less consistent or absent, and there was no systematic evidence of sustainability funding or strategic planning. This suggests that leadership is not changing in a way to support the transition from research project to a nonprofit business. If NSDL and the pathways indeed have people operating
in these positions or have developed longer-term staffing and funding plans, communicating this information may enhance stakeholder confidence in the sustainability of the initiative. If not, and if the projects seek to become sustainable (either as independent start-ups or in coordination with their host institutions), our literature review provides guidance about how to promote and enhance their strengths.

**NSDL and the pathways have diverse stakeholders, and this broad customer base can be an asset as NSDL looks to diversify its revenue streams.** However, it is also a potential risk if the portal does not invest in the expertise and staffing to understand the needs of each market segment, perform an environmental scan to identify competing alternatives for services for each segment, and tailor a high-quality portal experience for each market segment. As described in the section on audience, the NSDL portal and pathways could profitably focus on their customer base and on identifying what differentiates them from competitors in the digital education market in order to appeal to customers who might purchase their products or to funders who might invest in the portal.

**Collections**

The final concept in our sustainability model is collections. The sustainability of pathways’ collections was assessed at length in Phase 2, thus providing us with comparable statistics to gauge change in critical areas of collection health. In the Phase 2 study, 13 of 14 available pathways showed signs of activity—for example, recent additions to their collections. All 18 of the currently available pathways also showed recent signs of activity. As in Phase 2 of the NSDL evaluation, we assess collection health for NSDL-funded collections and the pathways in terms of the two attributes discussed in our sustainability model: **authoritativeness** and **usability**. Each of these attributes of collection health is examined in turn, followed by our assessment of the extent to which NSDL and pathways have published policies of copyright and permitted uses.

**Authoritativeness**

A collection can be considered authoritative if it contains current and accurate resources that are well maintained. Authoritativeness is ascribed by the collection audience to the resources within the collection and to the creators or curators of the collection (Xie, 2006; Xie, 2008). Resources from trusted information providers are assumed to be authoritative because of the standards and practices of evaluation and review associated with those providers (Bikson et al., 2011). Our measures of authoritativeness considered several indicators of published policies and collection management activities, as shown in Table 4.12.
Table 4.12. Questions for Authoritativeness

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection development policies</td>
<td>Does the site provide a collection development policy that ties mission, scope, and audience to the collecting practices of the initiative?</td>
</tr>
<tr>
<td>Collection management practices</td>
<td>Have resources in the collection been selected by a peer-review process or other professional oversight, with selection (accessioning) according to a documented process and removal (deaccessioning) when they are no longer viable?</td>
</tr>
<tr>
<td>Availability (or attrition rates of resources)</td>
<td>Can resources that a user discovers via metadata be accessed for use? Are resources available for ten metadata records in each pathway?</td>
</tr>
</tbody>
</table>

Most pathways lack a collection development policy. A comparison of pathways’ collection development policies and management practices from the Phase 2 and Phase 3 assessments is shown in Table 4.13. In both Phase 2 and Phase 3 assessments, most pathways lacked a collection development policy to tie mission, scope, and audience to the collecting practices of the initiative. The NSDL portal, however, had an exemplary collection development policy, describing mission, scope, and audience (National Science Digital Library, 2012), that can serve as a model for pathways to emulate.10

Table 4.13. Authoritative Collection Management Practices

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pathways with Collection Development Policy</th>
<th>Pathways with Peer Review</th>
<th>Pathways with Professional Oversight</th>
<th>Pathways with Accessioning Practices</th>
<th>Pathways with Deaccessioning Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 2</td>
<td>4 (29%)</td>
<td>9 (64%)</td>
<td>12 (86%)</td>
<td>4 (29%)</td>
<td>2 (14%)</td>
</tr>
<tr>
<td>Phase 3</td>
<td>5 (28%)</td>
<td>15 (83%)</td>
<td>16 (89%)</td>
<td>6 (33%)</td>
<td>2 (11%)</td>
</tr>
</tbody>
</table>

Support for authoritative collection management practices improved slightly from Phase 2 to Phase 3 in every area except resource deaccessioning. As Table 4.13 shows, the use of peer review for selecting resources increased from the Phase 2 to Phase 3 evaluations. Professional oversight had always been a strength for pathways, because the collection developers often belong to organizations that are leaders in the pathway focal area (whether subject-based or audience-based). Published practices for accessioning increased slightly, but published practices for removing resources decreased slightly. Thus, with the exception of domain expertise in resource selection, there was very little evidence of adherence to other collection stewardship practices promulgated by the library science community. However,

10 The NSDL collection policy also describes collection types, access (whether use of resources must be free or require registration, log-in, or subscription), and criteria for accessioning and deaccessioning collections.
selection by recognized experts is the most important method to build trust in a collection among the collection users, and the pathways were generally strong in this area.

**Resources provided by the pathways tended to be available.** Another important attribute of an authoritative collection is availability—that the resources a user discovers via metadata can be accessed for use. We assessed availability by verifying that resources were available for ten metadata records in each pathway. For this analysis, we conducted ten portal-appropriate searches and selected the first resource appearing in the results list. As Table 4.14 demonstrates, the low attrition rate for resources in their host collections was a significant strength in Phase 2 and was reduced still further, to 2 percent, in Phase 3. NSDL, as a federated portal for all pathways, offers the implicit promise of a one-stop shop—i.e., that the resources in each pathway will be available at NSDL.org. NSDL improved substantially on its ability to provide coverage for all pathways resources, although, as shown in Table 4.14, there is still room for improvement in ensuring the coverage of pathways resources in the common NSDL portal.

<table>
<thead>
<tr>
<th>Table 4.14. Resource Attrition Rates and Persistent Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Phase 2</td>
</tr>
<tr>
<td>Phase 3</td>
</tr>
</tbody>
</table>

**Usability**

Authoritativeness can lead a user to a collection, but usability will ensure that users find what they need and return to the collection to meet future information needs. In the Phase 3 assessment, we revisited two critical aspects of usability examined in our Phase 2 analysis: the search strategies supported by each pathway and by the NSDL portal and the metadata quality of their resource descriptions. In Chapter Six, we apply additional approaches to assess the usability of the NSDL portal and some of the pathways.

**Search Strategies Supported**

To assess search strategies, we examined whether three common search strategies were supported on the NSDL portal and the pathways, and we looked at the accessibility of the search box, as shown in Table 4.15.
Table 4.15. Questions for Search Strategies

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple search</td>
<td>Does the website offer basic search capabilities?</td>
</tr>
<tr>
<td>Advanced (filtered) search</td>
<td>Does the website offer multiple ways to tailor searches that reflect the needs of most users?</td>
</tr>
<tr>
<td>Browse by category</td>
<td>Can users browse as well as search? Can they use different categories to structure their browsing activities?</td>
</tr>
<tr>
<td>Search box is easy to find and use</td>
<td>Was the search box readily accessible from the top page on the site, or were users required to click through to another page to initiate a search? Were search boxes available in multiple locations on the site? Was it clear what source was being searched (the collection, the website, or both)?</td>
</tr>
</tbody>
</table>

Simple search and browse capabilities continued to be fully supported by the NSDL portal and all the pathways (Table 4.16). Advanced search was implemented in all but a few pathways, and its availability was similar across both assessment periods.

Table 4.16. Search Strategies Supported

<table>
<thead>
<tr>
<th></th>
<th>Number of Simple Searches</th>
<th>Number of Advanced Searches</th>
<th>Number of Browsing Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL.org Phase 2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NSDL.org Phase 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pathways Phase 2</td>
<td>14 (100%)</td>
<td>11 (79%)</td>
<td>12 (86%)</td>
</tr>
<tr>
<td>Pathways Phase 3</td>
<td>18 (100%)</td>
<td>15 (83%)</td>
<td>18 (100%)</td>
</tr>
</tbody>
</table>

We found mixed results for search box accessibility and ease of use. The search box was sometimes located in more than one area of the home page, offering more than one opportunity for its discovery—e.g., the search box might be in the content section of the page (center) and the browse capability might be in the navigation section (left). We also noted whether the search was prominent, based on such features as size of lettering and appearance of the search box. Finally, we noted whether users had to click to another page to be able to enter a search term or key word.

Table 4.17 shows that many pathways position the search box or the search and browse capabilities on multiple parts of the home page, and most (89 percent) prominently display the search capability. However, some pathways could improve search features for their collection portal. For example, several sites required users to click through to another page to enter search terms, which is inconsistent with best practices for collection-based initiatives (Fekete, 2008; Mifsud, 2011; Web Designer Depot, 2009).
Table 4.17. Prominence and Ease of Use of Search Box

<table>
<thead>
<tr>
<th>Search Box Feature</th>
<th>Number of NSDL Portals</th>
<th>Number of Pathways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content location</td>
<td>1</td>
<td>10 (55%)</td>
</tr>
<tr>
<td>Header location</td>
<td>0</td>
<td>9 (50%)</td>
</tr>
<tr>
<td>Taskbar location</td>
<td>1</td>
<td>6 (33%)</td>
</tr>
<tr>
<td>Prominent</td>
<td>1</td>
<td>16 (89%)</td>
</tr>
<tr>
<td>Zero clicks to enter key word</td>
<td>1</td>
<td>12 (67%)</td>
</tr>
<tr>
<td>One click to enter key word</td>
<td>0</td>
<td>6 (33%)</td>
</tr>
</tbody>
</table>

Metadata Quality

As discussed in Chapter Three, along with search capabilities, *metadata quality* is a key predictor of the usability of a collection or digital initiative. Metadata afford structured information about a resource to provide consistent descriptions that enable users to filter, compare, and select resources based on criteria important to them. Good metadata also provide context to enable users to match resources to their particular workflow needs. Educators bring questions to the discovery process that metadata should attempt to answer. For example, a sixth-grade teacher might be looking for a small-group activity that enables students to learn fractions. Metadata can enable the teacher to filter the search by education level (sixth grade), type of resource (educational activity), and topic (fractions).

Since the Phase 2 assessment, metadata have seen the most-substantive improvement of any area of digital collections management in NSDL and the pathways. The NSDL portal and many pathways have added more data elements, improved consistency, and added educator-specific information to improve responsiveness to educator workflows. NSDL has made these advances largely through the development of the Learning Activity Readiness (LAR) metadata schema (see box). The NSDL rubric for assessing metadata for LAR compliance includes the following elements: title, URL to resource, description, subject, educational level, format, rights usage, access restrictions, contributor, and language (National Science Digital Library and University Corporation for Atmospheric Research, 2012). In our Phase 3 metadata assessment, we adopted the LAR rubric to assess metadata, slightly modified to use standard terminology.

Park (2009) identified accuracy, completeness, and consistency as

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**Learning Activity Readiness in NSDL**

NSDL developed LAR as a conceptual framework that is part metadata application profile, intended to provide complete, accurate, and useful metadata that are consistently applied by resource suppliers, and part assessment rubric for determining the responsiveness of existing metadata and the resources they describe for supporting pedagogical use.

“"The LAR refers to how closely resources, collections, and their related metadata are aligned to educational goals, curriculum or professional development needs of users, and how readily the resources and collections can be embedded in tools and services that educators and students use” (Ginger and Goger, 2012).

Support for LAR in the metadata of an NSDL collection can indicate a high probability of impact and usefulness.
the common rubrics in use for most metadata-quality assessments. We used these concepts, along with metadata extensions, to address the quality of NSDL metadata, as shown in Table 4.18.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>Do specific metadata records accurately describe their associated resource? Are the values (unique information) populating the metadata record spelled correctly, are they appropriate to the elements they populate, and do they reflect the reality of the resource (e.g., if the resource said a log-in was required for access, was this true in practice)?</td>
</tr>
<tr>
<td>Completeness</td>
<td>Do the metadata records capture the complete key resource information with respect to the LAR metadata elements? Do the records contain all or most of the elements in the core LAR compatibility rubric?</td>
</tr>
<tr>
<td>Consistency</td>
<td>Are metadata elements consistently applied across resources? Do a preponderance of records have approximately the same amount of information and an equivalent look and feel, to enable easy comparison of resources in a results list?</td>
</tr>
<tr>
<td>Innovative metadata extensions</td>
<td>Have NSDL metadata elements been extended beyond established standards such as LAR, to address new educational needs? Specifically, has the pathway provided paradata and comments or recommendations about resource use and the alignment of resources to educational standards?</td>
</tr>
</tbody>
</table>

We examined ten metadata records from each pathway and these same 180 records in NSDL (using the same records assessed for availability described earlier). We rated each of these criteria (accuracy, completeness, and consistency) on a three-point scale, with 1 = needs improvement, 2 = acceptable, and 3 = very good. Innovative metadata extensions were also factored into the overall scoring for metadata quality for NSDL and the pathways portals.

**Results show strong metadata for the NSDL portal and pathways (see Table 4.19).** In Phase 3, we found that the metadata for the NSDL portal were much more complete and consistent than in Phase 2, with a few exceptions—specifically, that NSDL lacked the owner or creator and generally lacked copyright or permitted uses, even when these were easily gleaned from the host metadata or the resource description. For this reason, we rated the NSDL portal’s metadata as acceptable for completeness, but gave it scores of very good for consistency and accuracy.

Metadata ratings for pathways are shown in Table 4.19. Only three pathways provided metadata that need improvement in completeness, and only one needs improvement in consistency.
Table 4.19. Metadata Quality Assessment, Phase 3

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Pathways (Phase 3)</th>
<th>Consistency</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>9 (50%)</td>
<td>14 (78%)</td>
<td>15 (83%)</td>
</tr>
<tr>
<td>Acceptable</td>
<td>6 (33%)</td>
<td>3 (17%)</td>
<td>3 (17%)</td>
</tr>
<tr>
<td>Needs improvement</td>
<td>3 (17%)</td>
<td>1 (5%)</td>
<td>0</td>
</tr>
</tbody>
</table>

In the Phase 2 assessment, we used more-general rubrics because metadata implementations were still evolving, making it difficult to compare metadata practices across sites or collections. The Phase 2 rubrics included (1) whether a metadata schema was used; (2) whether the metadata supported the portal search strategies (e.g., if the user could filter by educational level, is that metadata element value provided in all or most metadata records?); and (3) whether a display was provided that was clean, jargon-free, and consistent, as well as, optimally, addressing educator workflow needs with educator-friendly terminology. Although the development of metadata in NSDL by Phase 3 enabled us to use more-sophisticated rubrics, we also applied the Phase 2 criteria to the pathways in Phase 3 to compare results with Phase 2 and assess progress over time.

As indicated in Table 4.20, the result shows considerable improvement in pathway metadata from Phase 2 to Phase 3.

Table 4.20. Metadata Quality Assessment, Phase 2 and Phase 3

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Pathways (Phase 2)</th>
<th>Pathways (Phase 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>6 (43%)</td>
<td>13 (72%)</td>
</tr>
<tr>
<td>Acceptable</td>
<td>7 (50%)</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Needs improvement</td>
<td>1 (7%)</td>
<td>0</td>
</tr>
</tbody>
</table>

Additionally, we found examples of several innovative metadata extensions that NSDL has developed. Some metadata at the NSDL portal are a composite of metadata from several pathways and are thus much richer than metadata records at any individual site, demonstrating the value of NSDL as a one-stop shop. In particular, NSDL often provides composite records consisting of reviews and suggestions for use from annotation metadata, along with aggregated use from paradata, such as number of views and comments. This is one of the innovative metadata extensions that NSDL.org has developed.

For example, Figure 4.1 shows the NSDL metadata for the CSERD pathway resource vPython. In this example, NSDL added paradata from the ComPADRE portal (see arrow) to metadata from the CSERD portal, where the resource initially appeared. These composites provide useful information to demonstrate the relative value of a resource. However, metadata records found in original pathways often provide much greater pedagogical depth and richness about the resource than the standardized NSDL metadata record supports. This is demonstrated
for another resource, “Molecular Expressions: Reflection of Light,” shown in Figures 4.2 and 4.3. In the NSDL metadata in Figure 4.2, the summary section, denoted by the red arrow, provides limited pedagogical information. It is limited to key words about the subjects, educational level, resource type, and format. In contrast, the ComPADRE metadata for the same resource are shown in Figure 4.3. Here, the metadata include more-detailed key words for the subjects (green arrow), provide a list of intended users (purple arrow), and describe related resources (red arrow) in detail, including the creators of those relationships.

Figure 4.1. NSDL Metadata for the CSERD Resource, vPython, Which Includes Paradata Contributed from the ComPADRE Site

Figure 4.2. NSDL Metadata for the ComPADRE Resource, “Molecular Expressions: Reflection of Light”

SOURCE: Screenshot of Molecular Expressions web page, 2013.
NSDL’s efforts related to metadata since the Phase 2 evaluation have also expanded to include the alignment of educational standards to resources in the NSDL portal and the pathways. Systematic data collection and analysis of this work are in their early stages, but we have compiled examples of ongoing efforts at standards alignment:

- The CLEAN climate literacy standards have been developed and promoted to the community through resources at the CLEAN pathway. Some CLEAN resources are also available at the Teach the Earth pathway but lack the climate-literacy standards. NSDL records provide the climate-literacy standards for these resources.

- NSDL has provided alignment with science literacy and national science benchmark standards for ChemEdDL (Chemical Education Digital Library) resources that are not available at the ChemEdDL portal.
The NSDL portal leaders, working in conjunction with several pathways partners, have compiled a growing collection of math Common Core resources, which are available in the main NSDL portal (Howe et al., 2011).

NSDL has worked with the Teachers’ Domain pathway to provide state standards for resources based on the school affiliation of registered users.

NCS provides the ability to harvest and align standards from the Achievement Standards Network (ASN) to resources as they are cataloged.

Figure 4.4 shows a resource from the ChemEdDL pathway that has been augmented in the NSDL portal to provide complete and pedagogically rich metadata, together with the alignment to standards. In addition to providing standardized metadata about type of resource (green arrow), educational level, there are also educational standards (purple arrow) and a Creative Commons license describing permitted uses for the resource (red arrow). Collectively, these are compelling new examples of NSDL providing considerable added value. In this respect, we see another way that NSDL is beginning to exceed the sum of its parts.

**Figure 4.4. NSDL Portal Metadata for the 360 (“3D”) Model for Quinoline C9H7N**

![Metadata for the 360 (“3D”) Model for Quinoline C9H7N](source: Screenshot of Chemical Education Digital Library web page, 2013.)
Copyright and Rights for Use

A final area of collection health to assess, which cuts across authoritativeness and usability, is that of rights and permitted uses. As in the Phase 2 assessment, in Phase 3, we looked for evidence in pathways and NSDL portals of multiple measures, as shown in Table 4.21.

Table 4.21. Questions for Copyright and Rights for Use

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Key Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copyright use policies</td>
<td>Is a copyright or permitted use policy, which provides general guidance on using the resources at the site, displayed prominently and clearly on the website?</td>
</tr>
<tr>
<td>Copyright metadata</td>
<td>Do individual metadata records on the websites include information on copyright for the resource each record describes?</td>
</tr>
<tr>
<td>Permitted use metadata</td>
<td>Do individual metadata records on the websites clearly outline permitted uses of the resource?</td>
</tr>
</tbody>
</table>

Most of the pathways had copyright or terms-of-use policies, although there was a slight reduction in their use over time. The results are summarized in Table 4.22. The NSDL portal has a published terms-of-use policy, accessible on the website from the footer taskbar that includes its copyright practices, including redress for copyright infringement. In the Phase 2 assessment, 12 of 14 pathways (86 percent) had copyright or terms-of-use policies. In the Phase 3 assessment, 14 of 18 pathways (78 percent) had copyright or terms-of-use policies, an 8 percent reduction. Table 4.22 also illustrates that many pathways fail to provide sufficient guidance for users about the rights associated with a resource (copyright metadata) and the uses they are permitted to make of a resource (permitted-use metadata).

Table 4.22. Rights and Permitted-Use Policies and Metadata

<table>
<thead>
<tr>
<th></th>
<th>Copyright and Use Policies</th>
<th>Copyright Metadata</th>
<th>Permitted-Use Metadata</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL Phase 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pathways Phase 3 (N = 18)</td>
<td>14 (78%)</td>
<td>10 (56%)</td>
<td>10 (56%)</td>
</tr>
</tbody>
</table>

The NSDL portal generally provides copyright and permitted-use metadata when these elements are supplied by the host portal.

Lack of copyright and permitted-use guidance, at both the portal and the resource metadata levels, remains a significant threat to the sustainability of NSDL and pathways collections. One central concern relates to NSDL’s unresolved relationship to OERs. As noted in the previous chapter, Borgman et al. (2008) recommended that educational materials developed by NSF projects be released as open educational materials under a Creative Commons license by default. NSDL’s mission statement says that NSDL will provide high-quality OER materials for
However, not all the resources offered via the NSDL portal conform to OER requirements for open access and reuse within a noncommercial setting.

There are two reasons that the NSDL portal cannot enforce consistency with the OER requirement. One is that when NSDL encourages users to provide their own resources, such as comments, and combine and repurpose resources for educational purpose (thereby fostering user engagement), it becomes difficult for the NSDL portal or pathways to control the content on their sites, much less to enforce OER licensing requirements. Second, for the most part, the NSDL portal and pathways have created and own only resource metadata, not the resources themselves. Thus, the portal and pathways may be able to enforce open-access Creative Commons licenses on metadata but may have little or no control over the openness of the resources they catalog. However, NSDL can exercise some measure of control by seeking collection partners that provide copyright and permitted-use metadata for each resource, particularly through Creative Commons licenses that identify uses that can be made of a resource.

**Conclusions About Collections**

*Overall, the NSDL portal and pathways have made consistent improvements in the authoritativeness of their collections.* Professional oversight of resource accessions has remained strong, and peer review has increased significantly. Most collection resources documented in metadata are available for use.

*In terms of usability, the NSDL portal and pathways continue to provide good basic search services,* although ease of searching remains problematic for some pathways in that they do not support searching directly from the home page.

*The most-dramatic usability improvements in NSDL involve metadata quality.* Many pathways now provide accurate and complete metadata that are consistent across records. Perhaps the most-important metadata improvements, however, consist of greatly enriched descriptions of resources, such as the alignment of NSDL materials to educational standards, and the growing availability of usage metadata (annotations and paradata).

The availability of paradata is a significant contribution of NSDL to the development of digital repositories more generally. Paradata tell the user about the types and number of uses made of a resource, providing information about its popularity and potential uses and allowing the user to make inferences about the value of the resource to the user community. Currently, paradata appear to be presented as static information to the end user, but they have tremendous potential to provide additional value. For example, paradata can be used to filter resources for relevance in a search, so that resources with paradata appear higher in a search-result list, or to filter searches based on other information, such as user ratings, whether the resource has been modified, or whether it has comments or links to related resources. Paradata also enable the easy identification of widely used resources, so that these resources can be studied to determine what makes them more popular and, presumably, more useful than other resources on the same topic.
or intended for the same audience. However, paradata will need to be deployed widely throughout the contributing collections for these innovative uses to take root.

**Although most pathways have a copyright or terms-of-use statement, many pathways fail to provide sufficient guidance for users** about the rights associated with a resource and the uses they are permitted to make of a resource.

### Key Findings and Chapter Conclusions

Assessing the health of NSDL collections depends on understanding the relationship between the NSDL portal and pathways and the resource collections they feature. In principle, NSDL and the pathways are gateways to other resources, providing collections of metadata that can be searched, which in turn provide links to resources hosted by third parties. Thus, the role of NSDL and the pathways is that of the selector, choosing collections and resources that serve the mission, collection scope, and audience of the portal and providing metadata to enable users to discover those resources. In contrast, the collection owner must manage the resources for ongoing usefulness and availability. However, the reality is somewhat different.

Sixteen of 18 pathways provide metadata for resources hosted at other websites and also provide their own resources, such as e-journals, courses, e-textbooks, and professional development resources. Portals that supply collections from their parent institutions can be considered to be hosting both metadata and resources. Even the NSDL portal, presumably merely a gateway to the collections of pathways and the third-party resources selected by the NSDL RC, has a significant investment in its science literacy maps, professional development resources, and the policy and guidelines resources developed for the pathway community. In addition, the NSDL portal and pathways are now jointly generating composite metadata and paradata. This means that in addition to the sites creating diverse and overlapping kinds of content, their resources are also often linked across portals and pathways. The health and sustainability of many collections, therefore, depend on others in the emerging NSDL ecosystem, as set forth in the NSDL logic model. We address this point in more detail in the remaining chapters.

**Based on our review, the prospects for sustainability and thus for long-term impact of NSDL and the pathways appear mixed.** The NSDL portal and the pathways have a number of strengths:

- They have shown considerable improvement in terms of collection health; in particular, they have broadly identified the audience served, improved peer review and professional oversight practices, and greatly improved their metadata strategies, particularly in comparison to their status in our Phase 2 evaluation.

- With respect to metadata in particular, NSDL has begun creating composite metadata and paradata from other pathways and has expanded metadata to include the alignment of resources with educational standards, advancing the vision of being a one-stop shop. (We note, however, that it would be useful to provide a link to the original metadata, since
metadata within pathways often provide links to other resources to be used in conjunction with the resource and to comments and suggestions for use that may not have been harvested as annotation metadata for the NSDL portal.)

- In terms of usability more generally, pathways have offered more value-added services, such as communities and personal folders.

We also identified a number of needs for improvement in collections, many of which are relatively straightforward to implement:

- In brief, all portals, and particularly those that require or encourage user registration, should publish privacy policies.

- All pathways should enable searching directly from the home page, publish a sound copyright strategy, and document copyright and permitted uses in resource-level metadata.

- In addition, most records available at the pathways should be available at NSDL.org. This could be accomplished by tailoring metadata harvesting to reflect recent additions to the pathway portal, rather than on a standard schedule, such as monthly (see Table B.4 for an analysis of the overlap between NSDL.org and the pathways).

**Bigger concerns for sustainability for NSDL and individual pathways lie with the other concepts in the sustainability model.** First, while NSDL and most portals have an identified audience, the audience identification is generally very broad. Although there is considerable improvement in metadata and metadata displays, there is no evidence that these changes are being made in collaboration with a well-defined service audience to ensure that clients’ and customers’ needs are being met (or, for that matter, that the audiences have been clearly identified). Second, there is also no evidence that NSDL and the pathways have identified their competitors in the digital education marketplace and are assessing the value of their offerings against those competitors. As a result, NSDL and the pathways lack a value proposition—a definition of what they offer that is unique, compelling, and competitive to an audience that is well defined and well understood. Without a value proposition, it may be difficult to promote NSDL and the pathways to prospective partners, parent institutions, or other stakeholders or to establish prices for services as a source of income for sustainability.

**NSDL and the pathways provide evidence of visionary or entrepreneurial leadership in project PIs.** However, a review of NSDL and pathway websites, and, in some cases, project documents, provides little evidence of other aspects of the organizational concept of sustainability, including clearly articulated and measurable goals, financial and operational leadership, and strategic planning. We note, however, that additional methods of evaluation, such as interviews with project directors and document review (e.g., annual progress reports to NSF, other documents pertaining to project operations), are needed to fully assess attributes of organization and their contribution to the longer-term impact and viability of NSDL.

**In addition to these and other research methods proposed throughout this chapter, additional methods of evaluation are needed to comprehensively assess attributes of the**
sustainability model for NSDL or any other digital initiative. In particular, data need to be collected directly from customers and clients to assess aspects of audience and collections. For example, surveys and interviews can be used to evaluate stakeholders’ perceptions of the usefulness of NSDL and the pathways, particularly as contrasted with competitive services. A competitive service might not be an actual third-party competitor but rather another strategy to obtain digital education resources in users’ current workflows. How does the NSDL service improve on the status quo for a busy educator?
Chapter Five. Digital Tools and Services

The previous chapter reviewed the health and sustainability of the NSDL collections from the perspective of the model of sustainability we developed in Chapter Three. In this chapter we review the development and sustainability of NSDL tools and services using the NSDL logic model as our organizing perspective. Tools and services are important attributes of sustainability because they support use of digital collections, and NSDL projects were expected to generate an array of diverse tools and services to discover, organize, and mix resources that would lead to improvements in teaching and learning (see Figure 1.1).

We define tools and services broadly as technology artifacts that facilitate or enrich the provision of, access to, or use of digital content, but are themselves not content. Tools and services include, for example, wikis that enable users to repurpose and combine resources or widgets that allow teachers to comment on a digital lesson plan. Tools and services also include application programming interfaces (APIs) that enable developers to quickly find and deliver digital resources. The distinction between digital services and resources, however, is sometimes blurry. For example, some educational materials are packaged together with data and tools to manipulate the data; in such cases, tools are integral to the resources rather than stand-alone. Other services, such as search, can be created independently of collections but cannot function without them.

In Chapter Four, we reviewed several tools, including search strategies and tools for engagement (e.g., tools to save or organize resources in personal spaces, share resources with others, or comment on them) supported by NSDL and the pathways. In this chapter, we focus on the array of services and tools provided by NSDL projects that were not as tightly coupled to digital content and search.

