

**Pathways to Progress:
Vision and Plans for Developing the NSDL
March 20, 2001**

Editors:

Cathryn A. Manduca, DLESE Program Center, Carleton College
Flora P. McMartin, SMETE.ORG, University of California at Berkeley
David W. Mogk, DLESE Program Center, Montana State University

I. Introduction

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

The potential impact of the NSDL on the quality of SMET education is great. However, building the NSDL to meet the diverse needs of its users presents many challenges, including:

- developing a shared vision for the form and function of the NSDL;
- meeting the needs of diverse learners;
- meeting the needs of the many disciplines encompassed by the NSDL;
- acquiring input from the community of users to ensure that the NSDL is both used and useable;
- developing a governance structure and Core Integration System that balances community needs with technical applications;
- integrating technologies that already exist, and promoting the development and integration of new technologies;
- providing mechanisms for sharing knowledge and resources, and building cooperation among NSDL collaborators;
- providing mechanisms for incorporating primary scientific research data;
- evaluating NSDL and its impact on SMET education; and
- coordinating these many interests and functions to provide an integrated whole.

This paper addresses the methods for meeting these challenges, and allows NSDL participants to identify the common and essential components of the social and technical infrastructure necessary to construct the NSDL. It discusses the primary educational goal of the NSDL, which

is to have a measurable impact on SMET learning and educational practices in ways that are closely aligned with SMET educational reform movements. It also identifies the partners participating in the inaugural development of the NSDL and serves to formalize our own plans for the NSDL. It is further intended to engage the larger SMET community in building the NSDL by describing the needs, opportunities, vision, scope, and plans for development.

The contents of this document were derived and assembled from the contributions of the participants of various NSDL grantee meetings held during 2000/2001. First, we provide a brief review of the background of the NSDL. Next, we focus attention on those areas where there is broad consensus, namely the vision, scope, goals, and principles guiding the development of the NSDL. Next, the paper discusses two components necessary to support this collaborative effort: the governing structure and the core integration system. This is followed by a discussion of those elements of the NSDL identified as essential by the NSDL working groups. The last section is an action plan (developed by the Interim Coordinating Committee) outlining the set of activities that need to be undertaken for this collaborative effort to succeed.

II. Background and Overview

The NSDL effort has emerged from the confluence of technological advances, changing educational practice, and a recognition of the fundamental importance of SMET education to our highly technological society. Today we are faced with a nation-wide call for improvement of SMET education at all levels (Project 2061, AAAS, 1989; National Science Education Standards, NRC, 1996; *Shaping the Future New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology*, NSF, 1996). Simultaneously, information technology now offers remarkable opportunities to improve learning through simulations, visualization, modeling, access to real-world scientific problems, and by enabling new collaborations, interactive learning, and alternative pedagogical approaches (NSF 98-82).

In this context, the NSDL has the potential to:

- answer calls from educators for easy access to high-quality, organized, and accessible educational resources and the tools, interfaces and other services to help them effectively use these resources (Education Teachers of Science Mathematics and Technology, NRC 2001);
- enable student-friendly access to scientific data to support learning by direct experience with the methods and processes of inquiry and discovery—the method recognized as most effective by research on learning (NSF 96-139); and
- support a new integrated community addressing the full spectrum of SMET education.

Significant progress has been made in developing technology fundamental to a successful digital library such as interoperability, authentication, persistence, and archiving functions. A substantial research base emerging from the results of the NSF Digital Library Initiative Phase I and Phase II projects is available to support the development of the NSDL. Building on these

bases, the National Science Foundation initiated the NSDL effort with a program solicitation (NSF 00-44) to establish an educational digital library for science, mathematics, engineering and technology:

“To catalyze and support continual improvements in the quality of science, mathematics, engineering, and technology (SMET) education, the National Science Foundation has established the National Science, Mathematics, Engineering and Technology Education Digital Library (NSDL). The resulting digital library, a network of learning environments and resources for SMET education, will ultimately meet the needs of students and teachers at all levels—K-12, undergraduate, graduate, and lifelong learning—in both individual and collaborative settings.”