As described earlier in this report, community-based, collaborative development was an underlying assumption of the NSDL logic model and distinguishes the NSDL program from many other NSF programs. In Chapter Four, we provided some examples of how the NSDL program and the pathways have developed products that exceed the sum of their parts, particularly in the area of metadata. Likewise, in this chapter, we address the community-based or collaborative processes to help us understand the value and impact of the tools and services that the projects created for the NSDL program. The answers will provide important insights for future cyberlearning programs that seek to improve the productivity of projects by encouraging collaborative and community-based development.

We assessed tools and services in two ways. First, we conducted a broad review of tools and services that have been funded in the NSDL program throughout its history. This enabled us to describe the kinds of tools and services developed by NSDL projects but did not provide detailed information about the processes by which the tools and services were developed and connected...
to other NSDL services. Second, we selected a few key tools and services that have persisted, and we conducted more-detailed analysis of the development of and user communities associated with them (selection criteria for the key tools and services are described below). We asked two sets of questions related to the logic model, the first focusing on the products and outputs of the tools and the second addressing the processes by which key tools and services were built and used by the NSDL community and others, specifically related to collaborative development.

To characterize the products and outputs of the tools, we posed the following questions:

- What kinds of tools and services have been proposed and developed?
- To what extent did projects succeed in developing proposed tools and services?
- Is there redundancy in development of tools and services across projects?
- Have useful or needed services not been developed by any projects (gaps)?

To address the processes by which key tools and services were built and used by the NSDL community and others, we focused on these questions:

- Have services been built using the shared NSDL technical platform or a common platform with an open API, which would encourage interoperability and integration?
- Have services reused or built on existing NSDL services, or on interoperable services outside NSDL, rather from starting from scratch?

Note that, with the data available for this evaluation, we could not address all questions in equal depth for all tools and services.

**Broad Review of Services Track Awards**

In this section, we describe the results of our broad review of tools and services that have been funded in the NSDL program throughout its history. As discussed in Chapter Two, one of NSDL’s original proposal tracks supported the development of tools and services. Projects in the Services track were “expected to develop services that support users and resource collection providers by enhancing the impact, efficiency, and value of the NSDL network” (NSF, 2010). From its inception in 2000 until 2010, NSDL made nearly 120 awards in the Services track, totaling approximately $43 million (see Table 5.1). In 2004, the Services track was divided into three subtracks:

- **Selection Services** projects expanded digital content in various STEM areas by tagging resources and integrating them into the NSDL data repository.
- **Integrated Services** projects developed services that could be incorporated directly into NSDL.org.
- **Usage Development** workshops targeted new communities of learners to enlarge the NSDL user base.
We focused our analysis on a subset of the projects from the first two subtracks and from projects in the earlier years that were in the general Services track, because these projects targeted technology-based tools and services (see shaded rows in Table 5.1).\textsuperscript{11}

### Table 5.1. Count of Projects Funded in Services Tracks

<table>
<thead>
<tr>
<th>Track</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selection Services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Integrated Services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Usage Development</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>80</td>
</tr>
<tr>
<td>TOTAL</td>
<td>9</td>
<td>13</td>
<td>12</td>
<td>11</td>
<td>15</td>
<td>11</td>
<td>4</td>
<td>10</td>
<td>4</td>
<td>15</td>
<td>14</td>
<td>118</td>
</tr>
</tbody>
</table>

**NOTE:** "Other" refers to all Services projects funded prior to the split of tracks in 2004, and to projects not funded in specific Services subtracks after 2003. The shaded rows represent technology-based tools and services.

**What Kinds of Tools and Services Were Funded?**

From the 96 projects in the shaded areas of Table 5.1, we selected a small number of abstracts that mentioned tools and services extensively, in order to characterize the types of services that were proposed. Using the NSDL abstracts database, we selected projects with the most mentions of *service* or *tool*, regardless of the type of tool or service proposed. Table 5.2 provides edited excerpts from the abstracts of the selected awards.

We found a diverse range of themes in the technology awards made in the Services subtracks. Many efforts sought to advance basic knowledge about the kinds of tools and services that would benefit users, as well as to conduct preliminary studies on tool and service technology—e.g., how to extract content from online videos to guide future video tool development. Some awards were aimed at developing tools to help users manipulate specific collections or resources in complex ways. For example, one project proposed a virtual observatory that allowed users to remotely control telescopes, while another facilitated complex data analysis on specific datasets. Other projects sought to develop stand-alone services for end users or developers, such as a tool that would help students and teachers visualize digital data sets. Finally, many projects planned to enhance the underlying NSDL infrastructure and improve search capabilities, metadata, and other features.

\textsuperscript{11} Not all NSDL Services projects developed software tools. For example, Usage Development supported workshops on how to use NSDL resources in classrooms. But in the context of these 96 projects, *tool* and *service* are synonymous, and the terms are used interchangeably in this chapter.
<table>
<thead>
<tr>
<th>Award Name and Number</th>
<th>Award Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Component Repository and Environment for Assembly of Teaching Environments (CREATE) (0085826)</td>
<td>This collaborative project develops interactive environments through a component design and production service and an assembly environment to support identification and reuse of curricular materials. The component design and production service support collaborative creation of learning objects. It is aimed at programmers and is focused on direct coding of components, from graphical user interface elements to complex simulations.</td>
</tr>
<tr>
<td>StandardConnection—Mapping NSDL Educational Objects to Content Standards (0121543)</td>
<td>The investigators are developing a natural language processing tool (“StandardConnection”) for the automatic assignment of content standards and benchmarks to educational resources in the collections of NSDL and to other educational resources on the Web.</td>
</tr>
<tr>
<td>Data Discovery Toolkit and Foundry (0121550)</td>
<td>This project is developing an initial set of data discovery tools to enable users to manipulate real (and real-time if needed) data sets for visualization purposes. In addition, an Internet-based community center for further tool building, the “Foundry,” is being created.</td>
</tr>
<tr>
<td>Digital Library Service Integration (DLSI) (0226075)</td>
<td>The DLSI infrastructure provides a systematic approach for integrating digital library collections and services. With this infrastructure, digital libraries will be able to share relevant services within a seamless, integrated interface.</td>
</tr>
<tr>
<td>Access NSDL (0226214)</td>
<td>Through this project, the NSDL is benefiting from and contributing to the national and international dialogue on access specifications for online learning resources to meet the needs of users with disabilities and to ensure interoperability of accessible content. Project deliverables include an automated evaluation tool that reports on a site’s accessibility and guides users to relevant resources to address barriers to accessibility by people with disabilities.</td>
</tr>
<tr>
<td>A Digital IdeaKeeper for K–12 (0226241)</td>
<td>This project is developing the IdeaKeeper, a specialized scaffolded NSDL portal and services for K-12 science learners. IdeaKeeper incorporates scaffolds, or software features, to support students in analyzing library resources and synthesizing the information into arguments addressing their driving questions. The project team will deploy versions of IdeaKeeper in Detroit middle school classrooms to assess the impact of such supportive digital library services on learning.</td>
</tr>
<tr>
<td>The Collaboration Finder (0226277)</td>
<td>The Collaboration Finder is developing a web-based, searchable and browsable database tool to capture information about the goals, ongoing activities, deliverables, schedules, development stages, and disciplines areas covered by NSDL projects.</td>
</tr>
<tr>
<td>The OCKHAM Library (0333497)</td>
<td>This project is developing OCKHAM, a networked middleware to facilitate and expand access to the content and services of the NSDL through the existing national infrastructure of traditional libraries and their service programs. Additionally, the project team is creating a reference model for integrating the NSDL into traditional library services; evaluating the utility, usage, and impacts of the local library tested services on the participating campus communities; and disseminating results and facilitating growth of the network among an expanding group of institutional partners.</td>
</tr>
<tr>
<td>Pedagogic Services for Digital Libraries (0532768)</td>
<td>Building on a successful example, the Starting Point Digital Library connects pedagogic materials to teaching materials in digital library collections. It is helping teachers and faculty understand how to use STEM materials in ways that are engaging, interesting, and effective. The project ensures that seekers of teaching materials also find pedagogic information, and vice versa.</td>
</tr>
<tr>
<td>NSDL: ASN Toolkit (0840740)</td>
<td>This project is integrating the Content Assignment Tool (CAT), the Teacher Domain Educational Standards Correlation tool (TD-ESC), and the Digital Collection Service into the Achievement Standards Network (ASN). Additionally, the NSDL Metadata Registry required by the TD-ESC and the Gateway to Educational Materials (GEM) Thesaurus Browser that facilitates cataloging by the Digital Collection System (DCS) are included. The resultant tool assists teachers by eliminating the cumbersoness of working with a set of separate tools that currently are not completely compatible.</td>
</tr>
</tbody>
</table>
Table 5.2—Continued

<table>
<thead>
<tr>
<th>Award Name</th>
<th>Award Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MiNC: NSDL Middleware for Network- and Context-aware Recommendations (1043583)</td>
<td>MiNC provides online integrated services for: a) understanding the personal activity context through access patterns and analysis of user documents, b) context-aware resource discovery, including search, presentation, and exploration support within the knowledge structure (e.g., Strand Maps) provided by NSDL, and c) peer discovery, peer-network management, and peer driven resource and knowledge sharing and collaborative recommendations.</td>
</tr>
</tbody>
</table>

NOTE: The first two digits in the award number indicate the FY of funding.

Not all of the projects funded by the Services track explicitly planned to develop services or tools. The review of abstracts indicated that many projects were designed to create or augment collections, which often included development of search tools and other services to provide access to the resources in those collections. This overlap between the Services and the Collections tracks is an indication of how closely related the different funding tracks were—which may have been because services and collections are inextricably bound, or may have been because expectations in the program solicitations were ambiguous.

Indeed, a quick scan of all 96 abstracts shows that services have appeared in every NSDL track. The CI (and later RC and TNS) projects took primary responsibility for the core search and metadata-harvesting services of NSDL.org. Targeted Research projects have investigated cutting-edge research topics related to the provision of innovative services, such as tools that can tailor the selection and presentation of digital resources to the cognitive needs of students or that can integrate NSDL content into online courses.

Our review of abstracts also showed that some projects proposed redundant services. For example, ten distinct award abstracts from 2000 to 2010 mentioned commenting tools, while more than 20 abstracts mentioned annotating resources.

Although we did not review all service projects, discussions with NSDL program officers also pointed to gaps in service development. For example, one program officer noted his frustration that no projects in the program’s early years proposed an “Amazon-like” recommendation service (Wattenberg, 2008). A founding program officer also commented that an early fear about the program—that NSDL would have the wrong balance of services (that it “might wind up with 5 beautiful kitchens but no bathrooms”)—had been realized (Wattenberg, 2008).

Overall, the NSDL services portfolio covered a somewhat haphazard range of tools and services; many of the services came from tracks other than Services; and many kinds of services were investigated by several projects, while others were not developed at all.

How Were Key Tools and Services Built and Used by the NSDL Community and Others?

The NSF abstracts for Services projects were useful in characterizing the types of technical services that projects were planning to develop and deploy. However, abstracts are brief, and
they are published at the beginning of an award, so they cannot be used to determine whether services were actually implemented and whether the NSDL’s collaborative process of service development helped promote tool creation in ways that independent development might not have. Ideally, these questions would be addressed by conducting interviews or surveys of project personnel and end users, as well as by reviewing other project documentation. However, we did not have direct access to project proposals or reports, nor were we able to gather data directly from more than a few project PIs and staff. As a result, our broad assessment of the use and sustainability of tools and services funding was limited to online searches for references to projects and a review of online documents retrieved through those searches.

Using project abstracts, we identified 70 projects awarded between 2000 and 2010 in the Services track that clearly indicated that the project would develop tools or services. We randomly selected 22 (31 percent) of those 70 service awards for further review. In addition to reviewing the project abstracts, we conducted a series of web searches to ascertain completion status and relationship of the project to NSDL. We searched for project outcomes by reviewing each project’s page on NSF’s website, which often lists publications. We also used Google Scholar to search for the PI, name of the tool or service, key phrases in the abstract, and the award number, and we reviewed PIs’ web pages.

To assess completion status, we looked for evidence of whether the projects were completed, partially completed, not completed, or of unknown completion status. Measurement of the relationship of services to NSDL captured two features of NSDL collaborative development: We classified projects as integrated (services built using existing NSDL tools and included in the NSDL.org technical infrastructure), external (built for and used in a different repository or library but of potential value to NSDL), or relevant (neither built nor included in NSDL or another repository but perhaps of interest to NSDL).

Project Completion Status

Results are shown in Table 5.3. Data in the rows reflect completion status. We found clear evidence that seven of the 22 projects (32 percent) successfully delivered tools and services that closely resembled those described in the project abstracts. All of these were awarded in 2005 or later. Of these seven projects, four were designed to improve use of a specific collection or pathway; for example, one service developed a Geographic Information Systems (GIS) mapping tool for a collection, whereas another linked a collection’s resources with relevant pedagogical materials. Two services consisted of more-general tools, such as a strand map service that drew logical connections between different scientific concepts, developed to meet the needs of a broader community of users or developers. The remaining completed service was discontinued when its funding ended.
Table 5.3. Analysis of Selected NSDL Services Projects by Completion Level and Relationship with NSDL

<table>
<thead>
<tr>
<th>Status</th>
<th>NSDL Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Integrated</td>
</tr>
<tr>
<td>Completed</td>
<td>5</td>
</tr>
<tr>
<td>Partially completed</td>
<td>1</td>
</tr>
<tr>
<td>Incomplete or unknown</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>12</td>
</tr>
</tbody>
</table>

Two projects (9 percent) seem to have partially implemented the tools and services that they originally proposed. In both of these cases, the abstracts described several features that were planned for development, but we found evidence that only a small subset of the proposed features were implemented.

For the remaining 13 awards (59 percent), there is no evidence of a completed tool or service. Of these, two projects proposed to develop digital library middleware—i.e., software that connects digital library components. While there is no explicit documentation of the middleware having been implemented, the collections and pathways that the projects sought to support with this middleware continue to function. Therefore, it is possible that these awards were used to improve other aspects of the infrastructure of these sites. For the other 11 projects, there is no evidence of any tool or service development. For two of these projects, the intent was not clear in the abstracts. There was evidence of some research and publications for five projects but no evidence of tools or services that were developed as a consequence of the research. Finally, we found no evidence of tool or service development, or research products, for the remaining four projects.

Relationship of Projects to NSDL Program

The columns in Table 5.3 show the sample of 22 services in terms of their relationship to the NSDL program, independent of whether the project was successful in completing its development. The NSDL program officers expected that most Services projects would emphasize the development of tools that could be used directly in NSDL.

According to their abstracts, and confirmed by web documents, more than half of the projects (12 of 22, or 55 percent) did indeed propose tools or services that would be integrated into NSDL.org or one of the pathways sites. Of the 12 counted in the table, at least three proposed to enrich or reuse NSDL resource content, three supported services for teachers and other NSDL users, one expanded access to NSDL content to new communities, and one planned to combine multiple services into a new one.

The remaining ten projects (45 percent) did not develop integrated services. Seven projects planned to develop services for digital repositories external to the NSDL program, with the expectation that the NSDL program might use the services as a model for similar services of
its own. One project proposed to develop a parallel service not only for its own repository but also to combine its service and repository content with NSDL’s. Two projects proposed to develop tools that would be relevant to the NSDL program without committing to create more than a prototype demonstration of their ideas—i.e., the tools would not be implemented either in the NSDL portal or another system. Presumably, like some of the services for external repositories, these could serve as useful models for future NSDL services.

**In our sample of projects, of those that proposed to develop integrated tools or services, fewer than half actually completed their implementation (five of 12, or 42 percent).** Projects proposing external or relevant services were less likely to be completed successfully. Overall, there did not seem to be any strong association between project completion status and NSDL relationship, although our sample is too small to draw strong conclusions.

**Conclusions from the Review of Services Awards**

Our broad review of abstracts and web documents related to NSDL Services projects revealed a mixed picture:

- Not all projects funded in the Services track implemented technical services or tools, and not all successful tools or services in NSDL came from the Services track.
- Many projects developed similar or redundant services rather than reusing existing ones; other services important to NSDL program directors went unexplored.
- From the sample we evaluated, results also indicate that many projects did not appear to complete the services they had originally proposed to develop.
- Other projects apparently never committed to developing NSDL-ready services, although their products may have led to new ideas, new projects, or new services, some of which stayed within the NSDL community and some of which may have taken root in digital repositories and communities outside NSDL.

However, Table 5.2 illustrates that NSDL projects designed a wide range of innovative-sounding services. And, judging by the handful of projects described in Table 5.3, some did attempt to follow NSDL’s collaborative development process, as they used components of the NSDL infrastructure to develop their services and intended that the services be included or integrated into NSDL.

However, in spite of these identified successes, our cursory assessment of services suggests that NSDL’s driving vision of an ecosystem of self-sustaining tools and services has not yet been realized. Few Services projects successfully built new services or tools on existing NSDL services or offered them as new ones to be added into the NSDL technical infrastructure. In the final chapter of this report, we discuss possible reasons for these results.
Review of Key Tools and Services

In this section, we review a small set of key NSDL tools and services. Key tools were defined as ones that have endured for several years, have had substantial numbers of users, and were either developed as part of the NSDL infrastructure or developed elsewhere and then integrated into the NSDL portal. We included all NSDL tools and services that met these conditions in our set of key tools. These cases enabled us to address in more depth some of the questions presented at the beginning of the chapter related to the community-based or collaborative processes by which the services were developed and maintained.

To address the questions posed at the beginning of this chapter, we used multiple methods, including an analysis of the inventory of NSDL project awards, informal discussions with RC staff and other project and pathways developers, analysis of web metrics (where available), and our own usage of specific tools and services. The services focused mainly on those created for NSDL users (teachers and students) rather than for NSDL developers. This distinction is not precise, as a few tools and services met the needs of both users and developers. Table 5.4 lists the key services we analyzed.

### Table 5.4. Key NSDL Tools and Services Reviewed

<table>
<thead>
<tr>
<th>User Tools/Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Expert Voices</td>
</tr>
<tr>
<td>• NSDL Wiki</td>
</tr>
<tr>
<td>• Science Literacy Maps</td>
</tr>
<tr>
<td>• Curriculum Customization Service</td>
</tr>
<tr>
<td>• Instructional Architect</td>
</tr>
<tr>
<td>• NSDL on iTunes</td>
</tr>
</tbody>
</table>

NOTE: We omitted a discussion of the Curriculum Customization Service, because it is discussed in depth in Chapter Seven as a case study. Additionally, we discuss Science Literacy Maps and the Strand Map Service together, since the former is a specific instantiation of the latter.

Although the services differed substantially in their purposes, user communities, and longevity, we established a standard template to capture the common features of the services that worked relatively well. The features include

- basic identifying information of the service or tool (year initiated, name)
- developers (the project or team that built and maintained the service)
- purpose (what functions the service provided)
- integration with NSDL (how tightly it was coupled to the NSDL infrastructure and other services)
- usage in NSDL (how frequently the service had been used)
• sustainability (how long the service had been in operation and its prospects for future use)
• antecedent and subsequent services (the services it arose from and led to, if any)

**How Were Key User Tools and Services Implemented and Integrated into the NSDL Portal?**

Table 5.5 summarizes features of all of the key services. Each key service is profiled in more detail in a separate table in Appendix C. As shown in Table 5.5, these are among the most enduring and heavily used NSDL services. For example, the Instructional Architect project was funded in 2001, in the second year of the NSDL program, and the Strand Map Service launched in 2002. All the services have had a life span of at least four years.

In contrast to many of the services reviewed in the previous section, **most of these key services were carefully integrated into the main NSDL portal**. For example, the Science Literacy Maps and iTunes on NSDL are accessible from the front page of NSDL.org and are directly associated with the NSDL domain name (strandmaps.nsdl.org and http://nsdl.org/page/iTunesU/). Most of the services accomplished their integration by using the underlying NSDL web platform. One exception was Instructional Architect (IA), which began as a separately funded services project and maintained its own website. However, IA is still tightly coupled with NSDL, since IA users draw resources from NSDL when creating its instructional web pages, and the new web pages can also be submitted to NSDL and thus shared with the educational community.

IA is also distinct from the other key user-oriented services because it was developed first as a relatively small, two-year service grant to Utah State University and then was extended by several follow-on projects. However, the remaining key services in this group were *not* funded by Services track awards, but rather by the longer-term cooperative agreements with UCAR and Cornell University to support the CI, RC, and TNS teams, which maintained the NSDL infrastructure and the NSDL portal. **Thus, most of the enduring services were developed by the CI, RC, and TNS rather than by other service projects.**

Looking at the use of the key NSDL services, Table 5.5 shows that some demonstrated **substantial uptake**. Expert Voices, for example, had many thousands of page views per month and hundreds of persistent users. IA has more than 7,500 registered users and has produced more than 17,000 projects. Nevertheless, of the services discussed here, only the Strand Map Service and the Science Literacy Maps remain very active; NSDL on iTunesU was still maintained (as of June 2013) but appeared to be shrinking in contributions and usage.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Tool or Service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Expert Voices</strong></td>
</tr>
<tr>
<td><strong>Year initiated</strong></td>
<td>2006</td>
</tr>
<tr>
<td><strong>Developers</strong></td>
<td>RC and TNS</td>
</tr>
<tr>
<td><strong>Intended purpose</strong></td>
<td>Blogging to increase contributions to NSDL and support resource use</td>
</tr>
<tr>
<td><strong>Antecedent services/tools</strong></td>
<td>Open-source WordPress blogging environment</td>
</tr>
<tr>
<td><strong>Integration with NSDL</strong></td>
<td>High</td>
</tr>
<tr>
<td><strong>Evidence of NSDL usage</strong></td>
<td>30,000–50,000 page views per week in 2010</td>
</tr>
<tr>
<td><strong>Sustainment</strong></td>
<td>Decommissioned, 2011</td>
</tr>
<tr>
<td><strong>Subsequent services/tools or uses</strong></td>
<td>None</td>
</tr>
</tbody>
</table>
Conclusions from the Review of Key Tools and Services

We surmise that there were several reasons why most of the core NSDL services were developed by the CI, RC, and TNS tracks rather than by Services projects. The CI, RC, and TNS tracks had the largest awards, which ran for almost a decade, thus ensuring a reasonable degree of continuity and sustainability. These tracks also controlled the NSDL technical platform and had the expertise needed to author and integrate needed services. By controlling the key services, they could also guarantee that the services were always available to users. Nevertheless, the NSDL program originally envisioned that most services would be funded by service grants and contributed by groups outside the NSDL.org team (Zia, 2008). The case of IA demonstrates that this was indeed possible.

Several reasons for the declines in activity of the NSDL Services projects are apparent. First, even popular services showed a quick decline and were eventually decommissioned when the grants that supported them ended. Grants are short-term revenue sources. And, for the most part, as discussed in Chapter Three, initial PIs are not necessarily the appropriate people to lead later stages of a digital initiative. Second, digital tools can become obsolete very quickly; in the case of blogs and wikis, which underpinned Expert Voices and NSDL wiki, informal discussions with pathways leaders and anecdotal remarks suggested that cheaper and more-functional versions arose not long after the services were first developed. Eventually, users and developers moved on to the next generation of these tools.

Perhaps more important, in the cases of Expert Voices and NSDL wiki, market responses dictated that developing a new service was not a winning idea. One of the valuable lessons NSDL program leaders learned from these tools was that focused social networking services are preferred to general ones (Darrell Porcello, personal communication, 2013). Most teachers, for example, do not want high-quality general educational resources or interesting discussions about general education topics with experts or peers. Time is a scarce resource for teachers, and to make best use of their time, most teachers want quick access to the most-relevant resources and peer experiences (Hanson and Carlson, 2005). For example, if they are middle school math teachers, then they want easy access to middle school math resources, and they want to interact with other middle school math teachers. The relocation of NSDL social networking tools that followed Expert Voices and the NSDL wiki from NSDL.org to the pathways portals and other more-specific sites should help support their use by the relevant community.

The case of NSDL on iTunes may point to a new way of thinking about services in NSDL.org and other educational repositories. The most common idea of an integrated NSDL service was one that was built on the NSDL technical infrastructure and thus became directly accessible through NSDL.org. Most of the key services discussed here, as well as others we reviewed earlier, were constructed this way. But integration can be accomplished in other ways. For example, integration of NSDL on iTunes was roughly the reverse of the common model: The NSDL program provided content and built a service using this highly popular external platform.
rather than using its own website and infrastructure. Although the NSDL program may continue to build innovative services on its own platform for as long as the enterprise is sustained, recent evidence suggests that different forms of integration may become increasingly important. For example, the NSDL program’s plan to reposition itself for the future (Howe et al., 2011) discussed the STEM Exchange, which is a system that enables education practitioners to integrate paradata and information about the use of resources from the NSDL portal and other providers directly into their own platforms (NSDL Network, 2012a). In effect, this effort, like NSDL on iTunes, will integrate NSDL services into other environments rather than integrating other services into NSDL.

Key Findings and Chapter Conclusions

The evidence we reviewed in this chapter showed that projects in the Services track created a wide range of interesting services and tools, but other NSDL tracks also contributed to the mix. There were marked differences in sustainability for key tools and services compared with smaller service projects. Key services enjoyed extended funding and showed relatively stable usage for several years. However, most of the smaller projects we investigated appeared to have developed tools that were used in just a few sites or repositories, and our preliminary evidence suggested that many services were only partially completed or were not completed at all. Even the key user services appear to be winding down; many have been decommissioned, partly because the NSDL program has ended, but also in some cases because new external tools and services appear to have overtaken them.

Project abstracts indicate both redundancy and gaps in service provision. In spite of the wide range of services and tools that were developed by NSDL projects, some areas, such as annotation services, might have been the focus of too many projects. The abstracts we reviewed suggested that a number of projects “rediscovered the wheel” rather than adopting an existing service and building on it. Based on anecdotal information, it appears that some service areas were relatively unexplored, but a much more comprehensive analysis is needed to draw conclusions about gaps in development of services.

The degree of integration of services with the NSDL technical infrastructure was variable. In terms of collaborative development, our broad review of NSDL Services projects indicated that roughly half of those we sampled intended to develop integrated services that would use the NSDL infrastructure and also add new tools to be shared by future users and developers. However, a surprising number of smaller projects planned to develop services that would not be integrated into the NSDL technical infrastructure. The key tools and Services projects, on the other hand, all planned to integrate their products into NSDL and were generally successful in doing so. This is likely because most of the services were developed by the CI track (and later the RC and TNS tracks) rather than by projects in the Services track.
The NSDL on iTunes project also expanded the idea of integration in an innovative way, by successfully integrating NSDL content in a broadly used platform outside the NSDL infrastructure. Given the range of widespread platforms, such as Facebook and Twitter, this is an approach that NSDL, as well as other cyberlearning programs, can explore in the future.

**Additional methods and measures are needed to evaluate tools and services.** As we noted at several points in this chapter, our analysis of NSDL services was limited, and therefore many of the conclusions discussed here should be considered tentative. The data collection and analysis of NSDL tools and services could be improved in several ways, which would lead to more-complete answers both to questions related to service outputs and outcomes, particularly outcomes related to learning and teaching impacts, and to answers related to the community-based or collaborative processes through which services were developed. Extensions could include

- reviewing all service projects rather than just samples, including developer and user tools
- developing complete taxonomies of types of services and tools
- expanding the secondary data set for projects by reviewing their annual reports and by commissioning assessment of services by subject-matter experts
- obtaining more-comprehensive primary data for each project by interviewing or surveying project managers, service developers, and users.

Text mining tools can facilitate the first three extensions, in particular, because such tools can be applied to unstructured textual data—such as project abstracts, annual reports, and web pages—to quickly uncover patterns related to the types of services being developed by projects, the frequency with which project services are being mentioned and used in the cyberlearning community, and the impact of their scholarly publications. Thus, in the future it should be possible to conduct a rich yet cost-effective analysis of the digital tools and services produced by hundreds of program projects.

The NSDL program has ended, so addressing questions related to its services in depth may be of limited value. However, we expect that many of the same questions about digital tools and services are or will be germane to other cyberlearning programs at NSF and to other federal agencies and nonprofit foundations. Although few future programs may have as their primary mission the development of a nationwide distributed educational digital library, many cyberlearning programs will likely fund the development of educational digital collections and services that enable a targeted community of users and developers to make effective use of those resources. Program officers, therefore, will want to be able to catalog these services, monitor their development, and understand their impact.

Future cyberlearning programs will also need to touch on several of the broad themes related to services that were discussed earlier. One relates to the trade-offs inherent in trying to control the digital resources and services being developed by projects, to ensure that they reuse materials
where possible, while trying to foster innovation and creativity in the generation of cutting-edge cyberlearning services. A related theme is the costs and benefits of developing services on a common infrastructure and using shared tools. The benefits in terms of efficiency appear obvious, yet such development, based on our limited data of the NSDL program, was the exception rather than the rule. These themes and others related to future cyberlearning programs will be discussed in the final chapter of this report.
In this chapter, we report on two studies we conducted to assess the usability of the NSDL portal and some of its pathways. The studies focused on the searchability and quality of NSDL resources for STEM teaching. In the first study, we conducted a pilot study in which a library search expert evaluated the configuration and implementation of the NSDL’s search service in comparison to a general search engine (Google). In the second study, we designed a usability experiment with preservice educators to assess the effectiveness and usefulness of NSDL metadata for middle-school STEM lesson planning. The usability study expanded on a pilot study conducted in our Phase 2 evaluation (Bikson et al., 2011) and is similar to that used by Khoo (2006), which is discussed below.

As described in Bikson et al. (2011), in usability testing, potential users exercise a system in realistic contexts (Nielsen, 1994), often performing specific, predetermined tasks that closely mimic ways in which the tools would be used in real settings. For digital libraries, usability testing typically involves such tasks as finding particular items or types of items in the library (e.g., a particular eBook, or any eBook on a particular topic), finding information about items (e.g., the year in which the eBook was published), and using those items (e.g., checking out the eBook and reading it) (Jeng, 2005b; Kim and Kim, 2008). Several types of data can be collected to assess usability, including web and computer logs of users’ activities, survey questions of users’ experiences, focus group discussions (Jeng, 2005a), heuristic evaluation by experts, cognitive walk-throughs, action analysis, and thinking aloud (Holzinger, 2005).

Our studies build on earlier efforts to evaluate usability in the context of NSDL. Sumner et al. (2003) conducted a usability study of DLESE, an NSDL pathway, with K–gray educators to understand their expectations and needs for digital resources in the classroom. That study offered insights into educators’ perceptions of quality, scientific accuracy, bias, advertising, design and usability, and other aspects of digital libraries. In McCown, Bollen, and Nelson (2005), public school teachers evaluated 38 search terms and search results from Google and NSDL, but participants were naive to the website used for the search. Khoo’s usability study (2006), on which our experiment is based, asked participants to complete a series of simple search tasks using a paper prototype of the NSDL’s search tool. Participants were asked to think aloud during the tasks, to explain their experiences to an observing researcher, and then to complete a survey about the importance of various search features.

For each study, we describe the goals and method and then discuss results and implications.

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12 Khoo (2006) reported that a few earlier usability evaluation studies of NSDL had been undertaken, but these appear to have been informal, and the results were primarily for internal use and not published.
Study 1: Evaluation of Search Facility Performance Based on Expert Analysis

Relevance and Efficiency of the Search

The sustainability of a repository such as the NSDL portal depends in large part on its search capability, including the relevance of results (i.e., how precisely they respond to the searcher’s query) and the efficiency of the search, including the order in which results appear (i.e., whether the most-relevant results are at the top of the search). As Arguello (2013, p. 61) noted, “users rarely navigate beyond the first page of results [and] users may not even look at results below ‘the fold.’” Based on McCown, Bollen, and Nelson (2005), we measured the precision of the search results, defined as the percentage of relevant resources to total resources returned from a search. We also used another common measurement for search precision or relevance, cumulative gain, and its corollary, discounted cumulative gain. Cumulative gain is a standard strategy for assigning degrees of relevance search results (Dupret, 2011; Järvelin and Kekäläinen, 2002; Roelleke, 2013).13

The NSDL portal uses Lucene, an open-source Apache search engine, as the core of its discovery service. It is lightweight yet provides considerable flexibility to configure the search engine relevance for search rankings. As configured for NSDL, a resource is ranked by the number of times search words appear in it, and the appearance of search words in short fields or in the title of a resource is weighted more heavily than ones appearing elsewhere in the resource.

Authoritativeness of the Results

Even if search resources are relevant and easy to find, users must also find them credible or authoritative. Authoritativeness can be attributed to the resource creator or host, in addition to being attributed to the collection (Xie, 2006; Xie 2008); it engenders trust in the resource and is an increasingly important measure of information retrieval effectiveness (Abdul-Rahman and Hailes, 1999; Karlgren, 2008; Ramachandran et al., 2009). The trustworthiness of the resource is particularly important on the web, where anyone can be an author and where a for-profit business model can mean that a site is cluttered with ads or incentives to buy a professional version of the resource.

13 Unlike the McCown, Bollen, and Nelson (2005) study, we assessed relevance to the subject matter of the search rather than the educational usefulness of the resource. This difference in approach was dictated by our methodology, which involved a librarian expert searcher who has developed, evaluated, and implemented search tools and services, and because our focus was on the performance of the search engine rather than the interaction of the search engine with its intended audience of STEM educators.
Application of These Criteria to Our Study

We applied these criteria to search results from the perspective of a library search expert who has substantial expertise in digital collection building, repositories, metadata, and digital rights management. The expert rated the results of a sample of ten representative searches for STEM content, using both the NSDL portal and Google. The first ten results of each search were rated in terms of relevance, ranking or order (i.e., how early in the results relevant documents appear), and authoritativeness.

It is common practice in libraries to rank results more highly based on controlled vocabulary values in metadata elements that are used for filtering searches, such as educational level or format. In other words, if a searcher types the key word volcanoes and selects the educational level “middle school,” a result with the key word volcanoes and the metadata element “educational level” containing the value “middle school” should rank more highly in the results list than a record with no educational level in the metadata element or a resource with the term middle school appearing as a key word elsewhere in the resource. In the Phase 2 assessment (Bikson et al., 2011), we concluded that key filtering elements—such as audience (educational level), resource type or genre, and physical format—were inconsistently applied in metadata and lacked common terminology, (i.e., a controlled vocabulary) across the NSDL portal and pathways, posing a significant problem for collection usability. We recommended that these filtering elements use a common vocabulary that reflects educator terminology and is consistently and rigorously applied. We also recommended providing, at a minimum, the ability to filter by educational level in the top-level simple search, which was also recommended by McCown, Bollen, and Nelson (2005).

Metadata and search functionality in the current NSDL portal are now aligned with these recommendations. However, it is not evident from the description of relevance ranking provided to searchers (NSDL, n.d.-b) that the presence of filtering-element metadata corresponding to the filter set by the searcher is used in relevance ranking. Therefore, we also examined whether the use of filters improved the relevance of results from NSDL searches.

Method

Search Tasks

As shown in Table 6.1, we developed ten educational workflow search conditions to simulate common searches for STEM lesson planning. Six of the searches focused on topic (e.g., climate

14 Our expert has written principles and requirements for developing a persistent and usable digital collection for a guideline of the National Information Standards Organization (NISO). She has served as principal architect for several grant-funded digital collection building initiatives at the international, national, state, and local levels; she has served as a consultant for metadata strategy for the Library of Congress, the Corporation of Public Broadcasting, and the Disney Corporation, among others; and she has authored two books on digital rights management and metadata.
change), two focused on contemporary science authors (Neil DeGrasse Tyson and Sylvia Earle), and two focused on titles (e.g., Ocean in a Bottle). Searches were conducted in the NSDL portal and in Google as key word searches. Key words were typed as a simple string in each search box, with no use of quotation marks to create phrases for searching and no use of Boolean operators (and, or, not). The first ten results for each search condition were scored as described in the next section. We then conducted a second search of the NSDL collection, applying NSDL filtering elements rather than entering the filtering element in the key word string (e.g., rather than entering volcano eruption simulation middle school, we searched using volcano eruption simulation and applied the NSDL drop-down filter to select middle school for educational level). The last table column shows the NSDL filtering elements used for the second NSDL search.

Table 6.1. Search Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Search Condition</th>
<th>Type of Search</th>
<th>Key Words Used</th>
<th>NSDL Filtering Element Useda</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Simulation of a volcano eruption for a middle school audience</td>
<td>Topic</td>
<td>volcano eruption simulation middle school</td>
<td>educational level = middle school</td>
</tr>
<tr>
<td>2</td>
<td>Classroom activity to demonstrate probability to a middle school audience</td>
<td>Topic</td>
<td>probability classroom activity middle school</td>
<td>educational level = middle school; resource type = instructional material</td>
</tr>
<tr>
<td>3</td>
<td>A classroom activity for high school using data to demonstrate the effect of climate change on sea level</td>
<td>Topic</td>
<td>sea level climate change data classroom activity high school</td>
<td>educational level = high school; resource type = data set, instructional material</td>
</tr>
<tr>
<td>4</td>
<td>Classroom activity to demonstrate pattern recognition in middle school mathematics</td>
<td>Topic</td>
<td>pattern recognition mathematics classroom activity middle school</td>
<td>educational level = middle school; resource type = instructional material</td>
</tr>
<tr>
<td>5</td>
<td>Photograph demonstrating animal camouflage to incorporate on a homework sheet</td>
<td>Topic</td>
<td>animal camouflage photograph</td>
<td>resource type = audio/visual</td>
</tr>
<tr>
<td>6</td>
<td>Biography of Marie Curie</td>
<td>Topic</td>
<td>Marie Curie biography</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Works by Neil DeGrasse Tyson</td>
<td>Author</td>
<td>Neil DeGrasse Tyson</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Works by Sylvia Earle</td>
<td>Author</td>
<td>Sylvia Earle</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>“Ocean in a Bottle”</td>
<td>Title</td>
<td>ocean in a bottle</td>
<td>N/A</td>
</tr>
<tr>
<td>10</td>
<td>“Percent Shopping”</td>
<td>Title</td>
<td>percent shopping</td>
<td>N/A</td>
</tr>
</tbody>
</table>

NOTE: N/A = not applicable.

a Applies only to search conditions 1 through 5.

b “Percent shopping” is a title of a resource describing an activity in which students calculate discounts when shopping for items.
Scoring

Relevance

We assessed relevance using a four-point scale, where 0 = not relevant, 1 = somewhat relevant, 2 = relevant, and 3 = very relevant. We calculated cumulative gain for each search condition by summing the relevance ratings across all ten results. Therefore, relevance scores for each condition could range from 0 to 30.

Relevance was determined by judging

- the degree to which the result matched the task (e.g., for condition 1, searching for a simulation of a volcano, did the result provide a simulation, such as a video or instructions for creating a simulation using baking soda and vinegar?), as well as the extent to which the key words searched appeared in the resource metadata, description, or resource top page
- whether the result matched the target audience (e.g., middle school students)
- how easy or difficult it was to find the resource within the search result (e.g., is the resource discoverable on the first page of the source identified in the result or linked from that page?).

Although the last criterion is not about the precision of the resource per se, it affects relevance in that, if the resource is difficult to find, teachers are unlikely to expend the effort to discover it.

To assess ranking, we documented the order in which each of the ten results occurred. Here, we calculated discounted cumulative gain, which discounts or penalizes the sum of the relevance scores (cumulative gain) to reflect where the results occur in the list. As Arguello (2013) noted, in discussing the utility of discounted cumulative gain, “a relevant document’s usefulness decreases exponentially with rank.” We used a log factor of 2, as recommended by Arguello (2013), to discount relevance based on rank.\(^{15}\)

For NSDL, we also did a second search to evaluate the impact of filtering elements on the relevance of results from topical searches (i.e., conditions 1–5). We applied appropriate filters to the first five results from each of these five search conditions and compared ratings of cumulative gain and discounted cumulative gain for the results from key word–only searches in NSDL and Google.

Authoritativeness

Finally, we evaluated and scored each result for the authoritativeness, or trustworthiness, of the host site by making judgments about several criteria: reputation of host organization; objectivity of the host site (whether or not it espouses a particular point of view, such as a

\(^{15}\) The discount factor is \(1/\log_2 i\) (where \(i = \text{rank}\)). For each rank below the rank of 1, the relevance for each result is multiplied by the discount factor to provide the discount gain. For example, a resource at rank 5 (fifth in a list of the first ten resources in a results list) with a relevance score of 2 is discounted through this process to a relevance score of 0.86, while a resource at rank 6 is discounted to a relevance score of 0.77.
political stance); and the degree to which the site was commercial in nature (by presenting ads or providing lesser or “lite” services at no cost, with incentives for the user to ramp up to a subscription-based service). We used a four-point scale similar to the one for relevance, where 0 = not authoritative or trustworthy to 3 = very authoritative or trustworthy. When a link was broken, we assigned an authoritativeness score of 0 because the site could not be evaluated for trustworthiness and because a broken link can be viewed as breaking the user’s trust.16

Relevance and authority do not tell the whole story of a successful search experience. Two additional points were highlighted in our study. First, we comment on how the presentation of the results (i.e., graphical display or text) may influence identification and selection of resources. Second, we note the range of media found in search results; in particular, material published in social media may be valued by the current generation of users for its currency and because such media often provide opportunities for interaction with scientific authors and peers.

Results

For title searches, the expected title appears first in the search results for both NSDL and Google. No further analysis was conducted for title searches (conditions 9 and 10).

Relevance

In relation to the relevance of search results (without the use of NSDL filters), Google outperformed NSDL in six of the eight searches after conditions 9 and 10 were eliminated. Table 6.2 shows the total relevance scores for NSDL and Google for topic and author searches. Results show that NSDL and Google produced comparable or similar results for conditions 4 and 7; for the remaining search tasks, Google outperformed NSDL, with difference scores ranging from 7 to 26. The cumulative gain for the eight searches was 124 for NSDL and 203 for Google. The total score for NSDL was 39 percent lower than the score from Google, showing that NSDL produced much less relevant results. Similarly, using a different approach for ranking relevance, McCown, Bollen, and Nelson (2005) found that teachers rated educational resources resulting from Google searches as more relevant than resources found via NSDL.

16 Ratings of resource relevance were not penalized for broken links, because search applications do not validate links—i.e., do not indicate whether specific resources are still available. Relevance was rated based on the metadata for the resource and the appearance of key words in the top page of the resource, with the proviso that the top page of a result could not be evaluated for relevance and appearance of search key words for resources with broken links.
Table 6.2. Comparative Relevance of NSDL and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>Cumulative Gain</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSDL</td>
<td>Google</td>
<td></td>
</tr>
<tr>
<td>1 (topic)</td>
<td>16</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>2 (topic)</td>
<td>11</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>3 (topic)</td>
<td>15</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>4 (topic)</td>
<td>20</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5 (topic)</td>
<td>4</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>6 (topic)</td>
<td>13</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>7 (author)</td>
<td>28</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>8 (author)</td>
<td>17</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>124</td>
<td>203</td>
<td></td>
</tr>
</tbody>
</table>

NSDL’s relevance scores improved when filters were applied. Table 6.3 shows the relevance scores for topical searches (conditions 1–5 in Table 6.3) after applying NSDL filters. Results show considerable improvement when filters are applied to the NSDL search, although relevance remained higher for Google overall. The cumulative gain score for NSDL filtered searches was 23 percent lower than Google, compared with 39 percent lower without filters. Results from only one search in NSDL (condition 2) were rated higher than results from Google.

Table 6.3. Comparative Relevance of NSDL, NSDL Filtered Search, and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>Cumulative Gain</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NSDL</td>
<td>NSDL Filtered</td>
</tr>
<tr>
<td>1 (topic)</td>
<td>16</td>
<td>19</td>
</tr>
<tr>
<td>2 (topic)</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>3 (topic)</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>4 (topic)</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>5 (topic)</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>TOTAL</td>
<td>66</td>
<td>95</td>
</tr>
</tbody>
</table>

NSDL’s relevance score improved only slightly when the order of results was considered. Table 6.4 shows the discounted cumulative relevance score, which adjusts the relevance score according to the order in which results appear. The comparison of NSDL with Google (Table 6.4) shows minor improvement in relevance for NSDL, with a total score that is 35 percent lower than the Google score.
Table 6.4. Discounted Cumulative Gain of NSDL and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>NSDL</th>
<th>Google</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (topic)</td>
<td>9.09</td>
<td>13.45</td>
</tr>
<tr>
<td>2 (topic)</td>
<td>8.27</td>
<td>14.63</td>
</tr>
<tr>
<td>3 (topic)</td>
<td>7.59</td>
<td>11.93</td>
</tr>
<tr>
<td>4 (topic)</td>
<td>10.07</td>
<td>9.79</td>
</tr>
<tr>
<td>5 (topic)</td>
<td>3.30</td>
<td>15.76</td>
</tr>
<tr>
<td>6 (topic)</td>
<td>9.68</td>
<td>13.1</td>
</tr>
<tr>
<td>7 (author)</td>
<td>14.50</td>
<td>14.73</td>
</tr>
<tr>
<td>8 (author)</td>
<td>7.22</td>
<td>14.22</td>
</tr>
<tr>
<td>TOTAL</td>
<td>69.72</td>
<td>107.61</td>
</tr>
</tbody>
</table>

When both ranking and NSDL filters are considered together, the NSDL relevance rankings are closer to those of Google. Table 6.5 shows discounted cumulative gain scores for results from the NSDL filtered search and Google. Results show much closer relevance scores. When filters are used and when ranking or order of results is considered, the discounted cumulative gain for NSDL is only 16 percent less than Google, demonstrating that relevant results in a filtered search appear much higher in the results set.

Table 6.5. Discounted Cumulative Gain of NSDL, NSDL Filtered Search, and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>NSDL</th>
<th>NSDL Filtered</th>
<th>Google</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (topic)</td>
<td>9.09</td>
<td>11.03</td>
<td>13.45</td>
</tr>
<tr>
<td>2 (topic)</td>
<td>8.27</td>
<td>13.87</td>
<td>14.63</td>
</tr>
<tr>
<td>3 (topic)</td>
<td>7.59</td>
<td>9.69</td>
<td>11.93</td>
</tr>
<tr>
<td>4 (topic)</td>
<td>10.07</td>
<td>11.18</td>
<td>9.79</td>
</tr>
<tr>
<td>5 (topic)</td>
<td>3.30</td>
<td>9.19</td>
<td>15.76</td>
</tr>
<tr>
<td>TOTAL</td>
<td>38.32</td>
<td>54.96</td>
<td>65.56</td>
</tr>
</tbody>
</table>

Authoritativeness

In terms of authoritativeness, NSDL scored well in comparison with Google. Scores for the authoritativeness of the results are shown in Table 6.6. The rankings have now been reversed, with the NSDL results rated as more authoritative than Google results. However, NSDL’s grade of 90 percent falls short of a perfect score, which should be the aim of a portal that purports to offer “high-quality online educational resources” (NSDL, n.d.-a). Five of the 80 links found through NSDL were broken, so 63 percent of the difference in authoritative scores between NSDL and Google was due to broken links.
Table 6.6. Comparative Authority of Results—NSDL and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>NSDL</th>
<th>Google</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (topic)</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>2 (topic)</td>
<td>27</td>
<td>21</td>
</tr>
<tr>
<td>3 (topic)</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>4 (topic)</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>5 (topic)</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>6 (topic)</td>
<td>24</td>
<td>9</td>
</tr>
<tr>
<td>7 (author)</td>
<td>27</td>
<td>17</td>
</tr>
<tr>
<td>8 (author)</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>TOTAL</td>
<td>216</td>
<td>155</td>
</tr>
</tbody>
</table>

Filtered searches also improved NSDL’s ranking for resource authority, as Table 6.7 demonstrates, although the gain is modest.

Table 6.7. Comparative Authority of Results—NSDL, NSDL Filtered, and Google

<table>
<thead>
<tr>
<th>Search Condition</th>
<th>NSDL</th>
<th>NSDL Filtered</th>
<th>Google</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (topic)</td>
<td>28</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>2 (topic)</td>
<td>27</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>3 (topic)</td>
<td>25</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>4 (topic)</td>
<td>30</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>5 (topic)</td>
<td>25</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>TOTAL</td>
<td>135</td>
<td>139</td>
<td>103</td>
</tr>
</tbody>
</table>

* The score for NSDL filtered results is lower for condition 2 because of an additional broken link in the set of results.

Presentation of Search Results and Gaps in Web Search Results

**Google performed better than NSDL did in the presentation of graphical search results.** The way results are displayed plays an important role in the user’s ability to identify and select relevant resources. This was particularly apparent in search condition 5, “photograph demonstrating animal camouflage to use on a homework sheet,” which was a graphical search. Google excels in such searches, as Figure 6.1 illustrates, whereas NSDL produces only text descriptions of links to other sites (Figure 6.2). Displaying the images enables the searcher to select the appropriate graphical resource directly from the results set, thus eliminating a cumbersome step.
Figure 6.1. Google Result Set for Animal Camouflage Photograph

Google also searches social networking sites, whereas NSDL does not. For example, for condition 2, “classroom activity to demonstrate probability to a middle school audience,” Google returned a link to a Pinterest site, compiled by a teacher, that shows several online activities at a glance. This resource was returned because Google searches the web generally and thus can find resources in social networking sites, whereas NSDL does not. Consequently, Google searches a much broader range of web sources than NSDL does, including new forms of web publication, such as social networking sites and other dynamic content areas. We discuss the benefits and disadvantages of indexing personal resource collections and making them accessible in Chapter Eight.

Study 2: Experimental Simulation

In our second study, a usability experiment, we asked preservice educators (i.e., undergraduate and master’s students in education and library science)—who are current and future end users of NSDL, its pathways, and other repositories—to search for STEM resources to use in lesson planning. The goal was to determine whether NSDL or the pathways were better at meeting certain types of needs. We asked study participants to perform several tasks, which varied in resource content, media type, and focus to represent a range of resources that teachers might seek.
Findings for the Phase 2 Pilot

The usability experiment was based on a Phase 2 pilot trial (described in Bikson et al., 2011) in which 30 preservice teachers conducted search tasks for materials to plan a lesson on plate tectonics for eighth graders. In the pilot, participants were assigned to one of four starting points: (1) NSDL.org, (2) a domain-specific site (DLESE), (3) a grade-specific site (Middle School Portal 2 [MSP2]), and (4) a general search site (Google). The participants were then asked to complete four search tasks to find different kinds of resources: (1) text plus image, (2) video or animation, (3) interactive activity, and (4) material about how the theory of plate tectonics was discovered or applied. They were then asked a series of questions regarding each task and the overall experience (e.g., ease of using the site, amount of time required, quality of resources).

Key Phase 2 results included the following:

- On average, participants found more resources, and more-diverse resources, when using Google than when using NSDL, DLESE, or MSP2.
- Participants found more resources for text plus image and for interactive activity than for video and animation.
- Different sites led participants to different resources—e.g., resources reported by DLESE and MSP2 users were only sometimes in the set of resources reported by NSDL users, and resources found by DLESE, MSP2, and NSDL users were only sometimes in the set of resources reported by Google users.
- Responses to post-task questions varied as a function of the task. There were few differences in ratings of sites for text plus image, with the exception of plentifulness of resources (with Google outranking the other sites). Pathway portals (DLESE and MSP2) appeared more favorable than Google and NSDL across most ratings for video or animation and interactive activity, and MSP2 was rated lower across most dimensions for the application task (task 4). Overall, participants appeared most satisfied with DLESE and least satisfied with MSP2; the latter may be due to a large number of broken links that participants encountered. While participants were generally satisfied with NSDL and Google, many commented that these sites produced too many resources through which to sift.

Discussions with study participants also pointed to recommendations for a larger usability study, such as providing participants with a practice session to get acquainted with their starting sites. We implemented this and other modifications in the Phase 3 study.

Design of the Phase 3 Usability Experiment

As in the Phase 2 pilot, the Phase 3 study design was shaped by the broad goal of understanding how the NSDL portal and its component pathways and collections could support teachers’ planning efforts and ultimately support teaching and learning. We sought to answer three questions:
• How and how well do the NSDL portal and the pathways support teachers’ efforts to find appropriate STEM resources for use in the classroom?

• Is the success in finding STEM resources affected by the user’s starting point (NSDL.org versus a grade-level–specific or content-domain–specific pathway), the type of resource sought, or the content domain?

• How does success in finding resources using NSDL sites compare with use of a general search engine (Google)?

We focused our analysis on objective measures resulting from search tasks, such as the number of URLs found. To assess the trustworthiness of results, the library search expert from the first study conducted independent evaluations of the authoritativeness of the organizations associated with the host URLs found by participants. We did not investigate users’ opinions about the search experience, for reasons discussed in Chapter One.

Method

The study was designed around a hypothetical lesson plan development effort for eighth-grade science. We chose an eighth-grade scenario for several reasons. First, middle school courses are important in making the transition to more-advanced and differentiated STEM learning in high school and beyond. Second, the development of an improved middle school pathway presents an opportunity to explore whether there are usability differences as a function of grade-level orientation versus subject-matter domain, in comparison to generic starting points, for acquiring good teaching resources. Finally, eighth grade is of particular interest because the Trends in International Mathematics and Science Study (TIMSS), National Assessment of Educational Progress (NAEP), and other major learning assessments sample this grade. We retained the earth science domain and expanded on the pilot by adding a second subject domain, physical science, with tasks modeled after those used for earth science.

Participants

Participants were 164 students (primarily graduate and advanced undergraduate students in education or library science) from three universities. The majority of participants ($n = 131$) came from site A; the remainder came from site B ($n = 23$) and site C ($n = 10$). At sites A and B, participants were recruited by email messages posted to lists of target student populations and through contact with relevant faculty who were asked to publicize the study and encourage participation; some participants heard about the study through word of mouth. As a result, we cannot calculate participation rates because we do not have an accurate estimate of the total number of prospective participants who were contacted. Participants from site C were recruited from a graduate education course of 15 students, yielding a participation rate of 67 percent. Students were given a $25 gift card for taking part in the study.
Design

The study used a 2 (domain) × 4 (starting point) × 4 (task) design. Domain and starting point were between-subjects factors (i.e., participants were assigned to only one domain and starting point), and task was within subjects (i.e., all participants completed all four tasks). There were 20 to 23 participants in each domain × starting point condition.

Domain

Participants were randomly assigned to one of two domains, plate tectonics or physical science, with a focus on Newton’s laws of motion. We used several criteria in selecting these units:

1. The unit must be part of a course that is typically required for middle school students.
2. The unit must be associated with learning objectives that typically are part of states’ science standards for that course.
3. There must be a pathway dedicated to that course unit.
4. There must sufficient and diverse resources addressing that unit in the chosen pathway and on NSDL.org.

The first two criteria helped ensure that the study broadly represented the needs and practices of middle school teachers. The last two ensured that the topic was well represented so that a usability trial was feasible and appropriate and so that we could design diverse and realistic tasks for participants to complete. The criteria also ensured that we could compare grade-oriented pathways (specifically, MSP2, which focuses on all STEM topics taught in middle school), subject-oriented pathways (which vary based on the subject chosen), and NSDL.org.

Starting Point

Participants were randomly assigned to one of four starting points for their searches: NSDL.org, a domain-specific site (DLESE for earth science and ComPADRE for physical science), a grade-level specific site (MSP2), or a general search engine (Google). Each participant was asked to complete search tasks within their assigned domains.

Tasks

Each participant completed four search tasks: (1) text plus image; (2) video or animation; (3) interactive activity, such as an online game; and (4) inquiry-based learning activities, ideally involving hypothesis testing or active or experiential learning. The first three tasks were the same as those used in the pilot trials. We replaced the fourth task from the pilot trial (discovery or application of theory) with inquiry-based learning, as the latter was becoming an increasingly important part of science curricula.
Procedure

Our study protocol followed the pilot trial, which was based on usability frameworks developed in the literature and on our task framework and design decisions. The protocol was computer-based, with each participant completing the tasks independently.

Participants were asked to imagine that they were eighth-grade science teachers seeking good online resources with which to build a lesson plan that introduces students to plate tectonics (earth science) or Newton’s laws of motion (physical science). Participants were subsequently led through the search tasks, starting with a practice task to gain familiarity with the website, followed by the four experimental tasks. Participants were told that, while they should start at their assigned websites, the resources they might find could be from linked websites. After finding resources that the participants deemed appropriate, they copied the URLs for each web page to the online form and provided a label for each page. The tasks were the same in both domains and were assigned in the same order. Participants were given a fixed amount of time, ranging from five to eight minutes, for each task. To more closely simulate the goals and constraints of real teachers—the need for high-quality resources and limited time to find them—we encouraged participants to find good resources and provide the best examples, gave them the option of indicating that they found no suitable resources, and required them to remain on a task until the full time had expired. Overall, the procedure required approximately one hour.

Results

Quantity of Resources Found

We analyzed the number of websites found using repeated measures analysis of variance (ANOVA), repeated over the four tasks. Denominator degrees of freedom varied because of a small number of missing responses.\(^\text{17}\) Results are shown in Figures 6.3–6.8.

Participants had an easier time finding resources for some tasks than others. Results show a statistically significant effect for task,\(^\text{18}\) indicating that it was easier to find resources for some tasks than others (see Figure 6.3). Participants identified the most text plus images and the fewest interactive activities.

\(^{17}\) We analyzed number of URLs using a 2 (domain) × 4 (starting point) repeated-measures ANOVA, repeated across tasks. Degrees of freedom for within-subjects effects were adjusted for nonsphericity using a Huynh-Feldt-Lecoultre correction. Post-hoc paired comparisons were conducted using a Tukey correction. Also, there was an interaction of location and task, such that participants in site B identified more URLs for the image-plus-text task than did participants in the other two sites, and site B students identified more URLs for the inquiry task than did students in site A. There were no interactions of location with domain or starting point and no three-way interactions; therefore, we did not estimate effects for location in subsequent analysis.

\(^{18}\) $F(3,468) = 86.07, p < 0.001$. 
There was also an interaction of task and domain, as indicated by the pairs of columns in Figure 6.3.\textsuperscript{19} Although earth science resources were generally more plentiful than were physical science resources, paired comparisons show a statistically significant difference between domains only for the video-or-animation task.