In fall, 2000, 42 grants were awarded from this competition in four tracks: 1) Core Integration System (CIS); 2) Collections; 3) Services; and 4) Targeted Research (<http://www.smete.org/nsdl/projects/index.html>). Representatives of these projects met in Washington DC on September 22-24, 2000 to lay the foundation for building the integrated NSDL. Minutes of these meetings and working group reports can be found at www.smete.org/nsdl/workgroups/index.html. These participants met again in Boulder, Colorado on November 1-2, 2000 to continue this formative work. The outcomes of these meetings include the creation of an interim governance structure; establishment of a set of working groups to examine the issues involved in collaboratively developing the NSDL; and a commitment to produce this document to communicate the vision, goals, and plans for NSDL.

III. Vision and Scope

The NSDL is a digital learning place that encourages and supports users in their efforts to create, discover, explore, and interact with the digital resources that support teaching and learning SMET education in all arenas. In this capacity, it will be a gateway to diverse digital collections of quality SMET educational content and services developed by a rich array of SMET educators. The NSDL is both a virtual and ‘real’ organization supporting educational partners who collaborate to provide collections of SMET educational materials, services that support the use and re-use of those materials, and collaboration among NSDL participants and users (i.e., educators; learners; scientists, mathematicians, and engineers; resource developers; and resource providers). The NSDL is organized around goals to create and enable the connections and synergies that emphasize inter- and multi-disciplinary approaches to SMET education, provide exciting new SMET educational opportunities in formal and informal educational settings, and ultimately make a positive impact on student learning.

As a digital learning place, the NSDL builds on the rich body of existing digital library research. Its technological infrastructure and architecture draw on this previous investment. By building on this technology base, the NSDL will enable a unique and innovative set of collaborations and learning tools that allow for sharing across diverse academic communities, school levels (i.e., K - 12 to higher education), and formal and informal learning situations. Perhaps its most important function will be to connect people from these diverse backgrounds and geographic locations to communities of SMET learners and learning environments. The NSDL's technology and

architecture will be innovative in that it will be a test bed for initiating technologies that , up to now, have only been utilized in the research realm. As such, it also serves to connect researchers and educational practitioners.

IV. NSDL Educational Goals

The primary educational goal of the NSDL is to increase scientific literacy for all Americans. The NSDL must support excellence in SMET education encompassing all disciplines in the physical, life, and social sciences, mathematics, and engineering and technical disciplines, and in all educational settings. The integrated delivery of resources and services to the SMET education community offers unique opportunities.

First and foremost, there is the opportunity to develop a SMET education community that is interdisciplinary. There is intrinsic value in recognizing and accentuating the connections among the knowledge bases, skills, and methodologies employed by those disciplinary communities that contribute to the NSDL. The NSDL can make a substantive contribution towards bridging current disciplinary boundaries by effectively integrating concepts, knowledge and methods across the SMET disciplines. In this way, the NSDL will create a synergistic resource that is greater than a simple collection of connected but disparate discipline-based libraries.

An opportunity also exists to seamlessly integrate SMET education at all levels, including K –12, undergraduate, graduate, professional development and informal education. The information and communication systems of the NSDL will provide a spectrum of educational opportunities for all learners – “from K to gray.” Learners will be able to pursue topics of interest to any desired level of sophistication by creating learning paths reflective of their personalized needs, interests, and capabilities.

Building on these broad themes, participants at the Washington, DC and Boulder, CO meetings defined the following educational goals for the NSDL:

- *Provide quality assurance of resources in the collections.* Accuracy and validity of content must be addressed, providing at minimum the source of information, integrity of the product, and information about pedagogy.
- *Enable contextual learning.* Users of resources must have the opportunity to review each learning object in the context of its use; both objective and subjective contextual descriptions (metadata) should be included.
- *Empower critical literacy skills.* Users must be allowed to make decisions and to draw independent conclusions regarding the use and quality of materials. The contents and tools must provide opportunities for students to reason scientifically.
- *Support new pedagogical approaches.* Collections and services must embrace innovative pedagogies, e.g., active learning, as well as support more traditional pedagogical modes, e.g., lecture.