![Figure 6.3. Mean Number of URLs by Domain and Task](image)

For the more-difficult tasks, participants using Google found more resources than did participants using other starting points. The main effect of starting point was not statistically significant, but there was an interaction between starting point and task (see Figure 6.4).\textsuperscript{20} A planned contrast between Google and NSDL-funded sites showed that participants found more resources using Google compared with NSDL, MSP2, and the domain-specific websites for the video-or-animation and interactive-activity tasks—which presumably were the more difficult tasks, as suggested by the average number of resources found across tasks.\textsuperscript{21}

The interaction of domain, starting point, and task was not significant.\textsuperscript{22}

\textsuperscript{19} $F(3,468) = 4.10, p < 0.05$.  
\textsuperscript{20} $F(9,468) = 2.11, p < 0.05$.  
\textsuperscript{21} For the video/or-animation task, $F(1) = 7.43, p < 0.01$. For the interactive activity task, $F(1) = 12.95, p < 0.001$.  
\textsuperscript{22} $F(9,468) = 1.92$.  

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Diversity of Resources Found

Next, we examined whether the starting points affected the diversity of host websites. Given that there were few effects for domain, we combined results across earth sciences and physical sciences for our remaining analyses.

**Google led to the widest range of results, followed by NSDL.** Figure 6.5 shows the total number of different host URLs from which resources were selected for each task and starting point. The patterns show far more unique sites when using Google compared with the other starting points for all tasks, followed by NSDL for three of the four tasks.

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23 Here we analyzed the top-level host or site—e.g., teachersdomain.org or ehow.com—rather than the specific pages or resources within each host.
Figures 6.6 and 6.7 show the distributions of the number of different host websites returned for one of the “easier” tasks (text plus image; Figure 6.6) and one of the “harder” tasks (interactive activity; Figure 6.7), combined across domains. Graphs show results for each starting point. The y-axis reflects the number of pages or specific URLs viewed within different sites or host URLs, and the x-axis represents the ranking of the different sites or host URLs, ordered by the number of page views. Focusing on the y-axis of Figure 6.6, for the grade-level starting point (MSP2), 25 pages were viewed in the most frequently selected host URL (www.pubs.usgs.gov), whereas, in Google, the most frequently selected host URL (for teachertech.rice.edu) had 16 pages viewed. The most frequently selected host URL in both the domain-specific websites and NSDL.org was Teacher’s Domain, with 19 and 18 hits, respectively. Focusing on the x-axis of Figure 6.6, MSP2-starters accessed the fewest number of different host URLs (n = 44), and Google-starters accessed the greatest number (n = 89). The tails of the distributions also show that roughly half of the unique host URLs within starting points were selected only once in NSDL, the domain-specific starting points, and Google. The greater number of one-off results in Google may indicate more variability in resource quality, which we address later in this chapter.
In Figure 6.7, the pattern of unique URLs is similar but more compressed, as there were fewer resources found for interactive activities. Page views were still skewed for each starting point, heavily favoring a relatively small number of sites. Participants accessed fewer total sites or host URLs, and the number of pages viewed per site was generally less than for the text-plus-image task. Findings differed slightly in that participants in the NSDL starting point had the smallest maximum page views (nine) compared with the other starting points. For the text-plus-image task (Figure 6.6), the highest-ranking NSDL starting point site had 18 page views.
These results led us to examine the extent of the overlap of resources found via the different search facilities. Table 6.8 lists the percentage of unique host URLs reported by participants assigned to a particular starting point (in columns) that were also reported by participants assigned to other starting points (in rows), combined across tasks and domains.\textsuperscript{24} For example, 47 percent of the total host resources reported by domain-specific participants were also reported by one or more NSDL participants, whereas 42 percent of the resources reported by NSDL participants were also reported by one or more domain-specific participants.

\textsuperscript{24} If $N$ is the set of unique sites found by NSDL starters and $D$ is the set of unique sites found by domain-specific starters, then the value reported in cell (NSDL, domain-specific) is $\frac{|N \cap D|}{|D|}$. This is the percentage of domain-specific sites that NSDL starters also found. This is not equivalent to the value reported in cell (domain-specific, NSDL), which is the percentage of NSDL sites that domain-specific users also found: $\frac{|N \cap D|}{|N|}$.
Table 6.8. Percentage of Common Resources Found via Different Starting Points

<table>
<thead>
<tr>
<th>Starting Point</th>
<th>NSDL</th>
<th>Domain-Specific</th>
<th>Grade-Specific</th>
<th>Google</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL</td>
<td>47</td>
<td>54</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Domain-Specific</td>
<td>42</td>
<td>41</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Grade-Specific</td>
<td>35</td>
<td>29</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>Google</td>
<td>30</td>
<td>36</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

Overall, the results confirm the findings of the earlier pilot (Bikson et al., 2011), indicating that different starting points lead participants to different resources. Similarly, McCown, Bollen, and Nelson (2005) found limited overlap in results of key word searches for educational content in NSDL and Google. In our study, resources reported by domain-specific and grade-specific users were only sometimes in the set of resources selected by NSDL users, even though the NSDL portal should theoretically include all resources in these pathways. Similarly, resources found by NSDL and pathway users were only sometimes in the set of resources selected by Google users, even though Google should theoretically find all resources on these sites. Differences among the NSDL and pathway starting points above and below the diagonal in Table 6.8 show that NSDL users were more likely to find resources also found by pathway starters than the reverse, suggesting that pathway sites are more discoverable through NSDL than the reverse. Likewise, the differences between common resources found by Google starters and participants in the other starting points above and below the diagonal in Table 6.8 show that Google users were more likely to find resources also found by NSDL and pathway starters than the reverse—suggesting that NSDL and pathway sites are more discoverable through Google than the reverse.25

There are at least two possible explanations for these patterns of findings. First, it may be that users who start in more narrowly focused pathways are better able to target the most-appropriate resources to serve their purposes. This explanation is supported by the distribution of host pathways shown in Figures 6.6 and 6.7. Alternatively, it could be that the more-general starting points, Google and NSDL, by virtue of their broader reach, offer users better resource selection from which to choose. Additional factors to consider have to do with the efficiency of evaluating search results based on the number of retrieved resources and the order in which they are presented to users. These factors were explored in the evaluation of search facility performance described earlier in this chapter.

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25 We do not know whether participants returned to their starting points after identifying each URL or whether they clicked on links found in those URLs.
Authoritativeness and Trustworthiness of Resources Found

An assessment of the most frequently selected host URLs for each starting point across content domains and tasks indicated that results were more trustworthy when users started their searches in NSDL or the pathways than in Google (see Table 6.9). Our expert judge rated the authoritativeness of the top-ten host URLs using the same criteria described in the first study. The expert did not know the starting point used to find these host sites.

Results show that the average rating for host URLs found through NSDL, domain-specific, and grade-specific starting points ranged from 2.9 to 3.0 (out of a maximum of 3.0), whereas the average rating for host URLs identified through Google was 1.2. In addition, six of the top-ten hits selected by NSDL starters were NSDL, pathways, or affiliated sites (see Table 6.9); therefore, we have some confidence that starting with NSDL was most likely to lead searchers to vetted resources. Four of the top-ten sites for domain-specific starting points and four of the top-ten sites for MSP2 starters were affiliated with NSDL, whereas no sites were NSDL-affiliated for Google users. Although we cannot conclude that websites or collections not affiliated with NSDL are not vetted, we do know that this is the case for some of the sites that were selected most frequently by Google users (e.g., youtube.com and quizlet.com). In addition, when users started their searches with Google, results did not include an NSDL-affiliated site until the 11th most frequently visited site.
### Table 6.9. Ten Most Frequently Returned Host URLs in Each Starting Point

<table>
<thead>
<tr>
<th>Starting Point (total number of different host URLs)</th>
<th>Top-Ten Host URLs(^a) (number of times selected)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSDL (142)</td>
<td>1. <a href="http://www.teachersdomain.org">www.teachersdomain.org</a> (86)</td>
</tr>
<tr>
<td></td>
<td>2. src.carleton.edu (62)</td>
</tr>
<tr>
<td></td>
<td>3. ia.usu.edu (45)</td>
</tr>
<tr>
<td></td>
<td>4. <a href="http://www.teachengineering.org">www.teachengineering.org</a> (31)</td>
</tr>
<tr>
<td></td>
<td>5. phet.colorado.edu (19)</td>
</tr>
<tr>
<td></td>
<td>6. msms.ehe.osu.edu (18)</td>
</tr>
<tr>
<td></td>
<td>7. amnh.org (14)</td>
</tr>
<tr>
<td></td>
<td>8. nbclearn.com (14)</td>
</tr>
<tr>
<td></td>
<td>9. ucmp.berkeley.edu (13)</td>
</tr>
<tr>
<td></td>
<td>10. fossils.valdosta.edu (12)</td>
</tr>
<tr>
<td>Domain-specific (129)</td>
<td>1. <a href="http://www.teachersdomain.org">www.teachersdomain.org</a> (121)</td>
</tr>
<tr>
<td></td>
<td>2. <a href="http://www.ComPADRE.org">www.ComPADRE.org</a> (47)</td>
</tr>
<tr>
<td></td>
<td>3. phet.colorado.edu (44)</td>
</tr>
<tr>
<td></td>
<td>4. <a href="http://www.ucmp.berkeley.edu">www.ucmp.berkeley.edu</a> (38)</td>
</tr>
<tr>
<td></td>
<td>5. <a href="http://www.nuffieldfoundation.org">www.nuffieldfoundation.org</a> (29)</td>
</tr>
<tr>
<td></td>
<td>6. physicsclassroom.com (28)</td>
</tr>
<tr>
<td></td>
<td>7. web.ics.purdue.edu (26)</td>
</tr>
<tr>
<td></td>
<td>8. pubs.usgs.gov (24)</td>
</tr>
<tr>
<td></td>
<td>9. beloit.edu (19)</td>
</tr>
<tr>
<td></td>
<td>10. thinkingfountain.org (18)</td>
</tr>
<tr>
<td>Grade-specific (MSP2) (91)</td>
<td>1. <a href="http://www.classzone.com">www.classzone.com</a> (65)</td>
</tr>
<tr>
<td></td>
<td>2. pubs.usgs.gov (43)</td>
</tr>
<tr>
<td></td>
<td>3. msms.ehe.osu.edu (39)</td>
</tr>
<tr>
<td></td>
<td>4. <a href="http://www.learner.org">www.learner.org</a> (38)</td>
</tr>
<tr>
<td></td>
<td>5. learningcenter.nsta.org (37)</td>
</tr>
<tr>
<td></td>
<td>6. phet.colorado.edu (35)</td>
</tr>
<tr>
<td></td>
<td>7. lessonopoly.org (30)</td>
</tr>
<tr>
<td></td>
<td>8. k12science.org (27)</td>
</tr>
<tr>
<td></td>
<td>9. teachersdomain.org (24)</td>
</tr>
<tr>
<td></td>
<td>10. msp.ehe.osu.edu (20)</td>
</tr>
<tr>
<td>Google (240)</td>
<td>1. <a href="http://www.youtube.com">www.youtube.com</a> (56)</td>
</tr>
<tr>
<td></td>
<td>2. tlc.ousd.k12.ca.us (37)</td>
</tr>
<tr>
<td></td>
<td>3. <a href="http://www.internet4classrooms.com">www.internet4classrooms.com</a> (30)</td>
</tr>
<tr>
<td></td>
<td>4. science.discovery.com (29)</td>
</tr>
<tr>
<td></td>
<td>5. quizlet.com (21)</td>
</tr>
<tr>
<td></td>
<td>6. ehow.com (17)</td>
</tr>
<tr>
<td></td>
<td>7. teachertech.rice.edu (17)</td>
</tr>
<tr>
<td></td>
<td>8. enchantedlearning.com (14)</td>
</tr>
<tr>
<td></td>
<td>9. fossilsforkids.com (14)</td>
</tr>
<tr>
<td></td>
<td>10. learner.org (14)</td>
</tr>
</tbody>
</table>

\(^a\) NSDL-affiliated sites are shown in bold. NSDL-affiliated sites include NSDL.org, sites of all of the NSDL pathways, nonpathway NSDL sites that received most of their funding from the NSDL program, sites that are hosted by NSDL.org or a pathway, and sites that are heavily represented at NSDL.org or a pathway and have had some funding from NSF.
NSDL and pathway sites led to a greater number of noncommercial URLs than did Google. Finally, a count of the number of URLs from different Internet domains (.org, .edu, .com, and other—which include .us, .gov, .net, and miscellaneous domains) across study conditions showed a much higher percentage of URLs in .edu and .org domains from NSDL and pathway starting points and a much higher percentage of commercial sites from Google, $\chi^2(9) = 66.14, p < 0.001$; see Figure 6.8 (there were relatively few .gov sites in the results). Although Internet domain does not necessarily reflect content quality, the search evaluation study provides some evidence that resources found on commercial sites may be less trustworthy. Whereas average relevance ratings of the results found in the search evaluation study did not differ significantly based on Internet domain, ratings of authoritativeness did, $F(3,91) = 5.15, p < 0.01$. A contrast showed substantially lower ratings of authoritativeness for resources in .com domains ($M = 1.71$ out of $3.0$) compared with those in .edu, .org, and .gov domains (means ranged from 2.52 to 2.75; $F(1) = 13.23, p < 0.001$). In combination with ratings of authoritativeness of the host URLs, these results suggest that STEM teachers are more likely to find trustworthy resources by searching NSDL or its pathways compared with Google.

**Figure 6.8. Website Domain Type by Starting Point**

[Bar chart showing the percentage of different host URLs by starting point]
Key Findings and Chapter Conclusions

Key Findings

Information retrieval is critical for a collections portal, and the way in which a portal returns and displays results is likely to influence use of its resources. These two simulation studies produced two important findings regarding the authoritativeness and relevance of search results for STEM education.

First, the authoritativeness of NSDL results was judged to be very high. In the expert-analysis study, NSDL results consistently outscored Google’s results on this dimension of quality and reliability (although broken links somewhat diminished the trustworthiness of results found when searching NSDL). Results from the usability experiment converged with these findings. The number of unique host websites, coupled with whether the most frequently returned host websites were associated with NSDL, suggested that users retrieved higher-quality (vetted) resources and more-focused results from the NSDL portal and pathways than from Google. In Google, the large number of host websites and the number of times each site was selected indicated much more variable quality (e.g., YouTube is at the top of the list). Likewise, the degree of overlap in host websites among different starting points in the usability experiment reveals a relatively robust result in that Google is more likely to lead users to NSDL and pathways resources than NSDL and pathways are likely to lead to resources found through Google. Independent expert ratings of the host websites, and the domains (e.g., .edu, .com) associated with host websites, also suggested that NSDL and the pathways yielded more-trustworthy resources.

Second, participants in the usability experiment found more resources using Google compared with NSDL, MSP2, and the domain-specific websites, a finding that was stronger for the more-difficult tasks. These results could indicate that STEM resources are more available or easier to find via Google, or that greater familiarity with Google facilitated more-productive search and retrieval. In the expert analysis, the relevance of results also showed higher scores in Google than in NSDL. Using NSDL top-level filters led to some improvement, but relevance ratings remained lower than those from Google. In addition, NSDL does not take full advantage of the metadata to rank the relevance of search results. It is common in digital library initiatives to rank information provided in metadata fields more highly than key words appearing elsewhere in the resource because metadata generally contain information derived from a review of the resource content, whereas key words are opportunistic and may be used in an irrelevant manner or different context. Rank ordering of search results based on filtering elements, such as educational level and type of resource needed, is also important for scoping a search to key educator workflows. Our search sample, though small, demonstrated the benefits of this approach.
Conclusions

The results of the usability studies are not surprising. Google has a long-established reputation for returning results that are strongly relevant to searches, even when the searches are simple combinations of informal key words, as in our first usability study. Google has invested years of effort and millions of dollars to refine their approach. In comparison, in recent years, NSDL has focused far more on targeting carefully curated collections than on perfecting its search algorithms.

Our evaluation demonstrates that greater configuration of the search utility, particularly to leverage metadata, should have a strong effect on retrieving results that are relevant and authoritative, and thus very useful. Metadata are an important strength of the NSDL portal and are targeted to educator workflows and educational standards. It is also important for NSDL to test any changes in its search facility configuration against Google and other digital portals that might be likely alternatives that educators would choose to obtain digital resources.

Improving the relevance of NSDL’s results while maintaining their authoritativeness is likely to have a positive effect on uptake of NSDL. However, an important conclusion of the first study is that the selection of resources may be hindered by the manner in which they are presented to users. The use of graphical displays, particularly in image searches, may affect whether users decide to view a particular resource. For images and other visual media, NSDL could consider adding graphics to search results, such as thumbnails, which are common in digital repositories. Displaying search results for images, using a presentation similar to that shown in Figure 6.1, would be an important enhancement to consider.

There are several ways in which these usability studies could be improved and extended. Our inferences about resource quality are tentative, as our analyses are based on rating host websites. Although YouTube, for example, has an enormous range in quality and content of resources, some channels are viewed as trustworthy. Future research should systematically review the content of the resources that users find. It also is critical to obtain feedback from users about the search experience. As noted, federal regulations on research limited our ability to investigate users’ views about the search experience.

Additionally, this research could be modified to enhance the generalizability of results. One approach is to leave search time unconstrained to examine how long teachers spend searching for and reviewing resources. If teachers tend to stop after identifying only a few resources or put limited effort into reviewing the resources they find, and if more-systematic evaluation of resources confirms our initial conclusions about resource quality, then results would indicate that using NSDL or its pathways will yield higher-quality resources in the classroom compared with Google. Future research also could ask participants to complete one or more lesson plans to show what resources users select and how they integrate the resources into STEM teaching activities.
The seminal report of the NSF Task Force on Cyberlearning (Borgman et al., 2008, p. 13) made clear that, while both cyberinfrastructure and science learning are high priorities for NSF, “little attention has been paid to the productive intersections between them.” Findings from our earlier formative evaluation of the NSDL program (Bikson et al., 2011) tended to corroborate this view, suggesting that the research program gave substantially greater attention to technology development than to its implementation in actual science-learning contexts. Sociotechnical systems theory, however, emphasizes the significant role of the implementation processes that underpin the intersection of technology development and science learning and in this way enable the technology to transform education.

Preceding chapters of the report assessed the health and sustainability of collections supported by the NSDL program and the digital tools and services that enable users to find, modify, extend, and share them, and this chapter examines full instantiations of the NSDL logic model. By this, we mean instances in which NSDL investigators received some type of award (see resources and inputs in the logic model) to engage in using elements of collections along with relevant digital tools and services for finding and modifying, storing, and sharing them (see activities and processes in the logic model) to yield educationally meaningful applications in real-world settings (see products and outputs in the logic model). Put more briefly, we looked for exemplary cases in which NSDL funding promoted the use of high-quality online resources with evidence that the resources were being used by teachers and learners in science classrooms. We also sought cases reflecting different models of implementation. Our intent was to find field settings where lessons could be learned about successful implementation of cyberlearning approaches to advance STEM education.

We evaluated these full instantiations of the NSDL logic model using a replicated case study design. Case study is the method of choice when the phenomenon of interest is inseparable from the real-world context in which it is embedded and where the variables of interest will surely outnumber the potential observation instances (Yin et al., 1973). In what follows, we first briefly review the case study procedures and then present case-by-case findings, ending with overall conclusions.

Overview of the Research Approach

We relied on a sociotechnical systems framework to develop classes of explanatory variables and outcome indicators. Sociotechnical systems theory suggests three broad classes of explanatory variables:
• Characteristics of the antecedent organizational context into which the technology will be introduced (the demand side) account in part for the willingness and ability to adopt it.
• Properties of the technology itself—including quality, ease of use, and reliably efficient performance—also account in part for adoption and use.
• Implementation processes and strategies—the series of decisions made and actions taken to integrate the new technology into an existing user context while facilitating adaptation of the context, its constituents, and their tasks to take advantage of the innovation—are further expected to help explain positive intersections between advanced technologies and extant adopting contexts.

Sociotechnical systems theory and our own prior studies using this framework converge on the hypothesis that implementation process variables will have the greatest influence on successful outcomes (Bikson and Eveland, 1991; Straus et al., 2010). For purposes of our case studies, we sought evidence for three chief types of outcomes:
• teacher uptake, use, and satisfaction, plus improved STEM teaching
• increased student engagement, plus improved STEM learning
• sustainability after the end of special research funding.

Based on a review of NSDL program award abstracts, project publications, NSDL annual meeting presentations, and discussions with NSDL resource center staff, we identified and recruited for participation three full instantiations of the logic model with widely varying approaches to its realization:

• The **Curriculum Customization Service (CCS)** aims to provide teachers with high-quality interactive learning resources to help engage students in mastering a science field and to support new standards-based curricula for science instruction in Denver Public Schools (DPS).
• The **Noyce Scholars program** seeks to improve K–12 STEM education by encouraging university undergraduates with STEM majors to become K–12 math and science teachers and by increasing the number of strong STEM K–12 teachers in high-need school districts.
• **iCPALMS** aims to create online tools and services to enable K–12 math and science teachers to integrate high-quality digital resources into standards-based instructional planning, to expand NSDL collections with high-quality digital resources that are aligned with standards, to establish a collaborative network of users, and to build sustainability.

For each case, our team collected available published reports, internal documents, and any other existing case materials. Our primary data source, however, was site visits involving unstructured individual interviews with key stakeholders (including customers, as defined in the digital library literature review) and group discussions with end users, or clients (chiefly in-service or preservice science teachers). Our accounts of the cases were vetted with primary points of contact from each site and corrected for errors of fact. We note that these accounts reflected the
state of affairs in 2012, when the case studies were conducted; the circumstances of each case might have changed since that time.

For replicated case studies, analysis was carried out in two stages (Yin et al., 1973). Within-case analysis was done first. This involved examining patterns of relationships among classes of explanatory variables and outcome indicators to assess the extent to which expected associations did or did not hold up—in each case, independently. Cross-case analysis was then undertaken to compare patterns of relationships across the cases to detect and explore similarities and differences. Where there were similar relationships between antecedents and outcomes in predicted directions, the cases were interpreted as confirming hypotheses drawn from prior research and applied to help explain successful introduction of innovative technologies to support STEM teaching and learning. Such results should provide useful lessons learned for future cyberlearning initiatives.

Curriculum Customization Service: A District-Based Approach

Overview

CCS is built around the hypothesis that customizing digital STEM resources to align with standards-based curriculum units and making them accessible in teacher-friendly ways will create demand pull (versus supply push) and result in better science teaching and learning. Led by faculty and researchers at the University of Colorado at Boulder (CU) Institute of Cognitive Science and UCAR’s Digital Learning Sciences (Sumner et al., 2009), the CCS effort received two separate NSDL targeted research awards.

The initial award supported a CCS development and demonstration project with three chief goals:

• Provide teachers with high-quality, highly usable interactive learning resources to complement textbooks.
• Engage diverse students of varied academic ability levels in mastering a science field.
• Support new standards-based curricula effectively for earth science instruction in DPS.

RAND’s prior formative evaluation study included a visit to the CCS and DPS site in a preliminary case study (Bikson et al., 2011). After successful realization of the development and demonstration goals (Bikson et al., 2011), the CCS project team obtained a second award aimed at addressing questions about outcomes:

• Will CCS use for earth science courses be sustained in DPS? Will CCS use show teaching and learning improvements?
• Can CCS use in support of earth science instruction readily be replicated in other districts?
• Can CCS use readily be extended to support other science curricula in DPS?
The second award covered dissemination and implementation in a relatively narrow sense. It provided training in the use of CCS tools for all participating teachers in all districts, which consisted of a mix of face-to-face training and webinars, depending on location. However, the second award precluded new development work.

This case study addresses success factors and challenges associated with both the initial development and demonstration project in DPS and the dissemination to other districts. A brief timeline with major CCS milestones is represented in Table 7.1.

Table 7.1. Major CCS Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 2008</td>
<td>CCS project funded as targeted research; planning starts; Teacher Advisory Board (TAB) selected; participatory design of prototype undertaken with TAB</td>
</tr>
<tr>
<td>2008–2009</td>
<td>TAB members pilot test the system as alpha users; regular use enables iterative teacher-driven improvements</td>
</tr>
<tr>
<td>2009–2010</td>
<td>Demonstration project fully implemented, with district-wide training and rollout of CCS for all earth science instruction</td>
</tr>
<tr>
<td>2010–2011</td>
<td>Regular use and evaluation of CCS continues in DPS, along with dissemination and outreach to other potential sites</td>
</tr>
<tr>
<td>201112</td>
<td>Introduction of CCS for earth science instruction in five more districts; CCS made available for use in middle school physical science at DPS, while use for earth science has been routinized</td>
</tr>
</tbody>
</table>

Organizational Context

The district offered an appropriate context for the initial development and demonstration project because of the relative autonomy of Colorado school districts. While districts need to meet minimum state requirements, they can do so in varied ways, add other requirements, and choose their own texts.

DPS constituted an ideal starting choice for a number of reasons. **One factor found in previous research that contributes to successful technological innovation is a need—recognized by the prospective user community—that a new technology could fulfill.** In the DPS case, a new district-wide curriculum had been adopted for earth science in the sixth and ninth grades, with associated texts and teachers’ guides. Curriculum units were framed in terms of standards, key concepts, and learning goals to be achieved. What was lacking were high-quality interactive and tailorable resources—the sorts of materials likely to engage diverse students with differing levels of English-language fluency, quantitative skills, and other abilities relevant to achievement in a science course.

**A second important feature of the adopting context was strong support from key stakeholders.** Among them, the DPS chief information officer and the senior DPS science curriculum coordinator played major facilitative roles. Perhaps most critical, the top district
officers demonstrated vision and leadership in pushing the plan forward. Even when prospective end users are enthusiastic, the digital library literature review, as well as prior research in innovation, suggests that without support from top-level customers, it is difficult to summon the resources required for successful implementation.

Third, and possibly related to the first two factors, DPS managed to establish technological readiness. Through a combination of the NSDL award and district funds, every earth science teacher in DPS was provided with a laptop, room projector, and Internet connectivity in the classroom by the start of the major CCS rollout for the 2009–2010 academic year.

The five school districts adopting CCS during the follow-on project varied widely along a number of dimensions (see Table 7.2) but shared with DPS the overarching aims of promoting teacher effectiveness and student engagement in science through use of high-quality online resources. For each district, the official customer—the district superintendent—made the formal go-ahead adoption decision. However, district science curriculum coordinators played gatekeeper roles, and, without their encouragement, it is unlikely that CCS would have come to the attention of the superintendent. Within schools, lead science teachers in both DPS and the later-adopting districts took on significant roles as technology champions.

### Table 7.2. Overview of Districts Using CCS in 2011–2012

<table>
<thead>
<tr>
<th>Sites</th>
<th>District Enrollment</th>
<th>Earth Science Teachers</th>
<th>Percentage of Minority Students</th>
<th>Percentage on Free/Reduced Lunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver*</td>
<td>80,890</td>
<td>120</td>
<td>80</td>
<td>73</td>
</tr>
<tr>
<td>District A</td>
<td>314,023</td>
<td>28</td>
<td>68</td>
<td>51</td>
</tr>
<tr>
<td>District B</td>
<td>67,736</td>
<td>36</td>
<td>15</td>
<td>26</td>
</tr>
<tr>
<td>District C</td>
<td>63,114</td>
<td>32</td>
<td>23</td>
<td>11</td>
</tr>
<tr>
<td>District D*</td>
<td>7,760</td>
<td>5</td>
<td>69</td>
<td>70</td>
</tr>
<tr>
<td>District E*</td>
<td>28,109</td>
<td>15</td>
<td>35</td>
<td>33</td>
</tr>
</tbody>
</table>

*Districts that the RAND team visited.

It is well-known that leading adopters differ from later adopters in many ways, so it was important to learn the extent to which the positive CCS experience in Denver would generalize to other sites. In fact, the visible and known success of the DPS demonstration proved to be a key consideration in other districts’ adoption decisions, as would be expected from prior research on technology diffusion (Rogers, 1995). However, some aspects of the organizational context raised concerns among the districts.
First, although acquisition and use of CCS was free, which likely promoted adoption, a nonnegligible amount of teacher time would be expended in developing the ability to make effective use of CCS. **Thus, a chief concern was whether CCS would persist and continue to be free after NSF award funding disappeared.** Consistent with the discussion of accountability in our digital library literature review, teachers and curriculum coordinators did not want to engage in changing science courses in major ways that would not be readily amenable to reuse.

A secondary adoption concern had to do with evaluation apprehension. Districts and teachers were working under considerable performance-assessment pressures and threatened or actual budget cuts. In this broader environment, the prospect of being further evaluated as part of a research project was less than welcome. Through a low-key, largely word-of-mouth dissemination effort, five additional school districts enrolled in the follow-on project—three in Colorado, one in Nevada, and one in Utah.

**Technology Factors Contributing to CCS Success**

Factors associated with provision of the technology itself—the supply side of the picture—would also be important in supporting the implementation of CCS.

Of potentially greatest importance is the highly competent and supportive technical development team, comprising faculty and researchers at CU and UCAR. Their expertise with the digital resource collections, tools, and services needed for building and populating the CCS, together with their understanding of the cognitive foundations for science teaching and learning, positioned them well to provide a technical system of the highest quality.

CCS is designed to support teachers’ planning activities. It assumes that effective planning typically involves identifying learning goals and reviewing the associated curriculum resources for a given unit, then devising lesson plans and complementary learning activities to help students attain the desired outcomes. Consequently, the user interface to CCS is organized by key concepts from curriculum units to link digital resources to learning goals. In particular, teachers can assemble resources selected with the abilities of their students in mind and related to a given goal and then save them in a personal online space (“my stuff”); they can also send such customized materials to a shared space (“shared stuff”) or browse that space to see whether others have posted learning materials there that they may find useful.

The CCS team’s familiarity with the digital resources accounted, in part, for the relatively rapid development of the initial system prototype. The digital objects used to populate the CCS system initially were drawn from the highly regarded DLESE pathway hosted by the National Center for Atmospheric Research at UCAR and well-known to the technical team. The follow-on effort examined whether the system could readily accommodate a different science domain; the choice of physical sciences was driven in part by the recognized high quality of the digital collection hosted by the ComPADRE pathway. Other NSDL digital resources used
Another technical factor on the supply side of the picture is represented by the textbook publisher’s willingness to provide PDF versions of the course texts and teaching guides to the technical team. While considerable effort was entailed in parsing these into curriculum-unit-sized modules to accompanying learning goals, standards, and linked resources, the CCS team believed it would be important to offer a one-stop shop for earth science teaching materials. Establishing this partnership meant overcoming sensitive intellectual property issues involved in enabling the use of digitized textbooks. When CCS was extended for use in physical science courses in DPS, the same publisher’s physical science text was used.

Implementation Processes Contributing to CCS Success

NSDL projects have sometimes been characterized as driven from a supply-side “if you build it, they will come” perspective (Giersch et al., 2004). In contrast, the CCS implementation processes were essentially collaborative in nature but driven from the user side. Once a go-ahead decision had been made, the project team selected a TAB comprising five sixth-grade and five ninth-grade teachers of earth science courses; they would take the lead in a participatory design effort to develop CCS (see Table 7.1).

Initial efforts of the collaborative design and development group produced a series of screen sketches and storyboards reflecting what teachers would like to see and do with online system support. These interactions yielded a rough prototype that could be implemented on a development server. Teachers asked for specific subsets of the text and teacher guides to be linked to particular learning goals and associated with relevant digital resources from DLESE and elsewhere (e.g., online news images of recent environmental events, teacher-produced materials). Teachers also asked to have the huge store of available DLESE resources pared down to a manageable group of hand-selected “top picks” for teachers of the sixth and ninth grades.

By the start of the 2008–2009 academic year, a functioning online prototype was available for TAB members. As alpha testers, they used the system in day-to-day earth science instruction planning and classroom delivery; their experiences enabled iterative system improvements. They also began to populate the “shared stuff” space with their own contributions. By the start of the following academic year (2009–2010), the system was judged ready for rollout; all earth science teachers in DPS received four hours of training led by the CCS principal investigators and TAB members. Subsequently, the CCS team was available to answer help calls and provide user support. Few help calls were actually received; most were easy to address (e.g., they typically concerned forgotten passwords). Regular use continued throughout the 2010–2011 academic year.

Although this CCS-based realization of the NSDL logic model was an agreed success in the DPS context with earth science, it was not clear whether similar positive results could be achieved in other locations or in other domains. The follow-on NSDL award explored
replicability and extensibility. As outlined in Table 7.2, the subsequent effort engaged five additional districts in CCS use; the effort also extended use of CCS for physical science in DPS. The follow-on award supported only implementation in a narrow sense of the term, excluding development efforts related to customization.

The diffusion of CCS for earth science instruction to sites beyond DPS was largely demand-driven (as hypothesized), based on word of mouth about DPS’s positive experience, along with outreach efforts by the CCS research team. Making the system available to additional sites for earth science instruction and providing appropriate training were unproblematic and well-received endeavors. However, use of CCS for physical science courses in DPS was met with much less enthusiasm. Unlike the implementation for earth science, there was no cadre of existing users among the physical science teachers to spark demand for CCS. Additionally, a user commented, and others echoed, that earth science is “an underdog in the STEM disciplines” and so is not likely to lead other science domains by example. Another key factor that might account for differences in receptivity is that the earth sciences customization in DPS coincided with a new curriculum and textbook, which required teachers to start from scratch in creating lesson plans. In contrast, customization for the physical sciences used an existing textbook, resulting in little incentive for teachers to change their lesson plans to use or develop digital resources. Ultimately, without contributions from the end users, the physical science implementation had a lower level of customization.

Boosters and Barriers for End Users

Although end users are often not the customers as defined in the review of what makes for a sustainable digital initiative, their embrace of the technology is critical to its continued support. With this in view, it is important to explore the key uptake boosters and barriers for end users of CCS.

Boosters

High Usability and Authoritativeness

According to participants in the districts we visited, a key point is that the CCS interface is intuitive, as is navigation. A second major consideration is that the resources CCS presents are selected from trusted providers of high-quality materials and have been vetted, so teachers feel confident using what they have found. User reviews, in the form of star ratings from other teachers, are also helpful guides for selecting CCS resources. Thus, the resources reflect high usability and authoritativeness, which are important elements of sustainable resources or collections.

Linking of Learning Concepts and Activities to the Learning Standard

Next, linking learning concepts and activities to standards is critical to CCS uptake. It saves time and is especially valued by newer teachers, teachers who are handling multiple course
preparations, and teachers who have not specialized in the domain. Finally, teachers in small schools particularly find it useful to connect with other district science teachers.

Barriers

Linkages of Online Resources to Curriculum

On the barrier side, we found mixed responses to the linkage of online resources with digitized curriculum units in the course text. Some teachers feared that it ties a district and its teachers to the chosen text. Their view was that the resources need only be linked to the related curriculum standards, since those should not vary across texts. Others, however, saw it as a welcome one-stop shopping venue for lesson planning: “I used to carry around the text, the teacher’s manual, and lots of other material I’ve gathered for particular units; now all I need is my laptop.” A comment from a member of the TAB who had transferred from DPS to an adjacent school district further supports this view: While he still taught earth science and could still access the CCS resources and tools, he found them to be only marginally valuable because they were not integrated with the textbook used in his new district.

Lack of Teacher-Developed Resources

A second concern is that, while teacher-developed resources work best, there are far too few of them. Users cited two chief reasons for this shortfall. First, teachers lack time and incentives to develop share-worthy resources (but teachers do have the time to develop resources for their personal use). A lack of incentives to develop new resources, as well as to use existing ones, appeared to be especially acute among physical science educators in light of the integration of CCS with an existing, rather than new, textbook. Second, while the district scope of the system respects district autonomy, it limits the likely extent of teacher-developed resources, particularly in very small districts (see Table 7.2, where one adopting district has only five earth science teachers). For small districts, that constraint also limits collegial interactions supported by the system and the utility of the resource ratings.

Outcomes

Effects on Teaching and Learning

Teacher uptake of CCS is widespread and voluntary in earth science instruction. CCS researchers estimated that across the six adopting districts, about a third of them are heavy system users, a third are regular users, and a third use CCS little if at all. Furthermore, teachers who use the system offered uniformly positive evaluations; they indicated that CCS improves lesson quality while concurrently saving lesson preparation time (Sumner and CCS Team, 2010).

Perhaps more important, teachers said that they personally learn more about earth science as they use the system. These self-report judgments have received promising preliminary confirmation in a qualitative assessment carried out by CCS researchers (Sumner
and CCS Team, 2010). Cognitive interviews with teacher-users of CCS suggested that they gain a deeper understanding of earth science constructs and explain them with greater accuracy and clarity after experience with the system.

**Teachers also reported improved student engagement.** They found that students pay more attention and exhibit more interest in earth science when given interactive presentations—and this is especially true for students who are, as one teacher put it, “reluctant readers.” They seem better able to cope with text-based material after the construct of interest has been presented in a rich audio-visual medium.

Prospects for CCS Sustainability

**With respect to the sustainability outcome, the jury is still out.** On the one hand, given increasing pressure to reduce costs in the face of education budget cuts, school and district representatives were not confident that they could continue to use CCS if it ceased to be free. On the other hand, teachers would be very reluctant to give up its use, especially at a time when there are efforts to link teacher pay directly to student test performance.

The CCS research team, in 2012, appointed an external advisory board headed by a chair with financial strategy and planning expertise; the job of the board was to help map out future moves for CCS. Our literature review suggests that this in itself should count as a step toward sustainability. Continuing to collect data using sophisticated research designs that increase understanding of how high-quality digital resources affect teaching and learning should further promote sustainability in a time when there is growing recognition of the need for evidence-based practice in STEM education.

Noyce Scholars and MERLOT

**Overview**

The congressionally funded Robert Noyce Teacher Scholarship program is a national program that seeks to improve K–12 STEM education in the U.S. by

- encouraging university undergraduates with STEM majors to become K–12 math and science teachers
- increasing the number of strong STEM K–12 teachers in high-need school districts in particular.

The Noyce program was first authorized in 2002 through the NSF Authorization Act and then reauthorized through America COMPETES in 2007 and 2010. The program provides funds to universities for student instruction, academic programs, teacher professional development, and other programmatic support. In particular, the program provides scholarships and stipends to undergraduate and graduate students in teaching credentialing programs. As a condition of participation, Noyce scholars are required to complete two years of teaching in a high-need
school for each year of Noyce support. Additionally, the program supports NSF Teaching Fellows and NSF Master Teaching Fellows, who receive salary supplements for a four-year teaching period or five-year teaching period in a high-need school district, respectively.

In the California State University (CSU) system, the use of digital resources in teaching is a key component of the Noyce program. Digital resources are embedded in the program through education curricula, professional development, workshops, and conferences. CSU connected two NSF programs—Noyce scholars and NSDL—to support math and science teacher education.

The CSU Noyce programs draw heavily on Multimedia Educational Resources for Learning and Online Teaching (MERLOT). MERLOT is a digital system offering online STEM education resources and a variety of tools and services that support their use. MERLOT originated in 1997 at the CSU Center for Distributed Learning and has been supported in part by NSF, through three NSDL grants, and through direct support from MERLOT’s institutional partners. MERLOT and the supporting tools and services can be tailored to the needs of user groups and campuses and are available by subscription to non-CSU campuses. For Noyce, the MERLOT “ecosystem” has been developed into the Noyce Commons, an interface to the MERLOT digital library and tools and services tailored to support a community of practice around digital resources for Noyce scholars.

Fourteen of CSU’s 23 campuses have Noyce scholarship funding (CSU, 2008), making CSU one of the largest institutions benefiting from Noyce support. Collectively, the CSU Noyce institutions have provided scholarships to more than 250 prospective teachers. As we noted, Noyce scholars must teach in high-need schools across the United States. This means not only that the CSU Noyce community is large but also that it is a highly distributed community when the Noyce scholars reach their schools. CSU perceived the degree of separation among Noyce peers as a threat to the persistence of these future teachers; absent support from other teachers and from mentors in the CSU system, many scholars may leave the program before completion. In this NSDL project, MERLOT was expected to provide a diverse set of tools to enable the CSU Noyce scholars to enjoy a rich virtual community and to access high-quality teaching resources from their classrooms, thus improving their retention and enhancing their professional development opportunities.

Noyce scholars also play a key role in developing and disseminating MERLOT. They participate in the peer review of digital resources for inclusion in MERLOT and provide input on the design and features of MERLOT and the supporting tools and services. Noyce scholars are also ambassadors of MERLOT, presenting MERLOT at national conferences and NSDL meetings, mentoring other students in using digital resources, and becoming technology leaders in the schools at which they teach. In these ways, the Noyce program and MERLOT are mutually beneficial. Together they provide a compelling example of digital resources embedded in a teaching program and a teaching program embedded in a STEM digital resource project.
Organizational Context

Both the Noyce Scholars program and MERLOT are established programs with synergistic goals. A goal of the Noyce program is to recruit individuals with backgrounds in STEM to consider careers in K–12 teaching. The American Association for the Advancement of Science (AAAS) works with the Noyce program to disseminate information about strategies for recruiting and preparing new K–12 STEM teachers and retaining them in the workforce. Dissemination occurs through the program’s annual conferences, proposal preparation workshops, a publication that highlights program accomplishments, and a program website.

As with CCS, strong support from key stakeholders was important in contributing to the success of MERLOT. MERLOT is championed by the CSU chancellor’s office, which provides institutional funding and supports ongoing development and expansion. Interviewees repeatedly noted that this home is critical for MERLOT’s sustainability. The CSU system has committed ongoing technology support for MERLOT as part of its institutional overhead. This includes technical support for webinars and workshops, to which teachers bring their own laptops; maintenance of hardware; and a helpdesk service for routine requests such as password resets. This ongoing support keeps MERLOT stable and responsive to user needs. In addition, a faculty champion is committed to sustaining MERLOT.

MERLOT is also embedded in an education program—not only with Noyce scholars but also in the broader CSU education programs. This gives MERLOT a substantial and persistent user community. It also facilitates participatory design, helping ensure that the technology meets users’ needs and is functional. Noyce and MERLOT together provide ongoing support and education related to digital resources—e.g., through ongoing webinars and conferences. Interview participants’ comments about these resources and support include:

Some of this stuff is in the methods class, but Noyce scholars see [digital resources] more frequently. Some are virtual, others are in-person day or multi-day workshops on how to use different resources. Those were very popular. And when presenter is partnered with Noyce alum, that makes a big difference.

Students find NSDL resources that aren’t in MERLOT and make contributions to MERLOT. It is an activity that the program encourages and facilitates—having them to go to NSDL and make contributions.

The program had a project a year and a half ago called Modeling Science, funded by the Department of Education, to enable charter schools to disseminate highly effective pedagogy. . . . They held a summer workshop with teachers and follow-up workshops with a number of teachers in the region and Cal Poly. Seventy-six teachers from these workshops used Noyce Voices to raise questions, ideas, and hold ongoing discussions. This became the largest discussion community in the MERLOT Voices.

MERLOT draws extensively on students as ambassadors—e.g., by participating in state and national workshops related to MERLOT, facilitating webinars, and keeping materials updated.
One administrator observed, “When teachers hear from teachers, that’s much more compelling than when you hear from professors.” Interviewees explained that this community of students is also important to the future success of the program:

The [Noyce] program has a sense of community, which is something it seeks to maintain, particularly in recognition that Noyce is not going to be funded forever. Teachers will continue to have lifetime access to resources. The program wants to maintain that enthusiasm for maintaining access to [Noyce] commons and MERLOT, as well as ongoing updates to both.

A good contact or counselor or liaison is also essential to maintaining the MERLOT/Noyce community. The program participates in the Western Regional Conference, which has talks by teachers.

Technology Factors Contributing to Noyce and MERLOT Success

Several technological features of MERLOT contribute to program success. MERLOT is an integrated, customizable ecosystem of digital resources and tools and services that support their use.

The MERLOT repository is a collection of approximately 40,000 digital resources from a wide range of sources, including NSDL. There are 20 different types of materials, such as animations, assessment tools, social networking tools, and tutorials (MERLOT, 2010a). Resources are contributed to MERLOT by registered members. Editorial boards (MERLOT has more than 20 editorial boards) then triage candidate materials for review by trained peer reviewers, who follow vetted, discipline-specific evaluation methods (MERLOT, 2010b).

Noyce scholars in our discussions felt that peer review led to higher-quality resources and enabled them to find more-complete, ready-to-use resources than with Google and similar search engines—reflecting views about resource authoritativeness and usability. One participant noted, for example:

I do a lot of “Frankenstein” stuff—sometimes I take individual photos, sometimes labs, and piece it together.

I “Frankenstein” more with Google than MERLOT. With MERLOT, I’m more likely to take the whole thing because I know it’s going to be better.

An administrator we interviewed echoed the value of peer review:

[MERLOT] is open source with vetting of materials to a significant degree, which is so important. Educators in the same fields can feel confident that the resources they are going to consider using have been examined by people they respect and value.

A number of tools and services support usability of the MERLOT repository. First, users can add materials to their own personal collections for easy reference and organization.
Second, with the MERLOT Content Builder, users can create instructional websites, called e-Portfolios, in which they can embed digital resources. These websites can be used as another means of privately storing and organizing resources, or they can be used in the classroom. The MERLOT Content Builder is integrated to the MERLOT Repository in two key ways: Users can directly embed resources stored in the repository, and e-Portfolios can be pushed to the Repository as another resource in the collection. One administrator noted the value of e-Portfolios:

Those students who develop and use e-Portfolios are much better organized. E-Portfolios serve as a format for scholars and others to organize their resources and make contributions. Their teaching philosophy is around their e-Portfolios. Sample lessons and samples of student work are very powerful. If they are looking for a new job, they use the e-Portfolio as a powerful tool to explain who they really are and the kind of work they’ve done.

**MERLOT Voices is a community discussion forum that fosters online communities and social networks.** Users can write on the group’s “wall,” post comments and questions, and upload documents.26

**MERLOT also offers partner institutions customized portals to the repository, Content Builder, and other tools and services:**

These portals can be an effective way to make the extensive resources and tools that are part of the main MERLOT site more relevant and useful to faculty on partner campuses and systems. The communities created may also be organized around a topic, technology, or theme that might involve faculty or academic technology staff from across campuses. (MERLOT, 2009)

The Noyce Scholars Teaching Commons uses this approach to tailor MERLOT to the specific needs and with the branding of the Noyce scholars program. The Teaching Commons provides a variety of links and resources—e.g., to locate other Noyce scholars in STEM disciplines, to examples of peers’ e-Portfolios, to information about effective classroom-management strategies, and to Noyce Voices, which is a Noyce-tailored portal to MERLOT Voices that helps Noyce scholars remain in contact with each other. Participants in our discussions noted that the Repository, Content Builder, and Voices foster audience engagement and help create a community of practice:

[MERLOT] provides a community of resources. If you feel like you don’t know or if you don’t have anything for a topic, you can go to a site. Both people and resources are part of the community.

26 There are a number of other tools and services that are part of MERLOT, but we focus on the Repository, Content Builder, and Noyce Voices as the key technology components needed to instantiate the NSDL logic model.
We’ve used MERLOT Voices to organize thoughts in different areas of study, for example, if you want to talk to people who all attended a workshop or a classroom management forum. The community of resources is about being able to be more specific about your search, instead of just Googling something, because you get a million hits, and 90 percent of the results are trying to sell you something. It is nice to find things that are peer reviewed, and where you can contact the author and say, “Hey what worked for you, what kind of class do you have? Block or normal?”

However, it is not clear the extent to which Noyce Scholars use Noyce Commons versus the original MERLOT system. One administrator commented:

I have no idea if anyone goes to Noyce Commons. There is very little on there that is unique to that site. If I know I want DLESE or virtual courseware, I can find it without having to go to Noyce Commons. And, unless you have somebody to continually update it, it gets stale. . . . We didn’t do a great job of keeping Noyce Commons updated.

**Implementation Processes Contributing to Noyce/MERLOT Success**

We identified two key implementation factors contributing to the success of the Noyce-MERLOT alliance: training and community building.

**MERLOT has engaged its audience as user-developers by providing training.** Faculty in postsecondary education institutions who are interested in serving as peer reviewers participate in an online course entitled GRAPE (Getting Reviewers Accustomed to the Process of Evaluation) camp. Likewise, students in the Noyce Scholars program also receive training on use of MERLOT. Both administrators and participants noted that students and the MERLOT system benefited from the digital resources training provided in the education program:

That was the nice thing about learning the resources in Noyce. We got a head start. There are so many activities that I have learned about because I had that while I was building portfolio and got to try them out in student teaching, and [could] ask [the] master teacher, “Do you think this would work? What would be pitfalls? How can I make it better?”

I was only in Noyce for a semester, but in that semester, I networked with inservice teachers and professors, and I was involved in NSDL grants and putting together physics resources. So this was a remarkable opportunity to create some of the content for NSDL. That came as a direct result of being a part of Noyce, so that connection was embedded and [a] huge part.

This has boosted Noyce Scholars’ credentials and attractiveness to potential employers:

[The] MERLOT content builder was the Keep Toolkit. We first started with it when we were undergrads. We started building an online portfolio and then applied for jobs, where we showed our portfolio of lesson plans. That was huge for showing we have technology experience, know how to put things on the web page, navigate the web, and we have lesson plans.
Sample lessons and samples of student work are very powerful. If they are looking for a new job, they use the ePortfolio as a powerful tool to explain who they really are and the kind of work they’ve done.

**MERLOT and Noyce together also provide an essential community for Noyce scholars, which seems particularly important after they leave their education programs:**

A lot of my community is made of people from Noyce scholars, more so than people at my school, because there are so many types of people with different teaching philosophies, agendas, and standing in schools. You can’t always work with the people you work with. We have another chemistry friend and the three of us [form our own community]. So we talk to people in Noyce more than [to] colleagues in our schools.

Comments illustrate the importance of both resources and community, reflecting both the two underlying assumptions of the NSDL logic model and the joint influence of social and technical factors as advanced by sociotechnical systems theory—e.g.: “[MERLOT] provides a community of resources. If you feel like you don’t know or if you don’t have anything for a topic, you can go to a site. Both people and resources are part of the community.”

**Boosters and Barriers for End Users**

**Boosters**

The community aspect of the Noyce Scholars program has been a key factor in the diffusion and uptake of digital STEM resources. Noyce scholars often become technology leaders and MERLOT champions in their schools, serving in a “marketing” capacity and being a source of support for others:

One of the advantages is that students who come from [the Noyce] program are able to influence their colleagues. We see students who have risen to a leadership capacity because of their knowledge. That is part of the model; that was one of the goals of the NSDL project.

**Barriers**

In terms of barriers, interviewees and discussion participants identified a number of obstacles to uptake.

*Variations in the Availability and Quality of Technology*

The technology available in high-need classrooms varies significantly, and many teachers do not have sufficient access to computers and projectors. Firewalls inhibit some teachers’ abilities to organize, update their materials, access things that others are doing, and regularly upgrade. In some cases, resources are available in the classroom but are not available to students outside the classroom, which restricts teachers’ ability to use digital resources for homework and other out-
of-the-classroom learning. The degree to which teachers reported bringing students online depends on restrictions that are in a district, and this varies significantly across districts.

**Lack of a Shared Vision**

Another barrier is that teachers’ school communities often do not share their vision for or have experience with digital learning.

With Noyce, we get trained the same way and at a higher level in our teaching. This includes differentiated instruction, videos, etc. With teachers already in school, they are stuck in a rut or don’t think it’s important [to differentiate or use digital resources].

A lot of teachers aren’t comfortable with technology. They are scared of what students might do [with the technology], or don’t think [digital resources are] worth it, or think it’s a play toy and not legitimate.

**Usability of NSDL Portal**

Whereas some interviewees were satisfied with the NSDL portal as a source of content, others felt that usability of the portal was a significant barrier to uptake, particularly given that teachers have limited time to develop resources for classroom use. Participants reported that NSDL.org is not user-friendly; it is difficult to find what they are looking for and a lot of the material is at the college level. This reflected a more general observation expressed by several interviewees—specifically, that there is a disconnect between teacher-users (clients) and NSDL developers, with inadequate understanding of teaching contexts and tasks on the part of purported experts on the developer side and insufficient efforts to obtain end-user input.

PhET [Physics Education Technology, at the University of Colorado] and ComPADRE are really user friendly. I don’t go on NSDL, I get frustrated, I can’t find what I need in 5 minutes because that’s all the time I have.

It is nice to have resources to get animations and online activities. I use ComPADRE, Jason Project, and the Khan academy. I only found out about them because of MERLOT.

**Outcomes**

**Effects on Teaching and Learning**

The Noyce Scholars we interviewed were enthusiastic about using digital resources in general and MERLOT in particular for teaching. They reported that these resources facilitate differentiated instruction and offer opportunities to conduct labs and exercises that would not otherwise be possible:

When you find videos, you find a way of teaching something you hadn’t really realized. It opens up your vocabulary for things. The way you say it to some kids makes sense, and you have to say it four different times in four different ways. And sometimes you run out of ways [so digital resources help offer new ways.]
Simulations are great because you can use them as a demo for concepts students can’t see, or use simulations as labs. Students have to discover things like gas laws. A lot of them are designed well enough that you can turn them into labs. That’s the benefit of NSDL and people have published things. Kids are so technology savvy so “if you can’t beat ‘em, join ‘em.” They all have phones—I’ve encouraged students to find resources and find apps on their iPhones. If they can watch a 10 minute video[,] they would much rather do that than listen to you talk. If you have a phone, I encourage them to take a picture of the assignment, white board, [or] what you see in the microscope.

As with respondents in our evaluation of CCS, Noyce scholars reported using digital resources to improve their own content knowledge:

I have a chemistry background. [When I was teaching physics,] Khan Academy, ComPADRE, and PhET saved my life because I didn’t know [physics] and the book was ridiculous.

When I don’t understand something, I go to watch his video and relearn it.

Last year we spent 20 minutes trying to figure out this magnetism topic, and then we were like, “Where is the video to teach my students?”

Several teachers noted that online resources coupled with standards enabled them to move away from textbooks when they were not suitable for students’ needs and to better customize lessons to fit the students’ knowledge and skills:

The structure comes from standards, but content comes from online resources.

We don’t even follow the book, and I don’t know what chapter things are in.

Books are either really simple and you can follow the key concepts, or the topics are over students’ heads. So why not get students a solid foundation?

For example, in our chemistry textbook, they gloss over the basic things, where electrons and protons are, how to find them, etc. and they focus on electron clouds. It’s so difficult because you can’t teach students this because they don’t know what an electron is.

Digital resources offer a way to tailor the curriculum to students’ needs.

It is easier to scaffold on your own rather than when you use a textbook.

Participants also showed growing sophistication in their use of resources:

At the beginning, I used to take what they have and go with it and hope for the best. But now, I know how to customize.
When I went through credentialing, it involves classes in all the subjects, and I’m used to using all these [online] resources.

The resources are more critical once we are advanced. We can know how much time the resources require, know if it is appropriate.

**Interviewees reported that digital resources also have positive effects on student learning by holding students' attention better than textbooks or traditional resources and by providing opportunities for review:**

Students are so much more engaged in learning, [for example, with a] YouTube video of a cathode ray tube. You can draw on the expertise of other science teachers and [the students] are glued to it.

When you do online labs, you can go back and review, whereas classroom labs the students don’t remember. Or in groups they get stopped from learning [if a member of their group is unfocused].

Prospects for Noyce Scholars and MERLOT Sustainability

**The future of both Noyce Scholars and MERLOT seems promising.** The dedicated institutional support from the CSU system promotes financial security and technology maintenance, as well as dedication to seeing the programs grow. Noyce scholars and other teachers at the CSU campuses provide a native community of users and a community of practice. We do not have any direct evidence about the sustainability of the pairing of the Noyce Scholars program and MERLOT. On the one hand, their sustainability as separate programs, the complementary nature of the two programs, and the way in which both programs benefit as a result of their alliance suggests that their union is likely to continue. On the other hand, cessation of funding for Noyce Scholars could break the link between future STEM teacher development and MERLOT.

**iCPALMS**

**Overview**

In 2010, NSDL awarded three years’ funding for iCPALMS. The iCPALMS program augments CPALMS, which was built as the Florida’s source for teaching standards, courses, and standards-based resources. CPALMS, the initial project, provided the infrastructure for iCPALMS, which in turn fostered further growth of CPALMS. Therefore, CPALMS and iCPALMS are inherently connected, and it is difficult to discuss them separately.

CPALMS and iCPALMS were motivated by required use of state instructional standards, coupled with the plethora of resources of unknown quality available on the Internet. The goals of CPALMS were to provide a source of sustainable online resources for teachers, to tie standards to courses, and to be free to use. The goals of iCPALMS were to provide a personalized portal
that allows users to customize the content, applications, and look and feel of their home pages on this platform. More specifically, iCPALMS aims to

- Create online tools and services to enable users to integrate high-quality digital resources into standards-based instructional planning.
- Expand NSDL collections with expert-reviewed, standards-aligned digital instructional resources for K–12 math and science teachers.
- Establish a collaborative network of users.
- Build capacity for long-term sustainability.

In brief, CPALMS is a website that provides standards-based, instructional content for users, and iCPALMS is a portal that allows users to customize the look and feel, content, and applications that they use; for example, iCPALMS has tools that can recommend instructional resources to users, and it provides a platform for educators to collaborate on instructional planning and to share resources.

**Organizational Context**

Florida State University (FSU) is the primary project manager of the CPALMS and iCPALMS projects. Development of these projects has occurred in collaboration with a number of partners. Initial partners included the Florida Department of Education (DOE), which was responsible for CPALMS integration; four school districts, including Brevard County, Seminole County, Duvall County, and the Panhandle Area Educational Consortium; and Sciberus, which is a software development company. However, CPALMS and iCPALMS involve participatory design via a large community of stakeholders (e.g., teachers) who develop, review, and use resources. In fact, implementers and end users of the resources are often the same. As noted by one of our interviewees:

> I can’t say enough about the people. That’s what is going to make CPALMS a wonderful resource, because it’s people who are going to make this go forward, and their passion is what’s going take it there.