- *Advance scientific knowledge and understanding.* As our scientific knowledge base expands, pedagogies associated with the library must be able to change and adapt to meet the educational challenges associated with this expansion.
- *Enable inter- and multi-disciplinary educational opportunities.* Connections between diverse subject areas in new and innovative ways must be made more effective through using digital technologies.
- *Implement the National Science Education Standards (NRC, 1996), Shaping the Future (NSF, 1996) and related SMET education reform programs.* The library must be a primary means for disseminating standards and reform efforts, as well as providing the subsequent and necessary professional development for teachers and instructors.
- *Support independent learning.* Learning plans must be adaptable according to personal needs, abilities, and aptitudes.
- *Support learning that is active, and that involves inquiry and discovery.* The library must provide support for current research in SMET education that calls for use of these new pedagogical methods.
- *Foster a sense of excitement about life-long learning.* Users from all walks of life must be able to look to the NSDL to be a primary resource for learning SMET.
- *Provide access for all.* The NSDL must adopt access goals associated with learning and physical disabilities, language needs, as well as needs of under-represented populations, and implement processes to meet those goals. In providing equal access for all, it must guard against creating an even broader digital divide.
- *Empower users.* Distributed services such as help desks, FAQ's, and ask-an-expert must be available to support novice users.
- *Support communities of scholars.* The NSDL must not be prescriptive in its educational mission. Recognizing that new advances in SMET education will emerge from communities of users, the NSDL must embrace an educational mission that builds upon and promotes excellence and innovation in SMET education.

V. Principles Underlying Development

A coordinated effort engaging the information technology, library, SMET, and education communities is required to achieve the educational goals outlined above and to establish an integrated digital library serving the collective needs of the broad SMET educational community. SMET education is a highly complex system that is currently fragmented by both disciplines and educational levels. Robust linkages are needed to allow discovery of resources across disciplines and educational communities. In addition, tools and resources are needed to meet the varied

needs and goals of individual learners, programs, and communities that range from integrated interdisciplinary learning to detailed, specific knowledge from a particular specialty.

No single educational or technical group has the intellectual resources required to create such a large, complex, interconnected digital resource. This challenge is increased by the need for rapid development of the NSDL to meet the immediate and changing needs of SMET education. The initial contributors to NSDL recognize the value of and need for collaboration in building the NSDL. As a group they are committed to initiating a coordinated and distributed building process to meet these challenges. This group of 42 projects forms the current core of the NSDL community that is guided by these underlying principles:

- The goal of the NSDL is to enhance, enrich and enable excellence in SMET education.
- Rapid development of the NSDL is best accomplished through a coordinated, cooperative and distributed effort.
- Our strength is in the variety of communities engaged in the NSDL. A governance structure is necessary to balance the collective needs and goals with the over-arching management of the library.
- Meeting NSDL educational and technical goals requires active interplay among the library's users, contributors and developers.
- The NSDL adds value through the human networks and other relationships among NSDL components as well as through its contents and services.
- The NSDL initiating partners share a core set of values, all of which will be reflected in the resulting digital library development.

The NSDL partners encompass a wide spectrum of talent able to address the complex technical, educational, and social problems inherent in creating this comprehensive, interdisciplinary, web-based learning resource. While this group is diverse and represents many disciplines and specialties with different approaches and goals, we share this common set of values.

- *A commitment to promoting excellence in SMET education for all learners.* NSDL is an experiment in the application of technology to learning. Of critical importance will be the application of rigorous research methods to understanding how people learn, and the effective use of information technology and learning resources.
- *A commitment to the value of sharing and to the collaborative development of the NSDL.* Implicit in this value is the understanding that participation involves both receiving and contributing. We recognize that effective collaboration is costly in both time and money, but we strongly believe it enables results otherwise not possible.
- *A desire to create a SMET educational digital library that serves the public good.* We believe that the NSDL should serve the needs of a diverse population representing a

variety of learning goals and needs, including those with limited access to technology. This requires that decision making focus on the needs of end users (i.e., above those of serving our own research needs or individual intellectual interests).

These commonly held values make the NSDL collaboration possible. However, even with this strong base, success is not assured. Tensions exist among and between education, technical, and research goals, as well as among the diversity of communities that the NSDL is designed to serve. A balance must be struck between uniformity and diversity. Similarly, the desire to allow individual creativity and competing approaches must be balanced by policies that enable development of a working integrated digital library. We must design a structure to assure that individual projects and communities can function autonomously to reach their own goals while enabling the benefits of working together as a NSDL community. Collaboration does not require common ownership of all things. However, to be successful, the NSDL collaboration must appear to be a coherent entity to the outside world and to its users.

Collaboration among members of the NSDL community can be made easier by developing a common culture, one in which individuals make responsible representations of what they can do, maintain a sustained commitment to the project including timely communication between meetings, and adopt a shared etiquette for communication. This commitment will greatly enhance our ability to work together. A strong set of tools for long-distance communication and effective facilitation of working groups will both simplify and enhance collaboration and should be priorities. In addition, multiple pathways to achieving goals, flexible approaches, and diverse tools can greatly relieve the tensions between individual and community needs. Robust communication mechanisms are needed to ensure input from stakeholders in the education, research and development realms. Finally, a design cycle approach can facilitate this type of decision making while allowing timely progress in development of the NSDL.

To enable collaboration and balance tensions, we have established an interim governance structure and are developing a Core Integration System (CIS). The governance structure provides a mechanism for community-based decision making and will provide guidance to the collective NSDL effort. The CIS is the interoperability mechanism that coordinates the social and technical components of the NSDL.

VI. Interim Governance Structure

To guide collaboration, an interim governance structure was established by the initial awardees of NSF NSDL funding (September 2000 NSDL PI meeting, Washington DC). Three major components provide for broad based engagement of the community in guiding policy, while providing the direction needed for rapid development of the NSDL:

1. Seven working groups were established to address issues associated with the development of the library (governance; community, education and pedagogy; collections; standards; services; evaluation; and technical infrastructure). These groups have open membership and project participants and interested individuals in the NSDL community are encouraged to participate.

2. An Interim Coordinating Committee (consisting of one representative from each of the CIS projects and one representative from each of the working groups excluding technical infrastructure) was established to guide cooperation among NSDL projects and, when needed, to make decisions based on broad input collected from the working groups and members at large via the NSDL community web site (www.smete.org).
3. A web site (www.smete.org) is being maintained to provide information, encourage participation, facilitate communication and support governance activities.

The NSDL project participants have charged the Coordinating Committee with the following responsibilities:

- provide guidance and make decisions on critical priorities and issues to enable rapid development of a working library;
- provide community input on development of the CIS;
- provide community-based prioritization of goals for the NSDL;
- balance needs and goals of different parts of the NSDL community;
- provide mechanisms for robust interaction among users, contributors and technology developers;
- develop and promote an iterative, human centered, product design process approach to building the NSDL;
- develop and maintain the community vision of the whole library and its future; and
- encourage NSDL projects and activities in directions guided by the vision.

The Coordinating Committee has met twice since its inception and has established an action plan (detailed at the end of this document) that addresses how it will accomplish these activities.

VII. The Core Integration System (CIS)

The Core Integration System (CIS) is the organizational structure that enables the various existing digital libraries and allied collections and services to function with and among each other in the context of the overall NSDL. It also provides a means for emerging and developing digital libraries and collections, services, and related functions to participate in, and eventually become members of, the NSDL. This structure is necessary to support the scope of the NSDL, its vision and its educational goals. As defined in National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL) -- Program Solicitation (NSF 00-44), the purpose of the CIS is to:

“... coordinate a distributed alliance of resource collection and service providers, and to ensure reliable and extensible access to and usability of the resulting network of learning environments and resources.”