CPALMS and iCPALMS have been funded in a modular fashion with support from multiple sources staged across several years. The FSU team obtained a variety of state and federal grants to support development. The projects were funded and built in pieces that could stand-alone or work together (see Table D.1).

In addition to direct funding, other organizations have obtained funding for STEM projects that contribute to iCPALMS sustainability. Twenty-five organizations, such as SeaWorld, the American Chemical Society, and various universities, are building and contributing resources funded through their own grants, using iCPALMS as a platform for development.
Technology Factors Contributing to iCPALMS Success

Several aspects of technology appear to account, in part, for the success of CPALMS and iCPALMS:

- **First**, CPALMS and iCPALMS are seamlessly integrated.
- **Second**, the system is user friendly, making it easy for users to access, contribute, and review resources. In addition, iCPALMS provides teachers with a virtual teaching assistant that recommends just-in-time instructional and learning resources. As teachers collaborate and develop instructional plans, the system learns what they need and when they need it.
- **Third**, in keeping with the philosophy of a participatory design, the software developers are an integral part of the CPALMS and iCPALMS team.
- **Finally**, the development process accounts for the technical capabilities of diverse systems. For example, in many districts, computers in the schools use outdated Internet browsers because other school software is not compatible with browser updates. As a result, iCPALMS developers designed the system to work with the technical capabilities of the browsers in use. This means, for example, that iCPALMS cannot use HTML 5, which would enable the same version of iCPALMS to work on laptops and mobile devices. Instead, developers need to create separate versions of iCPALMS for laptops and mobile devices.

Similar to the modular funding approach, the system provides a modular development platform for partnerships, resources, and tools. Organizations can use the iCPALMS tools to build their own resource collections using the iCPALMS system and review process. Similarly, organizations can build and integrate new web applications and tools to integrate with iCPALMS rather than building a complete system. This approach seems to provide efficiencies and promote sustainability of the content, tools, and CPALMS and iCPALMS.

Implementation Processes Contributing to iCPALMS Success

A number of implementation factors contribute to the success of CPALMS and iCPALMS. **First**, the FSU team is a strong champion for these projects. The project director is atypical in the sense that he has a background in business rather than in education. This reflects an important aspect of sustainability, as discussed in our review in Chapter Three. The director has strong skills in strategic management and has been very successful in forging partnerships and obtaining funding. However, he appears to have been the sole source of some of the underlying plans and management activities, including provision of technical support for users. While this has not been an obstacle to development and implementation of CPALMS and iCPALMS, it raises a concern about sustainability in future years; if the director left suddenly, it is not clear whether there are other team members who could fill his shoes.

**A second important implementation factor was the development of a strategic plan.** The development team at FSU developed a clear strategy of small pieces but with a big picture
vision. The team envisioned and implemented CPALMS and iCPALMS using a modular approach, whereby components of the systems can stand alone or interact with other components. Funding for development mirrored this modular strategy. A related strategy was using a measured pace to roll out the system, waiting to launch until it had a critical mass of resources. This decision was based on early consultation with end users, who reported that they would be unlikely to return to a website if they found few resources on an initial visit.

A third component of the implementation strategy was marketing the system and providing training for early adopters, who would then spread the word among other potential contributors and end users. For example, the management team introduced CPALMS at conferences for district math and science curriculum specialists whose role it is to recommend resources to teachers. Many of these specialists also contributed resources (which helped build the collection) and were reviewers, so they could promote the systems effectively to others. Many of these specialists remain involved in formulating plans for the system, and a number of them are among recipients of 50 minigrants that support their work as champions—i.e., who serve as local experts for other teachers. Champions and facilitators are required to conduct certain activities; for example, they have facilitated lesson plan development workshops for teams of five to ten teachers. So far, 400 teachers have taken part in these workshops, close to 1,000 resources have been submitted through this program, and more than 1,000 resources are expected from similar users in the coming year.

These conferences for district specialists and workshops are two of many examples of how FSU has supported user training. As shown in Table D.1, teacher training has been a focus or component of many of the funding awards for CPALMS and iCPALMS. Thus, FSU is not the sole champion for CPALMS and iCPALMS; the project has developed a community of user-implementers who also serve as champions, as reflected in the pathway’s theme, “Built by educators for educators.”

Barriers for Development and End Users

Barriers

Despite these success factors, CPALMS and iCPALMS have encountered a number of barriers to implementation. Most of these obstacles are administrative or technical in nature.

Multiple Sources of Funding

Different sources of funding for components of the same system have resulted in conflict about ownership. For example, federal funding allows FSU to hold intellectual property rights, whereas state funding requires state ownership of it. FSU and the Florida DOE devised an agreement that allows FSU to control the intellectual property of the tools, processes, and software developed by state funding. The content and resources are published under the Creative Commons license, and the author maintains ownership.
Fifty percent of any income that FSU generates (e.g., through commercialization) goes to maintaining iCPALMS so that the state does not need to pay for upkeep, and the remaining income gives FSU the freedom to expand the system.

**Inadequate Equipment to Host CPALMS and iCPALMS**

A second barrier concerns the availability of equipment to host CPALMS and iCPALMS. Originally, FSU provided a server, but it quickly became insufficient to serve the rapidly growing user community. This obstacle was apparent to end users, many of whom remarked about slowness (in fact, speed and reliability of the server were the only complaints that case study participants reported). This problem was resolved by obtaining funding through the Teacher Standards Instructional Tool grant to add servers and update software at the Florida DOE and transfer CPALMS and iCPALMS to this hosting environment. In fact, since the change, users have commented on improved access to the system.

**Transition to Florida DOE Servers**

Transition of the system to Florida DOE servers also posed some challenges. CPALMS was the first of several systems to move to DOE’s hosting environment, and the initial transition process required establishing procedures to enable FSU to make changes to the system and install needed services and software applications. Initially, the FSU team needed permission to make even minor changes to the system, which impeded development. FSU worked with DOE to relax these constraints, and the relationship between FSU and the DOE evolved such that FSU no longer needs permission to make changes but merely reports or logs when it has made a change.

**Poor Technical Infrastructure in Some Districts**

Another issue, described earlier, is poor technical infrastructure in many districts, especially outdated browsers. The CPALMS and iCPALMS team has developed the system to accommodate the technology in use, but local software remains a limiting factor.

**Teachers’ Lack of Computing Skills**

Some teachers do not possess basic computing skills, which has been a barrier to uptake. This issue is being addressed by local support through iCPALMS champions and regional coordinators. In addition, the problem is resolving itself as teachers become increasingly skilled in using information technology.

**Time Constraints**

Finally, the process of reviewing resources is quite time-consuming. The FSU team has addressed this issue by holding workshops to provide reviewers with dedicated time
to conduct review and to train new reviewers. In addition, when there is a backlog of resources to review, the team holds competitions and provides incentives to encourage participants to complete reviews.

**Outcomes**

Effects on Teaching

CPALMS and iCPALMS success is evident in enthusiastic responses from individuals in the user community. Case study participants spoke passionately about the benefits of instructional resources in terms of access to vetted resources that are aligned with state and Common Core standards; easing planning; allowing more time to focus on students; improved student engagement; and increased teacher confidence. Participants used terms such as energizing and addicting in describing their experiences using CPALMS and iCPALMS. Some users described how CPALMS and iCPALMS level the playing field, building capacity in rural and underserved schools. Similar views are also apparent in online testimonials about CPALMS and iCPALMS. Several participants in the case study provided comments that illustrate these benefits:

- It’s great to know that teachers have a one-stop shop where they can put in the benchmark, find a great aligned activity that’s age appropriate, that’s already vetted and ready to go for their students.

- No matter what you teach, you can find lesson plans and activities that help you to address the Common Core standards in your classroom, made easy.

- Teachers, especially in small schools who don’t have a lot of collegial support, can get a wealth of information and ideas.

Other benefits included increased confidence among teachers and early access to resources. Users who contribute or review resources noted a number of additional benefits for teaching. Participants reported that knowledge of the review criteria and process that they acquire by creating or reviewing resources contribute to their confidence in the quality of the available resources as a whole. Reviewers also noted that they benefit by having early access to resources through the review process.

More striking were a number of benefits related to professional growth and development. Comments included:

- This experience has really been enlightening to me as an educator because I have an opportunity to compare the lesson plans to the actual standards.

- I’m excited [about lesson plan development] because I know it’s going to have an impact on my teaching.
These benefits extend to teacher training via higher-education faculty who serve as reviewers:

I have an opportunity to share what I’m learning with pre-service teachers, so that they can find out about Common Core standards, look at what a good lesson plan is, and find some excellent resources so that they will be prepared as they move into the classroom.

Contributors and reviewers reported other benefits in terms of experiencing a sense of contribution to the community, as well as personal pride and empowerment. For example, one participant reported that Lesson Study, a professional development activity in which teachers collaborate to develop, observe, and analyze lesson plans, helped “build social capital.” Others reported:

I got an email yesterday saying my resource was published and I have been bragging about it all day. I received great feedback from the reviewers and I plan to share more lessons very soon.

The work we’re doing is so important for Florida’s teachers, and I think what we are doing now is going to be at the forefront of what the nation uses.

A faculty member and subject-matter expert reviewer, who has preservice teachers submit resources for review, reported a similar sentiment:

If it passes peer review, that’s very exciting for my [pre-service] students, because they then know that their work has been accepted by established classroom teachers and experts and is worthy of being a resource for other teachers.

Other Effects

Although iCPALMS was still under development at the time of this case study, and the study did not identify effects on learning other than statements about improved student engagement, CPALMS and iCPALMS have demonstrated success in terms of other outcome measures. A number of metrics demonstrate widespread uptake of CPALMS and iCPALMS resources and involvement of the community. By summer 2012, more than 8,200 resources had been submitted from approximately 5,000 people, plus there were approximately 3,000 private resources in individual users’ collections. More than 3,000 of the submitted resources had been approved on the basis of peer review. Six hundred reviewers had been trained, with 500 more people signed up for reviewer training. The project expanded from four initial partner districts to all districts in the state and expanded from science and math to include language arts. Users come from all states in the United States and more than 200 other countries.

This enthusiasm has spread beyond teacher–end users; members of the development teams are frequently asked to give talks at conferences in Florida. In fact, whereas in the early stages of CPALMS, the FSU team had to apply to give
presentations at conferences, members have since been invited to every supervisor conference in the state. They also receive frequent inquiries about the system from educators in other states.

Prospects for iCPALMS Sustainability

Many factors appear to be contributing to iCPALMS’s sustainability. The growth and uptake of CPALMS and iCPALMS and an enthusiastic user and developer community are important factors contributing to sustainability. In addition, the CPALMS and iCPALMS strategy and funding model promote sustainability in several ways. First, the cost to sustain infrastructure and existing resources is low because it is distributed across several projects and built on the existing DOE infrastructure that is supported by the state. Second, iCPALMS is integrated with the standards database and course directory (parts of CPALMS), which the Florida DOE is required by law to maintain. Third, the shared ownership model that the FSU team negotiated provides resources for maintaining iCPALMS. Finally, use of the systems in other projects and by other organizations (sometimes required, as in State of Florida requests for applications) helps promote the long-term survival of CPALMS and iCPALMS.

Lessons from Cross-Case Analyses

Similarities and Differences Across Cases

Distinct Organizational Contexts and Implementation Processes

These successful cases highlight distinctive organizational contexts and implementation processes.

CCS

In CCS, the initial focus of the project was earth science, and implementation was at the district level. The program used a process of demonstrating and then replicating the process in other districts and for other topical domains (physical science). CCS fostered technology readiness by providing all earth science teachers in DPS with hardware and Internet connectivity prior to rollout, in contrast to MERLOT and Noyce Scholars and CPALMS and iCPALMS, where technical infrastructure for clients was variable. CCS tapped an advisory board and used a financial services professional to promote commercialization. It also pursued research on the cognitive role of digital media in advancing science mastery among both teachers and learners.

Noyce and MERLOT

For Noyce scholars using MERLOT, the focus of the implementation was on STEM teacher credentialing. Key implementation activities included embedding digital resource use in preservice and in-service programs and fostering a large and persistent user-developer
community whose members also served as exemplars and ambassadors of the system. Forums, such as Noyce Voices, helped to foster community development among the scholars.

*iCPALMs*

For CPALMS and iCPALMS, the focus of the implementation was a statewide system. The programs used a modular but integrated approach to funding and development, used a strategically timed approach to roll out and market the system, and quickly established a critical mass of users and contributors.

**Commonalities in Activities, Processes, and Outputs**

Despite these differences in context and in some aspects of implementation, there were a number of commonalities in key activities, processes, and outputs contributing to success across cases (see Table 7.3). All teams had strong support from a host organization and key stakeholders that provided funding or other resources. In addition, each project had free and direct access to highly usable digital collections and to services to support the customization of resources, which were linked to educational standards. Participating teachers in all projects also could create their own resources or personal collections. Finally, each case supported the development of a large community of user-developers who contributed and reviewed resources and fostered diffusion.

There were, however, differences in the ways in which some success factors played out in each case:

- All three cases had visionary leadership or champions who played a central role in marketing the system and fueling demand among users. CCS had champions at multiple levels: the superintendent at the district level, science curriculum coordinators who played gatekeeper roles between CCS and the superintendent, and lead science teachers within schools. For Noyce and MERLOT, a CSU faculty member was a champion for MERLOT, and the Noyce scholars served as ambassadors by presenting the system at national conferences, mentoring other students in the use of digital resources, and becoming technology leaders at their schools. In CPALMS and iCPALMS, the project director was the primary champion, but a growing community of user-developers also served to stimulate demand for digital resources.

- All three cases used participatory design of the system beyond the project’s core development team; these participants included members of the TAB in CCS, Noyce scholars in MERLOT, and district math and science curriculum specialists in CPALMS and iCPALMS.

- All three projects provided training for users. This consisted of two weeks of training for all DPS earth science teachers, embedded training in CSU’s education program for Noyce Scholars, and training conferences and workshops in CPALMS and iCPALMS.

- All three cases provided technical support for users, although support came from difference sources: the development team in CCS, CSU and Noyce in MERLOT, and the project director in CPALMS and iCPALMS.
Table 7.3. Key Activities, Processes, and Outputs Contributing to Success

<table>
<thead>
<tr>
<th>Factor</th>
<th>CCS</th>
<th>Noyce/MERLOT</th>
<th>CPALMS/iCPALMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent organization or stakeholder support</td>
<td>DPS chief information officer, DPS senior science curriculum coordinator</td>
<td>CSU chancellor’s office provided institutional funding and supported ongoing development and expansion</td>
<td>FSU and the State of Florida provided funding and technical resources; other organizations and universities are using iCPALMS as a platform for development, contributing digital resources and funding</td>
</tr>
<tr>
<td>Goals</td>
<td>One-stop shop, usable, authoritative, linked to standards, customizable</td>
<td>One-stop shop, usable, authoritative, linked to standards, customizable</td>
<td>One-stop shop, usable, authoritative, linked to standards, customizable</td>
</tr>
<tr>
<td>Cost</td>
<td>Free</td>
<td>Free</td>
<td>Free</td>
</tr>
<tr>
<td>Visionary leadership or champions</td>
<td>District superintendent, district science curriculum coordinators, lead science teachers</td>
<td>Noyce scholars, CSU faculty champion</td>
<td>Project director, community of user-developers</td>
</tr>
<tr>
<td>Participatory design</td>
<td>Members of the TAB</td>
<td>Noyce scholars</td>
<td>District math and science curriculum specialists</td>
</tr>
<tr>
<td>Training</td>
<td>All earth science teachers in DPS received two weeks of training when system was rolled out</td>
<td>Use of digital resources embedded in education program for Noyce scholars</td>
<td>A focus or component of many of the funding awards, workshops and conferences to train teachers to develop and review resources</td>
</tr>
<tr>
<td>Technical support</td>
<td>Highly competent and supportive development team</td>
<td>CSU technical support and Noyce scholars</td>
<td>Project director</td>
</tr>
</tbody>
</table>

As the previous discussion suggests, several of the activities, processes, and outputs are interdependent and cumulative, as depicted by the logic model.

Providing access to usable, authoritative, and customizable collections, coupled with training and outreach, fostered the development of user-developer communities and other partners. The growing social infrastructure helped fuel demand for resources, and community members’ contributions in the form of creating, sharing, and vetting resources, plus support from partners, furthered the development of diverse collections of high-quality STEM instructional resources—thereby fueling additional demand and expansion of the community.
Lessons for Sustainability

Finally, we see three important lessons about sustainability from these full instantiations of the NSDL logic model. Again, there are several common factors across cases, although some played out in different ways:

- **First, a host institution provided strong support**—DPS in the case of CCS, CSU in the case of Noyce and MERLOT, and FSU for CPALMS and iCPALMS.

- **Second, there was funding from multiple sources**, particularly in the case of CPALMS and iCPALMS, which received support through a variety of grants and through partners using the platform for their own development.

- **Third, all three cases established large and persistent user-developer communities and partners** that can promote sustainability through their demand for resources and services and through the social capital they generate as they contribute back to the digital initiative.

Roles of NSDL in CCS, Noyce Scholars and MERLOT, and iCPALMS

NSDL played two distinct roles in these cases and in other projects it has supported over the years: It provided funding to enable projects to build or enhance digital collections or services, and through this funding, NSDL created a community and network of resources that enabled the projects to grow and contribute back to the collective NSDL effort.

**From a program perspective, the NSDL program’s chief role was to provide financial support to the projects.** Funding from NSDL helped each of these projects achieve promising preliminary results, but NSDL was only one source of support for these large projects. The CCS project began with NSDL support, but MERLOT and CSU had been working together for years before the NSDL project that established the Noyce Scholars Teaching Commons. Similarly, as Table D.1 illustrates, iCPALMS is part of a larger within-state enterprise that has enjoyed multiple sources of support before and after its NSDL award. Thus, NSF gave start-up funding to the CCS project, whereas, for Noyce and MERLOT and CPALMS and iCPALMS, it provided support to augment or enhance ongoing projects.

**From a digital library or community perspective, the NSDL portal has played a variety of roles in supporting projects** by providing:

- access to high-quality digital resources for project or user collections
- access to digital tools and services to develop project sites and systems
- capabilities to customize resources or tools and services by project developers or users
- repositories where projects can add new or revised digital materials
- sites where projects can add new or revised tools and services.

The NSDL portal has also helped to foster communities of developers and users who can share ideas and resources, tools, and services.
These roles reflect the components of the NSDL logic model and also mirror its dynamic processes: The NSDL program not only provides materials and services to its projects but also encourages the sharing of new and improved resources and services back to the NSDL portal and hence to the broader NSDL community. Give and take occurred between the NSDL portal and each of the case study projects, although the degree of exchange differed substantially. The CCS project made extensive use of NSDL content and services and also provided new or revised resources and tools back to NSDL. For example, the CCS service itself was built on EduPak and on the Strand Map services, both of which were provided by NSDL. When the CCS service was completed, it was incorporated into NSDL.org. The NSDL (DLESE) resources that were used by CCS were tagged with learning standards during the project, and these augmented resources were then submitted to NSDL.org. In contrast, the connections of Noyce and MERLOT and CPALMS and iCPALMS with NSDL were much less extensive and were confined largely to the use of NSDL resources and, in some cases, to sharing back with NSDL the digital resources that had been modified and tagged with educational standards.

The relationships between (1) Noyce and MERLOT with NSDL and (2) CPALMS and iCPALMS with NSDL may seem limited, but they are typical of the connections among NSF projects within a program. For the most part, NSF projects were funded individually, created independent products, and shared their products and findings with the research or education community through websites and other publications, such as research reports. Both the Noyce and MERLOT and CPALMS and iCPALMS projects went well beyond this sort of collaboration by making good use of existing NSDL resources and sharing their new resources directly with the digital library and community. Nonetheless, while NSDL funding may have helped these projects attract a broader funding base, it is not possible to document extensive use of the NSDL platform by these projects or tight collaboration between them and other NSDL projects, nor is it possible to establish the distinct value or impact of NSF’s investments in these enterprises.

The CCS case, in contrast, demonstrates how extensively the NSDL program can support a project, enabling it to build on the results of many prior projects and thus implement and deploy a system that has a positive impact on teaching and learning. It also demonstrates how a project can enrich the NSDL platform for other projects. The CCS project is thus a nearly ideal illustration of the synergistic power of the NSDL program—the whole being greater than the sum of its parts—that was originally envisioned in the NSDL logic model. To our knowledge, however, CCS is one of the only NSDL projects that has approached this ideal. In the final chapter, we discuss some of the reasons that this goal has been so challenging for the NSDL program to achieve, and we identify some implications for future cyberlearning programs.
Chapter Eight. Conclusions and Recommendations

In our concluding chapter, we summarize the key findings in terms of products and outputs of the NSDL logic model and other attributes of sustainability, draw conclusions from the evaluation results, and offer recommendations for fostering the development of sustainable digital initiatives. The conclusions and recommendations are not intended for the NSDL program per se, since it has ended, but instead are directed at two distinct audiences:

- NSDL projects that may continue in the future, specifically NSDL.org and the pathway projects
- future cyberlearning programs, which likely will need to address some of the same challenges that confronted the NSDL program.

In addition, throughout the report, we noted that our ability to assess products, processes, and outcomes of NSDL projects and the program as a whole was limited. Thus, we also provide recommendations regarding methodological approaches and research questions to inform future evaluation efforts for other cyberlearning programs.

NSDL Products and Outputs

We first consider how the results of this evaluation correspond to key products and outputs of the NSDL logic model. Overall, results about the success of NSDL are mixed.

To What Extent Did NSDL Produce Diverse Collections of High-Quality STEM Educational Resources?

We identified a number of strengths of NSDL resource collections, as well as improvements in the health of collections, between our Phase 2 formative evaluation and the Phase 3 summative evaluation. Notably, resource collections improved in terms of the authoritativeness and trustworthiness of materials represented. We also saw improvements in other aspects of collections’ health, such as some collections’ management practices (peer review for resource selection), publication of privacy and permitted-use policies, and basic search services.

Metadata quality and metadata harvesting processes also improved over time, and resources that we expected to find via metadata were generally available. Several important value-added features and services were also developed that should improve the ability of teachers and students to discover and use educational resources. These include the emergence of the LAR initiative and the alignment of resources with educational standards. Results of representative search tasks for lesson planning showed that the trustworthiness of the NSDL portal’s sources exceeds those from Google, but the relevance of search results needs to be improved, as does the accessibility of search from the top-level page for pathway portals. The NSDL portal may be
able to improve the relevance of search results by capitalizing on existing strengths—i.e., by making use of its high-quality metadata, connection to educational standards, and paradata. Research is needed, however, to determine the impact of these services on effective use of resources in classrooms and other educational settings.

To What Extent Did NSDL Produce Resources That Are Customized to a Range of Highly Specific Learning Goals or Standards?

We saw mixed evidence concerning the provision of customizable resources in the NSDL program. On the one hand, the alignment of educational standards to resources in metadata within the NSDL portal and some pathways is a significant contribution. The CCS project, reviewed as one of our key case studies, also demonstrated that resources could be effectively customized to the needs of middle school students and teachers in earth science curricula. On the other hand, few other projects have shown how materials could be tailored to specific educational requirements, nor have projects established that such customization can lead to improvements in teaching and learning outcomes.

Audience-specific portals, such as ones that target a specific grade level or audience role, are another way to provide resources that are customized to specific learning goals. In our review, we found few pathways that provide audience-specific portals. Additional efforts are needed in these areas, along with research on how availability of resources aligned to standards affects teacher practice.

To What Extent Did the NSDL Program Produce a Growing Array of Services That Discover, Organize, Reuse, and Mix Resources for Educational Practice?

The NSDL portal has a strong technical infrastructure. Some of the services that are directly tied to collections, such as those related to search, support item discovery and use. In addition, our review shows that funding was provided for development of a diverse array of tools and services. These ranged from innovative tools to help students assemble ideas gleaned from searches to ones that enable the content and services of the NSDL portal to be accessed through the existing national infrastructure of traditional libraries. Some Services projects focused on integrating new tools and services into the NSDL technical infrastructure, but others, such as NSDL on iTunes, demonstrated that the NSDL portal could be integrated into popular commercial platforms.

Although many NSDL projects created innovative services, the overall array of services developed by the program was mixed. A sizable number of projects showed no evidence of completion. Some projects developed similar or redundant services; other services important to NSDL program directors went unexplored. Overall, most projects appeared to develop their tools and services independently of other projects, and thus we did not see as much collaborative reuse and mixing of services as the NSDL logic model might have predicted.
To What Extent Did NSDL Produce a Growing and Vibrant Community of Educational Digital Library Users, Developers, and Partners?

Our evaluation of community development in NSDL focused on several overlapping features of the logic model:

- user contributions to collections within individual projects
- the development of new resources, including metadata, and services and tools by individual projects, which were then shared with NSDL
- the reuse of existing NSDL resources and NSDL tools and services by projects, with revised resources, tools, and services shared or integrated back into NSDL
- the use of a common technical platform or infrastructure that facilitated the sharing of interoperable resources, tools, and services among NSDL projects.

The NSDL program and the pathways have demonstrated a number of strengths with respect to the first two features. Projects have developed services that enable users to organize, comment on, contribute, and share resources, which provide opportunities for engagement and may improve workflow practices of education practitioners. The use of annotations and paradata at NSDL.org provides richer contextual information that may help teachers find and make effective use of digital resources, although much more research is needed to understand the use and effects of these features, particularly paradata. The case studies, particularly CPALMS and iCPALMS and Noyce and MERLOT, document how community participation engenders user enthusiasm about digital resources and enhances teacher professional development.

The evidence for community development processes across projects (the last two bullets above) was relatively weak. On the one hand, the CCS project case study showed that the process could produce substantial benefits in terms of the speed with which projects and tools could be implemented and deployed. On the other hand, it was one of the few successful cases that demonstrated the value of the collaborative and community-based approach at the program level. The review of services in Chapter Five indicated that, while some projects planned to work collaboratively to integrate their services into NSDL, a sizable number did not. NSDL program officers tried to encourage the community-based development process by funding the infrastructure projects as large cooperative agreements and more generally tried to control the products and processes of grants through the refinement of tracks, especially the pathways. However, results suggest that using blunt instruments, such as program tracks for grant-funded endeavors, provided limited control over the direction of projects.

Is the NSDL Enterprise Sustainable?

The NSDL program ended in FY 2011, and many of the NSDL pathways continue to operate. As of December 2014, management of NSDL.org was transferred to the Institute for the Study of Knowledge Management in Education and is available at https://nsdl.oercommons.org/.
The NSDL program’s original mission was to assemble a distributed library that would be widely available to the public, so it is still sensible to ask whether the NSDL enterprise is sustainable, even though the program itself has been discontinued. The short answer is that it faces challenges on each dimension of sustainability that our framework identified.

The results document a number of strengths with respect to important attributes of collections. However, improvements are needed in the pathways to enhance accountability to the audience and usability in terms of publishing a sound copyright strategy, documenting copyright and permitted uses in resource metadata, and enabling searching from the front page of each site.

**Pathways need substantial improvement in other aspects of audience.** Critical areas of needs include audience identification, clear distinctions between clients and customers, and collaboration with those audiences to meet clients’ and customers’ needs. Ultimately, clearer statements of audience, along with efforts to identify competitors in the digital education marketplace, are needed to establish the value proposition of each initiative.

The greatest need for improvement in NSDL is in attributes of organizational sustainability. We found little evidence of staffing for operational roles. Although project PIs served in entrepreneurial roles for the initial development and research activities, it is not clear that leadership is changing in a way to support sustainability over time. Although there are diverse stakeholders across pathways, it is not always clear what roles these stakeholders play, and there is little direct evidence of strategic plan or funding for sustainability.

**In short, it is still unclear whether the NSDL enterprise and its main portal, NSDL.org, can be sustained.** Long-term success may require changes not only in these aspects of sustainability but also in culture or mind-set. The current mind-set of NSDL leaders is that of academics and researchers whose primary customer is a sponsoring research agency or foundation. The mind-set may need to change to that of a nonprofit organization focused on meeting the needs of a more diverse range of clients and customers.

**Trade-offs in Developing Sustainable Digital Initiatives**

Results of the Phase 3 evaluation point to a number of trade-offs in developing and sustaining digital initiatives. We discuss these trade-offs here, followed by proposed recommendations to resolve these tensions.

**Innovation Versus Trust**

As the web grows, NSDL and other digital library initiatives must continue to expand collections to provide access to innovative content and genres and to present resources in compelling and informative ways (e.g., images rather than text), particularly to maintain relevance to digitally savvy users. This poses a potentially thorny trade-off. **On the one hand, NSDL projects have focused on providing access to high-quality digital resources by vetting collections, resulting in trust in the authoritativeness of hosted resources. On the other**
hand, this strategy excludes a good deal of dynamic and interesting content on the web, such as YouTube channels, Twitter feeds from prominent scientists, open-source online textbooks, and massively open online courses. Likewise, when users can annotate, rate, and perhaps combine and repurpose digital materials and place them in personal collections, their actions pose challenges to the authoritativeness of collections even while enriching those collections.

**Innovation Versus Control**

The vision of NSDL creating a complex digital library and community was very ambitious. **In terms of services, for example, a critical challenge to this vision was to ensure that a complete and coherent set of tools was created and maintained**—yet we identified redundancies and gaps in tools and services, as well as products that were not integrated with the NSDL portal. A single technical infrastructure, search and browse capabilities, and other needed tools and services might have been best built through contracts that articulated detailed delivery requirements and insisted on timely compliance, much in the same way that an automobile manufacturer contracts out production of different components of a car. However, in the early days of NSDL, it was far from clear what the program would become. Under such circumstances, it was reasonable that the NSDL program used grant funding—which provides much less control by the funding agency—to support several different approaches, learn from the experiments about which services worked best, and then abandon most of them while funding the refinement of only a few. Indeed, greater program control over development might have discouraged the discovery of unexpectedly useful services, such as OCKHAM’s tools, which seamlessly integrated digital collections with traditional libraries. That we observed many service projects which did not fulfill all their plans may be evidence of healthy research experimentation rather than project or program failure. Additional investigation is needed to explore these alternative explanations.

The importance of promoting research to foster innovation may also partly explain why projects in the Services track had varied relationships with the NSDL program and its portals, which ranged from tight couplings with the NSDL portal to very loose connections, in which projects developed ideas and prototypes that were relevant to NSDL but not implemented in NSDL sites. For well-established services, such as faceted search or browsing, it was reasonable that the program would expect funded projects to implement versions that could be integrated quickly into the NSDL platform. However, since the program also sought to fund a flow of innovative, potentially high-risk ideas for new services, it was also understandable that NSDL would first support projects that would develop these services as prototypes—or perhaps in a smaller-scale repository than the NSDL portal—with the expectation that these projects would be transitioned to and refined in the larger repository. This approach reflects the logic model for NSDL, which emphasizes the development of a growing array of services to discover and reuse resources for educational practice.
Similarly, the program structure and funding mechanisms may explain shortcomings in sustainability, particularly with respect to organizational attributes. Most of the PIs and institutions that successfully competed for NSDL grants were primarily interested in conducting research and development in the area of digital libraries or related aspects of cyberlearning; they may have had neither the background nor the interest in developing a sustained digital enterprise. Their original proposals did not include support for a financial or marketing manager, nor was this expected by NSF, particularly in the early stages of the NSDL program.

Collaboration Versus Efficiency

The previous sections note several reasons why collaborative yet relatively independent and parallel processes to develop NSDL collections and services might lead to more-innovative results than highly controlled and tightly coordinated processes would yield. However, there are clearly areas where the efficiency of a central decision is preferable. It is easier to manage copyright and permitted uses, for example, when a collection is centrally controlled. Indeed, having a single usage policy across multiple NSDL collections and pathways, not just within each one, can greatly help users understand what they can do and cannot do with NSDL resources.

Community development can create synergistic results, but also may engender coordination costs. Users who want to submit composite or repurposed materials to an NSDL collection, for example, may pose compliance challenges for centralized copyright and terms-of-use policies, impose additional accession burdens on collection managers, and strain the collection policies of digital libraries. Privacy policies may also be challenged as users become more-active participants in digital library communities rather than mere consumers of digital resources—and thereby risk sharing more information than they want to about themselves. In general, NSDL, like many digital libraries, wants to encourage its users to become producers rather than just passive consumers of digital resources, but this will impose additional management and monitoring costs on the library operators—assuming that they want to maintain high levels of quality.

Recommendations to Address Trade-offs

Some of the tensions we identified in NSDL program structure, processes, and products may be understandable and, in some cases, even predictable. However, several of the issues persisted over the lifetime of the NSDL program, which suggests the need for remediation. Moreover, future cyberlearning initiatives are likely to encounter similar issues. The following recommendations aim to anticipate and address these issues in these new ventures.

The tension between innovation and trust could be addressed, in part, by tagging content to indicate that it is not vetted or to have different collections for vetted and nonvetted content. In concert with this approach, digital initiatives could solicit reviews of new content.
from trusted (e.g., registered or trained) users and provide an indicator of rater expertise along with each review. These approaches would enable a digital repository, such as NSDL, to acquire new content at a faster rate than it once did while preserving its reputation for quality.

If sustainability is a goal of future digital learning initiatives, the tension between innovation and control can be addressed by (1) making it clear from the outset that projects seeking ongoing funding are expected to plan for sustainability and (2) supporting projects using a combination of grant and contract funding. That is, in early stages of the program, grant funding can provide project teams with freedom to experiment and innovate. In later stages of the program, projects that have produced promising results and have designed plans for sustainability can be funded under contract or cooperative agreement to implement such plans and transition their products to other sponsors. Likewise, contracts or cooperative agreements could be used to fund development of specific tools, services, and collections to fill gaps identified as a program evolves. Use of these alternatives to contracts may be particularly appropriate when a program is attempting to develop a collaborative enterprise rather than fund independent research activities.

An important strategy to complement this approach is to ensure that projects are evaluated on criteria for sustainability in annual progress reports, following the concepts and attributes identified and applied in Chapters Three and Four in this report. For example, PIs might be asked to provide evidence that they have identified and engaged a specific target audience, articulated their value proposition, hired operational staff, built linkages with other departments, formulated a strategic plan, and so forth.

Several components of the Phase 3 evaluation demonstrated ways in which the whole of NSDL is greater than the sum of its parts; indeed, many of the projects’ products are highly interdependent. For example, the NSDL portal and pathways are jointly generating composite metadata and paradata; in addition, resources are often linked across pathways and portals. As described above, this creates a variety of coordination costs. Thus, an important consideration for future community-based digital initiatives is that sustainability cannot be addressed simply project by project; sustainability requires an integrated or holistic approach to management.

In Chapters Three and Four, we discussed the need for digital initiatives to be accountable to their clients and stakeholders through such avenues as measurable goals, annual activity reporting, and active engagement with clients in understanding and responding to their changing needs. The recommendation regarding criteria in progress reports requires that projects be accountable to the program. The tension between collaboration and efficiency in the evolving ecosystem of collections, tools, and services can be addressed, in part, by promoting mutual accountability among all the stakeholders engaged in developing the digital initiative. Improving accountability provides a means of getting stakeholders more involved while also providing a structure to guide their involvement and collaborative activities. Inconsistencies in collection-building strategies and services, such as metadata application and use, which were
documented in our Phase 2 assessment (Bikson et al., 2011), were evidently attributable, at least in part, to the fact that pathways were accountable only for delivering what they promised in proposals to the funding agency, NSF, and not to the policies and practices of the NSDL RC. Mutual accountability requires engaging partners in developing the program purpose and mission, clearly communicating goals and expectations for participation in the program, documenting mutually agreed on requirements with each contributor, and evaluating compliance with requirements. Such requirements might call for projects to

- commit to producing particular resources, tools, or services to meet program needs
- make digital resources, such as learning modules and curriculum components, broadly available to the community
- develop resources and services on a common infrastructure
- use common standards so that products can interoperate with those developed by other projects
- reuse materials where possible rather than duplicate tools or content.

Improving Evaluation of Digital Initiatives

The Phase 3 evaluation addressed a range of inputs, processes, products, and outcomes in the NSDL logic model and reviewed the attributes in the sustainability model using multiple methods, including document and website review, expert judgment, a usability experiment, and replicated case studies. At the same time, as we have noted throughout this report, a wider range of research targets and methods is needed for a thorough evaluation of NSDL or other digital initiatives.

Most important is evaluating impact on student engagement and learning, given that these are the principal aims of the NSDL program. Research resulting from individual projects—particularly using methods that allow inferences about causality—is a critical component of a comprehensive evaluation. In the Phase 2 evaluation, a review of reports and research papers from the 250-plus NSDL projects that directly involved teachers or learners found that most projects used self-report methods, which do not support inferences about teaching or learning effects (Bikson et al., 2011). Experimental or quasi-experimental methods are needed to draw inferences about teaching and learning effects and other outcomes. Ideally, randomized controlled trials would be used to assess the direct effect of using NSDL resources, by teachers or by students, on students’ STEM content knowledge, as well as on learning process, such as time that students spend engaging with educational resources. Alternatively, quasi-experimental studies could be used to assess pre-post knowledge gain and engagement among students using NSDL resources compared with matched controls. Likewise, assessing teachers’ knowledge gain and performance as result of using NSDL resources should be investigated.
Collecting data about related processes and outcomes from NSDL clients and customers is also important given the significant roles they play in the program’s logic model—and, presumably, in other digital enterprises, particularly those that rely on community-based, collaborative development. Evaluation methods, such as focus groups, individual or group interviews, and surveys can be used to address a variety of elements in the logic model, as well as other research questions we have identified. For example, data collection from clients might investigate the following questions:

- How do metadata support educators for lesson planning and delivery?
- How do paradata influence the identification and selection of resources?
- How does the presentation of search results affect resource selection?
- How do users evaluate their experience using the programs’ digital collections, tools, and services, particularly as compared with competitors’ resources?
- What factors promote or inhibit use of digital resources?

We had designed a teacher survey for the Phase 3 evaluation to address some of these issues. However, NSF decided not to go forward with that component of the evaluation. The teacher survey can be found in Appendix E. It can be used or modified for evaluating other digital initiatives.

Data from program and project staff can be used to assess processes related to organizational sustainability, such as development of strategic plans and funding for sustainability, and how the initiative contributes to the mission of the parent and sponsoring institutions (and vice versa). Data from parent and sponsoring institutions would address the same question regarding joint benefits.

In addition to collecting primary data from clients and customers, secondary data can provide a variety of additional information about the health of digital initiatives’ inputs, processes, and outputs, and outcomes.

- As described in the Phase 2 report (Bikson et al., 2011), web metrics can be used monitor traffic flow, usage patterns, sources and destinations of users, use of private spaces to store and tailor materials, contributions to shared spaces, and the like. Assessment of use of private and shared spaces, in particular, may shed light on how users are customizing resources to meet teaching needs, as the logic model predicts. Web metrics also can be used to examine the effect of program innovations on resource uptake, such as NSDL’s integration of services with iTunes.
- As we have described in this report, projects’ annual and final progress reports include data that can address whether projects form alliances with other partners, change their plans to achieve revised program goals, and successfully complete proposed products. Moreover, these reports can be designed to assess specific criteria associated with creating sustainable enterprises, such as audience identification, operational staff, and strategic planning.
• We reviewed a subset of abstracts from NSF public data to examine development and sustainability of NSDL tools and services. A more comprehensive review of abstracts and updates of all projects (including collections) can be used to develop a taxonomy of products to support a gap analysis—i.e., to characterize the types of objectives a program’s projects targeted, and ones they did not pursue, to complement results from primary data about specific project goals and activities.

• As described in the Phase 2 report (Bikson et al., 2011), a review of articles, conference presentations, and other scholarly research products can point to lessons learned at the project and program levels. Similarly, other scholarly sources, such as bibliographic databases, citation indices, and impact metrics, can be used to assess project outputs. These measures not only would reveal the productivity of individual project investigators but could enable evaluation teams to characterize the evolving social network of collaborators across projects.

New text-mining and visualization tools are making it possible to uncover key themes and topics in secondary data. Application of these methods can enable evaluators to examine thousands of projects that may be funded over the lifetime of a program, rather than restricting data collection and analysis to a relatively few key projects and results, yielding more-complete information about outcomes, such the diversity of products, gaps, and redundancies in tools and collections and perhaps unexpected new topics of research and development.

Finally, a key recommendation for other programs is that cyberlearning initiatives, particularly multiyear, collaborative initiatives such as the NSDL program, need a much greater focus on sustainability from the beginning to balance the emphasis that NSF has traditionally placed on innovation to demonstrate broader impact. Initiatives such as NSDL require years to demonstrate impact, and thus the elements that contribute to impact need to be tracked over time. Our sustainability model is the first attempt that we have discovered to identify the key concepts and attributes of sustainability and to develop rubrics that assess the likelihood of sustainability for complex multiyear digital initiatives. We encourage NSF to build on our work to incorporate concrete sustainability requirements into solicitations and annual reporting requirements and, in particular, to target funding directly to products that have been identified as sustainable and worthy of ongoing development and support.
Appendix A. NSDL Organization Leadership

From 2000 through 2002, several pilot CI projects were funded, but by FY 2002, a single CI team emerged, comprising partners from UCAR, Cornell University, and Columbia University. They were supported by a five-year cooperative agreement with NSF. The CI awards were renewed in FY 2007, and the track was recompeted, with some changes organizational changes in FY 2008 (see Table A.1 for details).

Table A.1. Timeline of the NSDL Leadership Projects

<table>
<thead>
<tr>
<th>Dates</th>
<th>NSDL Organization Leadership</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000–2002</td>
<td>Several pilot CI projects funded</td>
</tr>
<tr>
<td>2002–2007</td>
<td>CI project awarded as cooperative agreement to UCAR, Cornell and Columbia</td>
</tr>
<tr>
<td>2007–2009</td>
<td>CI project provided “bridge funding” in a new cooperative agreement to UCAR, Cornell, and Columbia</td>
</tr>
<tr>
<td>2008–2012</td>
<td>CI project split into Resource Center and Technical Network Services, and the projects are recompeted; UCAR wins the Resource Center award and Cornell wins the Technical Network Services award</td>
</tr>
<tr>
<td>2011–2013</td>
<td>Resource Center and Technical Network Services merge under UCAR, and they are awarded a final grant to reposition NSDL for the next generation of digital learning</td>
</tr>
</tbody>
</table>
Appendix B. Evaluation of the NSDL Technical Platform

This appendix looks at the underlying technical infrastructure that enables NSDL to fulfill its purpose as a search portal for educational resources that currently support education in the STEM disciplines. The content reflects the situation as of 2013. An infrastructure that is sustainable, robust, and extensible is critical if NSDL is to be sustained and to have the impact it intends on STEM education for the long term. We examine the major components of the NSDL technical infrastructure and assess them according to standard and emerging rubrics for open-source software applications. The components that are evaluated are those identified by NSDL as the primary components of its technical architecture for NSDL 3.0 and forward.

Overview

The NSDL technical platform is a multilayered service architecture that is lightweight, integrated, and very functional for its stated purpose of providing high-quality, trustworthy educational resources for educators and end users in the STEM arena, and indeed across the broad spectrum of subjects taught in the K–20 educational environment.

The NSDL technical platform is a metadata-centric platform—that is, the platform provides major services to ingest and create metadata records and to organize, index, and display metadata records in response to search user queries. Services were developed to enhance the usefulness and relevance of metadata, including harvested paradata. The resources themselves are hosted at third-party sites and are out of scope for the technical platform, except that links to external resources are checked periodically and metadata are removed in response to broken links.

Many articles have been written on open-source software evaluation (Donham, 2004; Mangalam, 2010; OSS Watch, 2010; Wheeler, 2004; Wheeler, 2011). Many experts coalesce on a number of attributes for useful and successful open-source software: functionality and fitness to purpose, integration with other components in an architecture, documentation, usability and ease of installation and use, maturity, security, and licensing terms. These attributes are used when relevant for the evaluation of major components of the NSDL Technical Platform, supplemented with measures specific to this evaluation. All of the NSDL technical components are offered under GNU General Public License, version 2 (GPLv2),27 an industry standard license permitting copying, modification, and redistribution of the open-source software when basic conditions with respect to copyright notice and warranty are met (GNU, 2013). All components were developed by Digital Learning Sciences, “a mission-centered, not-for-profit

27 GNU is a Unix-like free operating system, as well as a recursive acronym that stands for “GNU’s Not Unix!” See http://www.gnu.org/.
organization dedicated to improving learning through the use of digital content and tools” (Digital Learning Sciences, n.d.). Digital Learning Sciences is a joint venture of UCAR, which is the parent institution for NSDL going forward, and the Institute of Cognitive Science at the University of Colorado at Boulder.

**Metadata Creation and Ingest**

Metadata ingest is provided through two applications: the NCS (NSDL Collection System) and the Java-based Open Access Initiative (jOAI) Protocol for Metadata Harvesting (OAI-PMH) application.

The NCS is a reference implementation of the Digital Collection System (DCS). The NCS is a web-based metadata creation and workflow management tool. It is built on Java servlets running in the Apache Tomcat servlet container. It has been tested on Linux, Windows, and macOS server operating systems. The NCS was originally developed for DLESE and is still used by that collection portal. It is also used by the SMILE pathway. Both of these portals have contributed functionality to the NCS. DLESE has contributed the adn and dlese_anno metadata frameworks. The adn metadata framework provides an application profile of IEEE learning object metadata, while the dlese_anno metadata framework provides a schema for capturing annotations, comments, ratings, reviews, and other ancillary information about resources. The SMILE portal contributed the bounding box widget, a GIS application that translates graphical coordinates, created by drawing a box in a Google map, into coordinates stored in metadata. In addition to SMILE, the NCS is used by the Middle School Portal and may be used by other collection portals associated with NSDL.

Functionally, the NCS is organized to manage metadata that are documented in Extensible Markup Language (XML) schemata. The metadata XML schema is used as the organizing paradigm, providing validation and elements for establishing metadata fields for use with input forms for metadata creation, as well as the rules for validating the information input into each metadata field. Several schemata are resident in the application, including ncs_item, an educational metadata schema for NSDL resources, and dlese_anno, adn and ncs_collect, for collection-level metadata. However, the application is very extensible and can be configured to support any XML schema-based metadata. One very useful functionality is the Content Assignment Tool, which uses natural language processing to recommend educational standards from ASN, which the cataloger can select for the metadata record or browse to find a more relevant standard. ASN files are downloaded as XML files for use in the application and can be kept current by periodic downloading from ASN. Other useful functionalities include capabilities to (1) add controlled vocabularies, either as ordered lists or enumerations within a metadata framework (XML schema) or as referenced XML files; (2) add best practices (context-sensitive help in populating metadata fields); (3) provide definitions for controlled-vocabulary terms; and (4) share records with others (including NSDL) through an OAI-PMH data provider application. The NCS integrates with the jOAI application to provide this functionality.
Workflow management is provided by user type (cataloger, manager, administrator) associated with privileges within specific collections. Workflow control at the record level is provided by statuses, with the ability to publish a metadata record in the NSDL Digital Discovery System (DDS) tied to a status indicating readiness for publication. Statuses support completeness not only in terms of catalog record quality but also in terms of resource content review (e.g., recommended, approved). The NCS integrates with the DDS, the repository service, through registering a collection with the NSDL DDS through the setting of a collection parameter. Once a collection is registered, records can be stored in the local NCS implementation, saved to the NSDL DDS, or synced across the two file storage areas.

NCS is a well-designed metadata management system that rates highly for design, functionality, and integration with the repository application or DDS of NSDL. The support for any XML schema–based metadata implementation (described as a metadata framework) is very functional because it enables users to work with any metadata format that is documented as an XML schema. We created sample records in the test implementation and found the NCS easy to use from the cataloger’s perspective. However, the decision to use the XML schema as the organizing principle for the NCS design is not without its drawbacks. To begin with, it limits implementation to metadata with an XML schema, thus requiring either the use of a standard XML-based metadata format (e.g., Dublin Core, Metadata Object Description Schema) or significant expertise in XML schema design. Since XML schemata require that elements be documented, the NCS limits customization for those not proficient in schema design to the adding of vocabulary terms and decisions on how to use existing metadata elements. Other drawbacks to the design are that duplicate records can be identified and vocabularies customized only within frameworks, not within collections. Collections, which are presumably content- and organization-based, would be the preferred structure for assigning vocabularies and deduping.

A key area of evaluation is that of maturity, which includes dimensions of robustness, reliability, and sustainability. Two important ways to look at maturity for an open-source application are to evaluate its adherence to Generally Recognized as Mature (GRAM) technologies (Mangalam, 2010; Wheeler, 2004). GRAM technologies are well understood and well documented, in widespread use, and have robust and stable performance. Java servlets and XML schemata are robust technologies with strong traction in the web application space. The NCS rates well in GRAM. In recent years, a number of models have emerged to rate the maturity of open-source software applications across sociotechnical dimensions, so that user support is weighted along with technical design, with the weights determined by the needs of the organization evaluating the software. A popular model is the Navica Open Software Maturity Model (OSMM) (OSS Watch, 2010). The OSMM assesses maturity across six categories, with each category weighted according to the need of the organization evaluating the application. The default weighting is provided in Table B.1.
Table B.1. Navica OSMM Categories

<table>
<thead>
<tr>
<th>OSMM Category</th>
<th>Default Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>4</td>
</tr>
<tr>
<td>Support</td>
<td>2</td>
</tr>
<tr>
<td>Documentation</td>
<td>1</td>
</tr>
<tr>
<td>Training</td>
<td>1</td>
</tr>
<tr>
<td>Integration</td>
<td>1</td>
</tr>
<tr>
<td>Professional services</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
</tr>
</tbody>
</table>


Table B.2 shows our evaluation of the NCS, using the Navica OSMM default weighting. The NCS receives a maturity rating of 55 out of a possible 100.

Table B.2. NCS OSMM Maturity Rating

<table>
<thead>
<tr>
<th>OSMM Category</th>
<th>Default Weighting</th>
<th>Possible Score (out of 100)</th>
<th>NCS Score (out of 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>4</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Support</td>
<td>2</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Documentation</td>
<td>1</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Training</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Integration</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Professional services</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

As noted, the software application is well designed, using mature, widely deployed technology, and it integrates well with the rest of the NSDL technical platform. Support, however, is minimal and consists of an email list on the SourceForge site and a generic contact form at the NSDL Documentation Wiki (Weatherley, 2015). Additional points were awarded for evidence of continued development of the application—specifically, the integration of an API for third-party plug-ins. There is no evidence of professional services to assist with implementation or training, other than a small sandbox where potential users can test-drive the cataloging module. The documentation is also minimal, consisting of a user guide without a date that explains basic functionality but lacks examples and screenshots.

A final concern with the application is the lack of security beyond password authentication for administrators, managers, and catalogers. Given the shared web environment, which might involve different organizations utilizing the same software implementations, encryption for the administrative functions, at a minimum, should be provided.
Java-Based Open Access Initiative Metadata Harvesting Protocol

The jOAI utility offers a Java-based OAI-PMH data provider and harvester tool that runs in Tomcat. OAI-PMH is an industry-standard protocol for supplying and harvesting metadata that is in wide use in the digital repository community. OAI-PMH implementations can support the data provider role, where the repository makes metadata available, and the harvesting or service provider role, where the metadata are harvested from data providers. The HTTP protocol and registered metadata formats (at a minimum, Dublin Core) are utilized by the protocol. Each metadata record, or item, must have a unique identifier. Metadata may be supplied based on such parameters as date range or as a defined set, which corresponds broadly to a collection of metadata items. OAI-PMH applications may support data provision (responding to requests), harvesting (requesting metadata), or both (Open Archives Initiative, n.d.). The OAI implementation within the NCS, discussed above, supports data provision only. The jOAI supports both. OAI-PMH, currently in version 2.0, is designed to be a “low-barrier mechanism for repository interoperability” (Open Archives Initiative, n.d.). Its use among repositories is widespread and well understood. The current release supports LAR metadata.

An in-depth evaluation of jOAI would require downloading the software or testing the NSDL jOAI implementation through either providing or harvesting metadata, neither of which was within the scope of this evaluation. However, based on a comparison with other OAI harvesters available for download, jOAI was assigned a rating of 70 out of a possible 100 on the Navica OSMM rating, using the default weighting for this rubric. The ratings for each category are provided in Table B.3.

Table B.3. jOAI OSMM Maturity Rating

<table>
<thead>
<tr>
<th>OSMM Category</th>
<th>Default Weighting</th>
<th>Possible Score (out of 100)</th>
<th>NCS Score (out of 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>4</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Support</td>
<td>2</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Documentation</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Training</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Integration</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Professional services</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
<td>100</td>
<td>70</td>
</tr>
</tbody>
</table>

The software was developed using industry-standard Java servlets in a Tomcat environment. Development for jOAI is quite active, with a history showing releases (primarily bug fixes), every few months. There is an active users’ forum at the SourceForge download site (SourceForge, undated). Additionally, jOAI compares favorably with other open-source harvesters in terms of software maintenance and documentation. OAI is a well-understood and
well-documented protocol that works in essentially the same manner with any software application. There are readily available guidelines and best practices on the web, so little documentation is needed. The use of Java under Tomcat ensures integration with the other components of the NSDL technical platform: the NCS and the DDS. Although the developers are responsive in terms of fixing identified bugs, there is no evidence that training or professional services, such as guidance in installation or direct troubleshooting for users, is provided.

In terms of NSDL’s own implementation, two specific areas of evaluation we considered are whether jOAI is being used to its best advantage in NSDL’s roles as (1) a data provider and (2) a service provider. NSDL can best expose its resources for harvesting through registering NSDL with prominent OAI repository-harvesting gateways, so that anyone wanting to aggregate STEM education resources would be able to do so. The NSDL OAI implementation is well represented in this regard and is discoverable at the University of Illinois OAI-PMH Data Provider Registry (University of Illinois at Urbana-Champaign Grainger Engineering Library, n.d.) and the OCLC WorldCat OAIster database (OCLC, n.d.), a union catalog of millions of metadata records harvested via OAI from OAI data providers.

The most important role for the jOAI implementation at NSDL is as a harvesting utility to aggregate metadata from participating repositories to fulfill the NSDL role as a union catalog of STEM educational resources. We examined ten resources from each of the 18 active NSF-funded pathway portals, as a component of metadata and collection evaluation. One part of that examination included checking that metadata records available at each pathway portal were also available at the NSDL portal site. Of the 180 metadata records examined, four were eliminated from this metric because the resources were not available at the resource links provided in metadata. These metadata records may have been appropriately weeded from the NSDL portal, because their links to resources were broken. One hundred and fifty of the remaining 176 metadata records were available at both the pathways portals and the NSDL portal, for an overlap of 85 percent. This measure was also used in the 2010 formative assessment of NSDL. In that assessment, 267 pathways metadata records were examined, and 184 of those records were available in the NSDL portal, for an overlap of 69 percent (Bikson et al., 2011).

The overlap by pathway is shown in Table B.4. Although there is considerable improvement in overlap between collections as a whole and NSDL from 2010 to 2013, the lack of overlap between the participating collections and the union catalog remains substantial, at 15 percent, largely because of a few of the pathways. As shown in Table B.4, overlap for most of the individual pathways ranges from 90 to 100 percent, but overlap for some pathways is quite low. Low overlap may be due to time lag; according to the NSDL technical lead, NSDL harvests from each partner OAI data provider approximately once a month. However, it may take up to two weeks before those changes are reflected in the NSDL Search API and OAI data provider indexes. Therefore, at any given time, there may be as much as six weeks’ worth of changes in the partner’s OAI data provider output that have not yet been reflected at NSDL (John Weatherley, personal communication, December 21, 2012). NSDL may want to consider
adjusting the harvesting schedule for those collections where overlap is weakest for any pathways collections continuing forward with NSDL 2.0.

Table B.4. Record Overlap Between Pathways Collections and NSDL

<table>
<thead>
<tr>
<th>Pathway Name</th>
<th>Number of Pathway Records</th>
<th>Number of Records Available in NSDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMSER</td>
<td>9</td>
<td>9 (100%)</td>
</tr>
<tr>
<td>BEN</td>
<td>9</td>
<td>9 (100%)</td>
</tr>
<tr>
<td>ChemEdDL</td>
<td>10</td>
<td>6 (60%)</td>
</tr>
<tr>
<td>CLEAN</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>ComPADRE</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>CSERD</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>DLESE</td>
<td>10</td>
<td>9 (90%)</td>
</tr>
<tr>
<td>Engineering Pathway</td>
<td>10</td>
<td>3 (30%)</td>
</tr>
<tr>
<td>Ensemble</td>
<td>9</td>
<td>1 (11%)</td>
</tr>
<tr>
<td>iCPALMS</td>
<td>10</td>
<td>9 (90%)</td>
</tr>
<tr>
<td>MatDL</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>MathDL</td>
<td>10</td>
<td>6 (60%)</td>
</tr>
<tr>
<td>MathLanding</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>Middle School Portal</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>SMILE</td>
<td>10</td>
<td>9 (90%)</td>
</tr>
<tr>
<td>Teacher’s Domain</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>Teaching with Data</td>
<td>9</td>
<td>9 (100%)</td>
</tr>
<tr>
<td>Teach the Earth</td>
<td>10</td>
<td>10 (100%)</td>
</tr>
<tr>
<td>TOTALS</td>
<td>176</td>
<td>150</td>
</tr>
</tbody>
</table>

**DDS Repository Search Service and Search API**

The DDS Repository Search Service and Search API provide the critical interface between the NSDL Technical Platform and the end user. The DDS is a service application that provides XML-based search using a Search API based on Lucene and repository management based on the Repository Update Service API. The DDS creates, updates, and deletes collections and items in the repository. The APIs are designed using RESTful API design that is a REST-RPC hybrid (REST stands for representational state transfer; RPC stands for remote procedure call).

The DDS can support customized search and display through portal configuration to support different audiences or applications. The DDS is used by NSDL, DLESE, the National Center for Atmospheric Research Library, CCS (Denver Public Schools), and the NSDL STEM Exchange. The DDS is in release 3.6.0, based on the release notes, although that version does not appear to be available for download at SourceForge.
RESTful API design, a lightweight client-server design intended for distributed environments, such as the web, is based on the concept of REST. In a client-server transaction, the client initiates a request to the server that reflects a change to the representation (state) of a resource. The server responds to the request. Each request-response transaction effects a transition to a new state for a resource, which can be anything that can be addressed with a URL. RESTful transactions are frequently managed via the HTTP protocol, which generally utilizes URLs for the resource and a small vocabulary of request methods: GET, POST, PUT, and DELETE (Nadareishvili, 2011). RPC is another client-server protocol for invoking subroutines or processes in another address space and thus is useful for procedure communication across a distributed environment like the web (Marshall, 1999).

The Repository Update Service API uses the HTTP commands PUT and DELETE for collections and records. It does not include authentication and authorization but recommends placing the Tomcat server ports behind a firewall, configuring the collection manager module to accept authorized Internet Protocol (IP) addresses or passwords, or encrypting communications using secure socket layer (SSL).

The Search API supports the ability to search the NSDL digital repository and to build customized search and browse interfaces for applications, such as an audience-specific portal. The Search API uses a REST-RPC hybrid approach to accept requests expressed as HTTP argument-value pairs and respond with structured data in XML or JavaScript eye-readable text or JavaScript Object Notation (JSON) format, allowing developers to embed and reuse NSDL resources using a wide range of technologies, such as JavaScript, PHP (Personal Home Page), and JSP (JavaServer Pages) (John Weatherley, personal communication, December 21, 2012). The Search API supports textual search, fielded search, faceted search, relation search (searching by relationship among records, such as members of a collection, or all metadata related to a resource, based on unique identifier), date ranges, and geospatial searching of bounding boxes. Results can be sorted by relevance or by the values contained in any field. A strength of the Search API, as noted by Weatherley, is that the API provides a resource-centric view of the repository—that is, for each resource (URL), Search operates over and can return all associated metadata, annotation, and use data and paradata records associated with the resource in a single search hit (John Weatherley, personal communication, December 21, 2012).

The Search API is available through the DDS and the NCS/DCS as part of the suite of Java applications in Tomcat that create an integrated technical infrastructure for NSDL. The components are lightweight and easy to deploy, and they reflect mature, industry-standard technologies. The Search API utilizes Apache Lucene, a Java-based indexing and search technology available as open source via the Apache Foundation, which is a popular and very functional search utility used in major open-source repository applications, such as Fedora Commons and DSpace. Table B.5 shows our evaluation of the NCS, using the Navica OSMM default weighting (OSS Watch, 2010). The NCS received a maturity rating of 55 out of a
possible 100. As with the NCS/DCS application, the major concerns are lack of support and lack of integrated security functionality for repository management.

<table>
<thead>
<tr>
<th>OSMM Category</th>
<th>Default Weighting</th>
<th>Possible Score (out of 100)</th>
<th>NCS Score (out of 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Software</td>
<td>4</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Support</td>
<td>2</td>
<td>20</td>
<td>5</td>
</tr>
<tr>
<td>Documentation</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Training</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Integration</td>
<td>1</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Professional services</td>
<td>1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>10</td>
<td>100</td>
<td>55</td>
</tr>
</tbody>
</table>

**Conclusion**

NSDL generally receives high marks for a flexible, extensible, largely Java-based platform that is robust and well suited to a metadata-based collections portal. The components are industry standard, based on common metadata schemas and industry-standard protocols for metadata harvesting and search. The primary concerns are the lack of integrated security beyond basic user identification and password protection and lack of support for users in terms of training and personalized services. These supports will be critical for components such as jOAI and NCS, if they are extended to participating collection portals in NSDL 3.0 and beyond. Finally, there is some concern with implementation of the components, particularly the scheduling of jOAI harvesting and the implementation of the DDS Search API. We evaluated search more extensively in Chapter Six, where we also provide recommendations for improving search precision through the setting of relevance parameters.
### Table C.1. Expert Voices

<table>
<thead>
<tr>
<th>Service/Tool Name</th>
<th>Description of Expert Voices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year initiated</td>
<td>2006</td>
</tr>
<tr>
<td>Developers</td>
<td>Resource Center and Technical Network Services teams</td>
</tr>
<tr>
<td>Intended purposes</td>
<td>A blogging environment intended to increase community contributions to NSDL, relate library resources to real-world science events, and provide context for science resources in NSDL collections (Krafft, Birkland, and Cramer, 2008)</td>
</tr>
<tr>
<td>Antecedent services/tools</td>
<td>Built on the open-source multiuser WordPress blogging environment</td>
</tr>
<tr>
<td>Integration with NSDL</td>
<td>Expert voices extensively customized WordPress. It bore the NSDL branding and was integrated into the NSDL.org website. It also provided plug-ins to enable contributors to add resources to NSDL, link to NSDL resources, and add metadata. Blog posts that drew on NSDL resources were added to the NSDL repository as aggregations of resources.</td>
</tr>
<tr>
<td>Evidence of NSDL usage</td>
<td>By 2011, Expert Voices hosted dozens of blogs with thousands of posts from scientists, teachers, and others on many topics and at many grade levels. Web metrics suggest that Expert Voices had between 30,000 and 50,000 page views per week throughout 2010.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Use of Expert Voices declined steadily starting at the end of 2010; near the end of 2011, it was decommissioned as a supported NSDL service. Several reasons for the decline in users were discussed by the NSDL community: (1) The funding for the service project came to an end and (2) Expert Voices was inexpensive to create, but recurring operational and maintenance costs, especially related to the review of submitted user content, were not insignificant.</td>
</tr>
<tr>
<td>Subsequent services/tools or uses</td>
<td>By 2012, Expert Voices content was archived. Some blogs continue to be active on NSDL-related sites, although not on NSDL.org. Many NSDL-supported projects have adapted free and open-source blogging and social networking tools for their specific user communities.</td>
</tr>
</tbody>
</table>

*a* Web metrics data provided by the Resource Center in November 2012.
Table C.2. NSDL Wiki

<table>
<thead>
<tr>
<th>Service/Tool Name</th>
<th>Description of the NSDL Wiki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year initiated</td>
<td>2008 (the National Science Digital Library was initiated in 2008–2009)</td>
</tr>
<tr>
<td>Developers</td>
<td>Resource Center and Technical Network Services teams</td>
</tr>
<tr>
<td>Intended purposes</td>
<td>A social wiki used to facilitate resource sharing and repurposing, discussions, and engagement in the NSDL community</td>
</tr>
<tr>
<td>Antecedent services/tools</td>
<td>Built on Wikimedia Foundation’s open-source wiki, Mediawiki.</td>
</tr>
<tr>
<td>Integration with NSDL</td>
<td>NSDL wiki is an extensively customized Mediawiki. It included NSDL branding and was integrated into the NSDL framework; new pages in the wiki were added to the NSDL repository, and plug-ins allowed the wiki editing tool to directly reference and incorporate content from the NSDL repository. Wiki pages that embedded NSDL resources were added to the NSDL repository as aggregations and were available for other users to find, access, and repurpose.</td>
</tr>
<tr>
<td>Evidence of NSDL usage</td>
<td>The NSDL wiki was used primarily by two groups in NSDL. First, the Middle School Portal, a Pathways project, used the wiki to collect resources into guides, which combined multiple resources around a particular middle school math or science topic. Second, NSDL’s technical-developer teams used the wiki to house technical documents related to NSDL tools and services.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The NSDL wiki was decommissioned as a supported service in 2011. Reasons for the decisions included (1) limited use of the service throughout its lifetime, (2) recurring operational costs of maintenance and reviewing user-generated content, and (3) the availability of free wiki services from outside NSDL.</td>
</tr>
<tr>
<td>Subsequent services/tools or uses</td>
<td>By 2012, the NSDL wiki content was archived. Both the Middle School Portal and the NSDL technical-developer team have used publicly available wikis to house their content.</td>
</tr>
</tbody>
</table>
Table C.3. Strand Map and Science Literacy Maps

<table>
<thead>
<tr>
<th>Service/Tool Name</th>
<th>Description of Strand Map Service and Science Literacy Maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year initiated</td>
<td>2001 for Strand Map Service and 2007 for Science Literacy Maps</td>
</tr>
<tr>
<td>Developers</td>
<td>The Strand Map Service was developed as a Services project by UCAR and the University of Colorado. The Science Literacy Maps project was developed by the Technical Network Services team of NSDL.</td>
</tr>
<tr>
<td>Intended purposes</td>
<td>The Strand Map Service is an open-source API that enables developers to create relational, interactive maps of the Benchmarks for Science Literacy, a set of standards that articulates the relationships among science concepts. Developers can customize these maps to associate their own content with the concepts and standards and embed the map on their websites as a user tool. The Science Literacy Map is an instantiation of the Strand Map Service on NSDL.org that links concepts and standards to peer-reviewed and curated resources drawn from the NSDL repository.</td>
</tr>
<tr>
<td>Antecedent services/tools</td>
<td>The Strand Map Service depended on the earlier Benchmaps for Science Literacy developed by AAAS’s Project 2061.</td>
</tr>
<tr>
<td>Integration with NSDL</td>
<td>The Strand Map Services tool was supported and made available through NSDL, and the Science Literacy Maps is a specific application of that tool, which is available directly through the NSDL.org site.</td>
</tr>
<tr>
<td>Evidence of NSDL usage</td>
<td>The Strand Map Services tool has been used to implement many specific services, some of which are noted below. The NSDL Science Literacy Map service (<a href="http://strandmaps.nsdl.org/">http://strandmaps.nsdl.org/</a>) continues to be used, with approximately 3,000 visitors a week between October 1, 2009, and September 30, 2012.</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The future of the Strand Map Service and the Science Literacy Map is unclear. New standards, such as Next Generation Science Standards and Common Core are beginning to replace the Atlas Standards, on which the Strand Map Service is based. There could be significant value in developing a mapping service that draws on new standards, or one that is agnostic toward standards. The increasing availability of generic, open-source relational mapping tools and services suggests that there may be multiple paths toward realizing these goals.</td>
</tr>
<tr>
<td>Subsequent services/tools or uses</td>
<td>A number of pathways, such as DLESE and CLEAN, have used the Strand Map Service to provide their own concept maps. Follow-on grants further enhanced the Strand Map Service by linking educational concepts with misconceptions about those concepts (NSDL Technical Network Services, 2010). Since 2011, AAAS has used the Science Literacy Map in workshops and professional-development activities with teachers to disseminate the Atlas Standards.</td>
</tr>
</tbody>
</table>
Table C.4. Instructional Architect

<table>
<thead>
<tr>
<th>Service/Tool Name</th>
<th>Description of Instructional Architect (IA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year initiated</td>
<td>IA was initiated in 2001. Later grants were used to refine IA through participatory design from teachers in preservice education programs.</td>
</tr>
<tr>
<td>Developers</td>
<td>Utah State University, with support from NSDL and other NSF programs</td>
</tr>
<tr>
<td>Intended purposes</td>
<td>IA is a web-based tool that allows users—principally, teachers—to author websites that facilitate classroom use of online learning resources. In particular, IA &quot;enables users (particularly teachers) to discover, select, sequence, annotate, and reuse online learning resources stored in digital libraries to create instruction&quot; (Recker, 2008).</td>
</tr>
<tr>
<td>Antecedent services/tools</td>
<td>None</td>
</tr>
<tr>
<td>Integration with NSDL</td>
<td>Like the NSDL wiki and Expert Voices, IA is closely integrated with NSDL's repository. IA offers a federated search of the NSDL repository and enables users to store and embed links to NSDL resources in their own projects. Users can publish their projects for others to use, which NSDL harvests for inclusion in the repository. IA also pushes paradata to NSDL.</td>
</tr>
<tr>
<td>Evidence of NSDL usage</td>
<td>IA had 7,500 user accounts and more than 17,000 projects and continues to be used by teachers (as of September 2013), although that use has declined with the end of professional development and other active outreach activities (Recker, Sellers, and Ye, 2013).</td>
</tr>
<tr>
<td>Sustainability</td>
<td>While IA is no longer actively maintained (its funding period ended in 2008), it is being offered as an ongoing tool to teachers through a partnership between Utah State University and the NSDL Resource Center. Subsequent grants from NSF also offered professional development to teachers and evaluated the effectiveness of those efforts.</td>
</tr>
<tr>
<td>Subsequent services/tools or uses</td>
<td>None</td>
</tr>
<tr>
<td>Service/Tool Name</td>
<td>Description of NSDL on iTunesU</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td><strong>Year initiated</strong></td>
<td>2008</td>
</tr>
<tr>
<td><strong>Developers</strong></td>
<td>NSDL Resource Center and Technical Network Services team</td>
</tr>
<tr>
<td><strong>Intended purposes</strong></td>
<td>NSDL provides free access to audio, video, and other multimedia resources for science and math education through Apple’s iTunes Store and iTunesU. These generally come from NSDL collections and pathways partners. NSDL has uploaded several hundred resources to iTunesU that compose more than 30 distinct collections covering a wide range of STEM areas.</td>
</tr>
<tr>
<td><strong>Antecedent services/tools</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Integration with NSDL</strong></td>
<td>NSDL on iTunesU is not integrated into the NSDL.org website, but a link on that site (nsdl.org/iTunesU) allows users access NSDL’s iTunes resources in iTunesU, which is part of iTunes, Apple’s stand-alone media player and library application. NSDL on iTunesU has its own space under the category Beyond Campus. The space provides browsing access to all resources, and it has all NSDL’s standard branding.</td>
</tr>
<tr>
<td><strong>Evidence of NSDL usage</strong></td>
<td>iTunes provides no direct information on resource usage and downloads. However, even the resources rated as the most popular in NSDL on iTunesU appear to have had limited usage, as indicated by few customer ratings and reviews.</td>
</tr>
<tr>
<td><strong>Sustainability</strong></td>
<td>NSDL started contributing resources to iTunesU in 2008 and continued this practice into 2013. Most of the resources were uploaded in 2008 and 2009, and submissions dropped significantly after 2011. Nevertheless, since the cost of maintaining these collections appear low for NSDL, the service may be sustainable in the future.</td>
</tr>
<tr>
<td><strong>Subsequent services/tools or uses</strong></td>
<td>None</td>
</tr>
</tbody>
</table>
Table D.1. CPALMS and iCPALMS Funding Sources

<table>
<thead>
<tr>
<th>Program</th>
<th>Year Funded</th>
<th>Source</th>
<th>Primary Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida Center for Research in Science, Technology, Engineering and Mathematics (FCR-STEM)</td>
<td>2007</td>
<td>State of Florida</td>
<td>Build standards database and course directory</td>
</tr>
<tr>
<td>A Partnership to Rejuvenate and Optimize Mathematics and Science Education (PROMiSE)</td>
<td>2009</td>
<td>U.S. Department of Education (funded through the State of Florida)</td>
<td>Develop URL submissions, review process, and teacher professional development</td>
</tr>
<tr>
<td>iCPALMS</td>
<td>2010</td>
<td>NSF</td>
<td>Develop iCPALMS portal (tools, services, content, professional development - PD, and research)</td>
</tr>
<tr>
<td>Teacher Standards Instructional Tool</td>
<td>2011</td>
<td>Race to the Top, Florida Department of Education</td>
<td>Build lesson plans, lesson study tool kits, model-eliciting activities, perspective minivideo and series; add professional development system and modules; roll out system to all districts; provide training opportunities to all districts; make several modifications to CPALMS; add servers to host CPALMS/iCPALMS; and update software</td>
</tr>
<tr>
<td>Math and Science Partnerships/Bioscopes</td>
<td>2011</td>
<td>U.S. Department of Education (funded through the State of Florida)</td>
<td>Teachers, along with arts and science faculty, collaborate to build curricular resources on iCPALMS, professional development modules, and a lesson study support system app on iCPALMS.</td>
</tr>
<tr>
<td>CPALMS Charter</td>
<td>2012</td>
<td>Florida State University School—Charter and Lab school (funded by the Florida Department of Education)</td>
<td>Train charter schools on use of CPALMS/iCPALMS and establish a social aspect of iCPALMS called Spaces</td>
</tr>
<tr>
<td>Mathematics Formative Assessment System (MFAS)</td>
<td>2011</td>
<td>Race to the Top, Florida Department of Education</td>
<td>Develop ~400 formative assessment tasks and rubrics to include on CPALMS, add professional development modules on formative assessment, and develop a formative assessment app on iCPALMS</td>
</tr>
</tbody>
</table>

169
<table>
<thead>
<tr>
<th>Program</th>
<th>Year Funded</th>
<th>Source</th>
<th>Primary Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida DOE requests for applications/requests for</td>
<td>2013</td>
<td>Florida DOE</td>
<td>Some Florida DOE requests for applications are requiring the use of CPALMS and iCPALMS; grantees are required to post their professional-development modules and other products on CPALMS to go through the review process and be shared with educators</td>
</tr>
<tr>
<td>proposals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Career and Technical Education</td>
<td>2013</td>
<td>Florida legislature</td>
<td>Integrate career and technical education programs into CPALMS</td>
</tr>
</tbody>
</table>
Appendix E. Proposed Teachers’ Survey

Teachers’ Survey

The National Science Foundation (NSF) is seeking input from users of the National STEM Digital Library/Distributed Learning (NSDL) program. NSF has asked RAND, a nonprofit public policy research organization, to conduct an online survey of NSDL users. We contacted you because you have been a registered user of Teachers’ Domain, one of the NSDL pathways.

The questions in this survey address the use of NSDL resources for science, technology, engineering, and mathematics (STEM) teaching and learning. The term resources in these questions refers to any content (e.g., graphics, images, lesson plans), tools, or services, as well as research papers or instructors’ guides, that you might access via NSDL.org or any of its pathways (e.g., Teachers’ Domain; BEN: Biological Sciences Pathway, MSP2: Middle School Portal, DLESE: Digital Library for Earth System Education).

The survey takes approximately 20 minutes to complete. Your participation in the survey is completely voluntary, and you should feel free to skip any question you don’t want to answer. As a thank-you for participating, you can earn a $20 gift certificate to Amazon.com by entering your email address at the end of the survey. No other identifying information is requested in the survey.

Your responses will be used for research purposes only. We will not link your email address with your responses. We will keep all responses confidential and will not retain your email address after the study.

If you prefer a hard copy of the survey, along with a self-addressed, stamped return envelope, please contact Michael Woodward at 310-393-0411, x6595, or michaelw@rand.org.

If you have questions about this study, please contact Dr. Susan Straus, 412-683-2300, x4925, sgstraus@rand.org, RAND, 4570 Fifth Avenue, Pittsburgh, PA 15213. If you have questions or concerns about your rights as a research participant, contact James Tebow, 310-393-0411, x7173, tebow@rand.org, Human Subjects Protection Committee, RAND, 1776 Main Street, Santa Monica, CA, 90407.

Thank you for contributing to this very important effort to support STEM teaching and learning.

Public-reporting burden for this collection of information is estimated to average 20 minutes per response, the estimated time required to complete the survey. An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to: NSF Officer Attention: PRA, Paperwork Reduction Project (XXXX-XXXX) address.
Background

1. Have you used NSDL in relation to STEM teaching—e.g., in planning or delivering lessons or in informing yourself about STEM content or teaching methods?

☐ No → if no, why not?

__________________________________________________________________________________________________

[If you answered “No,” please skip to question 13.]

☐ Yes → continue

2. Approximately when did you start using NSDL for STEM teaching? (choose month and year) [drop down menus]

☐ Summer
☐ Fall
☐ Winter
☐ Spring

☐ 2004
☐ 2005
☐ 2006
☐ 2007
☐ 2008
☐ 2009
☐ 2010
☐ 2011

3. Have you taken any professional development courses offered by Teachers’ Domain or another NSDL pathway?

☐ No

☐ Yes (please specify the course(s) and year(s) taken)

__________________________________________________________________________________________________

__________________________________________________________________________________________________
Uses of NSDL

4. How often do you go to NSDL sites for teaching resources?

☐ Daily
☐ 2–3 times a week
☐ Once a week
☐ Once or twice a month
☐ Once or twice a term
☐ Less often

5. How have you accessed NSDL resources?

☐ Through Teachers’ Domain or PBS Learning Media
☐ Through NSDL.org
☐ Through another NSDL pathway
☐ Other
☐ Don’t know/not sure

6. How often do you use other search engines, such as Google, to find teaching resources?

☐ Daily
☐ 2–3 times a week
☐ Once a week
☐ Once or twice a month
☐ Once or twice a term
☐ Less often
7. Please check all of the ways that you have used NSDL.

☐ Find information about a STEM subject to plan or update a lesson
☐ Find other resources to use for delivering a lesson, such as video clips or simulations
☐ Find resources for students to use, such as simulations or online activities
☐ Find resources to print and distribute to students, such as homework or pencil-and-paper activities
☐ Modify a resource or adapt it for a lesson
☐ Increase my knowledge of STEM subjects
☐ Increase my knowledge of how to teach STEM subjects
☐ Find professional development opportunities, such as workshops or conferences
☐ Connect with other teachers
☐ Share a STEM teaching resource that I developed or adapted
☐ Share other information about STEM education, such as research findings or professional development opportunities
☐ Annotate, rate, review, or recommend a resource for others
☐ Post questions, answers, or comments on a discussion forum
☐ Find tools to help organize resources
☐ Learn about learning management systems
☐ Learn about the use of social media (such as Web 2.0, wikis, Twitter, Facebook or other social networking tools) for STEM education
☐ Other (please describe): __________________________________________________________
8. Please rate the following statements about the impact of NSDL resources on doing your job, using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Disagree Somewhat</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Using NSDL resources enables me to prepare lessons more quickly.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>b. Using NSDL resources increases my overall productivity.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>c. Using NSDL resources enhances my teaching effectiveness.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>d. Using NSDL resources makes it easier to do my job.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>e. NSDL resources are engaging to my students.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>f. Using NSDL resources expands my content knowledge.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>g. Using NSDL resources expands my knowledge of teaching methods.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>h. NSDL resources complement my other professional development activities.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>i. Using NSDL resources has helped me form professional connections with other STEM teachers.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>j. Using NSDL resources has enabled me to contribute to the STEM teaching community.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>k. I have found resources on NSDL that I would not have found any other way.</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
9. Please rate the following statements about the resources you have found through NSDL, using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th>The resources that I have found through NSDL . . .</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Disagree Somewhat</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. are current.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. are comprehensive.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. are accurate.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. reflect real-world content.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. are appropriate for the topics I teach.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>f. are appropriate for the grade levels I teach.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g. are culturally appropriate for my students.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h. are aligned with my state’s standards.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. Please rate these statements regarding how easy or difficult it is to use NSDL, using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Disagree Somewhat</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. It is easy to find useful resources on NSDL.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>b. Finding resources on NSDL is time-consuming.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>c. It is easy to navigate through NSDL websites.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>d. Finding NSDL resources requires too many steps.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>e. Metadata (terms or keywords that describe the content) clearly indicate what I’ll get when I click on a link to a resource.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>f. NSDL has a lot of broken links.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>g. I get too much information when searching for resources on NSDL.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>h. It is hard to judge the quality of NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>i. NSDL resources are difficult to adapt to my needs.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>j. Policies about what I can do with NSDL resources (such as copy, alter, or send to others) are clear.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>k. I avoid using NSDL resources on sites that require registration.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
11. Please indicate if you have the resources and support you need to use NSDL using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Disagree Somewhat</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>I have the knowledge necessary to use NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>b.</td>
<td>NSDL resources work with the computer equipment I have.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>c.</td>
<td>Effective guides for using NSDL resources in teaching are available.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>d.</td>
<td>There are other teachers whom I can go to if I need help using NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>e.</td>
<td>A specific person (or group), like a helpdesk, is available for assistance with difficulties using NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>f.</td>
<td>Accessing NSDL resources is convenient.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>g.</td>
<td>My school provides enough equipment (e.g., computers, printers, projection systems, scanners) for me to use NSDL resources in class.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>h.</td>
<td>My school allows me to download the applications, such as a media player, needed to use NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>i.</td>
<td>The school’s network access (e.g., speed and reliability) supports my use of NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>j.</td>
<td>My network access at home supports my use of NSDL resources.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
12. Please rate the following statements about how NSDL affects your confidence about teaching STEM subjects, using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th>Because of NSDL, I am more confident in my ability to...</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. teach STEM subjects.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>b. reach even the most difficult students.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>c. be responsive to my students’ needs.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>d. use technology in my STEM instruction.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>e. develop creative ways to teach STEM subjects to my students.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>f. motivate my students to become interested in STEM subjects.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>g. exert a positive influence on the academic development of my students.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
</tbody>
</table>

13. Please rate the following statements about other educators and use of NSDL, using a scale from 1 to 7, with 1 being “strongly disagree” and 7 being “strongly agree.”

<table>
<thead>
<tr>
<th>Other statements about other educators and use of NSDL</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Other teachers I know use NSDL resources.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
<tr>
<td>b. Leaders at my school encourage the use of NSDL resources.</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
<td>[  ]</td>
</tr>
</tbody>
</table>
14. Please indicate how many of the following devices you have access to:

<table>
<thead>
<tr>
<th>Type of Device</th>
<th>Number of Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Desktop computers in your classroom</td>
<td>0</td>
</tr>
<tr>
<td>b. Laptop computers in your classroom that your school provides</td>
<td>0</td>
</tr>
<tr>
<td>c. Laptop computers that your students bring for classroom use</td>
<td>0</td>
</tr>
<tr>
<td>d. Mobile devices (e.g., smartphones, iPads) in your classroom that your school provides</td>
<td>0</td>
</tr>
<tr>
<td>e. Mobile devices that your students bring for classroom use</td>
<td>0</td>
</tr>
<tr>
<td>f. Computers in a shared room, such as a computer lab</td>
<td>0</td>
</tr>
<tr>
<td>g. Shared computers to bring to your classroom</td>
<td>0</td>
</tr>
<tr>
<td>h. Shared mobile devices to use in a computer lab or to bring to your classroom</td>
<td>0</td>
</tr>
<tr>
<td>i. Projection systems in your classroom (e.g., to display computer screens)</td>
<td>0</td>
</tr>
<tr>
<td>j. Projection systems in a shared room, such as a computer lab (e.g., to display computer screens)</td>
<td>0</td>
</tr>
<tr>
<td>k. Printers in your classroom</td>
<td>0</td>
</tr>
<tr>
<td>l. Printers in a shared room, such as a computer lab</td>
<td>0</td>
</tr>
<tr>
<td>m. Other computer peripherals, such as digital cameras, scanners, and interactive white boards (please list each separately)</td>
<td>0</td>
</tr>
</tbody>
</table>

Device

1.
2.
3.
4.
5.
15. Using a 1 to 7 scale, with 1 being “strongly disagree” and 7 being “strongly agree,” please rate these descriptions of your experience with technology.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Disagree Somewhat</th>
<th>Neither Agree nor Disagree</th>
<th>Agree Somewhat</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>If I heard about a new information technology, I would look for ways to experiment with it.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>Among my peers, I am usually the first to try out new information technologies.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>In general, I am hesitant to try out new information technologies.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.</td>
<td>I like to experiment with new information technologies.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Demographic information

16. What grade level(s) do you currently teach? (Check all that apply)

- Lower elementary school, K–2
- Middle elementary school, 3–5
- Middle/junior high school, 6–8
- High school, 9–12

17. In what type of school do you teach?

- Public
- Charter
- Private
18. In what setting do you teach?

☐ Rural  
☐ Urban  
☐ Suburban

19. What STEM-related subjects do you currently teach? (Check all that apply)

☐ General science  
☐ Life sciences  
☐ Physical sciences  
☐ Earth and space sciences  
☐ Engineering  
☐ Mathematics  
☐ Computer science/technology  
☐ Social science and/or social studies  
☐ Other (please specify):

________________________________________________________________________

20. Including this year, how many total years have you been teaching?

☐ 3 years or fewer  
☐ 4–9 years  
☐ 10–19 years  
☐ 20 years or more
21. Including this year, how many total years have you been teaching STEM topics?

☐ 3 years or fewer
☐ 4–9 years
☐ 10–19 years
☐ 20 years or more

22. Where do you have regular access to the Internet? (Check all that apply)

☐ At home
☐ In my classroom
☐ In a room that is shared with others, such as the school library or computer lab
☐ Other (please specify):

☐ I do not have regular access to the Internet

23. What is your highest level of education?

☐ Bachelor's degree
☐ Master's degree
☐ Ph.D.
☐ Other (please specify):

24. What is your gender?

☐ Male
☐ Female
25. What is your age?

☐ 25 or under
☐ 26–30
☐ 31–35
☐ 36–40
☐ 41–45
☐ 46–50
☐ 51–55
☐ 56 and over

26. If you have any other comments or suggestions about NSDL, please use the space provided below.

Thank you for participating.

If you would like to receive a $20 gift certificate to Amazon.com, enter your email address here. Your email address and answers to the survey questions will be stored in separate locations.

Email: ________________________________
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