The CIS supports the development, implementation, operation and growth of the NSDL. As such, the CIS must be responsive to the needs of the SMET user community through integration

of social and technical systems. Discussions among working groups, CIS partners, and the Coordinating Committee at the November, 2000 meeting in Boulder, CO identified five primary responsibilities for the CIS:

1. provide technical infrastructure needed for an integrated NSDL;
2. support community-based governance of NSDL;
3. support collaborative construction of NSDL;
4. perform and support NSDL outreach; and
5. enable evaluation of all aspects of NSDL.

Based on working group discussions, the Coordinating Committee and CIS partners have developed an elaboration of desired functionalities and example deliverables (Table 1). This table, which serves as a starting point for discussion, illuminates and gives shape to the meaning of the goals rather than prescribing CIS functionalities. The deliverables are intended as examples and are not comprehensive.

Table I: CIS Requirements and Functionalities

CIS Requirement	Functionality	Example deliverables
1. Support the technical requirements of the initial NSDL digital library	A. Search across multiple collections	<ol style="list-style-type: none"> 1. Create centralized/normalized metadata harvester/repository 2. Create specifications and reference implementation for cross-collection queries
	B. Metadata and cataloging	<ol style="list-style-type: none"> 1. Negotiate agreement on the metadata for queries 2. Support Dublin Core, FGDC, IMS 3. Make available tools to facilitate use of Dublin Core, FGDC, IMS 4. Develop metadata extensions to pedagogical concepts
	C. Content delivery	<ol style="list-style-type: none"> 1. Provide support for tailored portals 2. Support a central portal with NSDL branding
	D. Rights management and authentication across collections	<ol style="list-style-type: none"> 1. Develop means for constraining metadata use and re-use 2. Create means for tracing authorship, revision, comments, etc.
	E. User access	<ol style="list-style-type: none"> 1. Support single 'login' service 2. Support authorization services 3. Support payment related services 4. Ensure services correspond to emerging privacy standards
	F. Community and governance	<ol style="list-style-type: none"> 1. Support communication tools (e.g., listservs, threaded discussions, etc.) 2. Support collaboration tools
	G. Evaluation	<ol style="list-style-type: none"> 1. Support aggregated data collection 2. Report on metadata conformance to standards
	H. Traffic Management	<ol style="list-style-type: none"> 1. Provide mechanisms for replicating or caching for NSDL collections in high demand
	I. Curation/persistence	<ol style="list-style-type: none"> 1. Document-change flagging service
	J. Systems interoperability	<ol style="list-style-type: none"> 1. Provide interoperability mechanisms for information discovery, data movement, metadata delivery

	K. Systems operation	1. Provide statistics on performance and usage
	L. Education and instruction	1. Provide knowledge management system i.e., a cross-discipline thesaurus 2. Link content to pedagogical goals 3. Integrate all NSF-funded service proposals
	M. Collection building	1. Integrate all NSF-funded collection proposals 2. Support collections tools (e.g., ingest, classification, query, protocols)
2. Support governance		1. Develop a working, community-based governance system 2. Act as the secretariat to the governance system 3. Provide administrative support to governance
3. Support collaborative construction of NSDL	N. Support/enable independent efforts that build on the core	1. Provide support systems for collection-inclusion 2. Provide support systems for service creation/provision 3. Create and support a collection-builders starter kit 4. Coordinate and implement workshops and conferences
	O. Support advancement of independent strategic initiatives	1. Sponsor a specific community-college initiative 2. Coordinate agency commitments to link with NSDL
4. Perform and support NSDL outreach		1. Engage new collections to fill identified gaps 2. Encourage new agendas 3. Implement marketing strategy
5. Enable evaluation of all aspects of the NSDL		1. Devise and implement framework for collection of evaluation 2. Provide collection baseline and comparative data sets

In addition, the CIS must assume fiduciary responsibilities for the maintenance and operation of central functions, address intellectual property rights issues, and engage in long-term business planning. Start-up costs will be substantial, and marketing/outreach strategies will have to be rapidly implemented. In addition, NSDL must be positioned to take advantage of new opportunities and strategic liaisons with interested partners.

The CIS is not the NSDL. It is the mechanism that supports the NSDL's vision, mission, and goals by creating and maintaining a framework that integrates and links its member collections and services.

VIII. Summary of the Working Group Reports

[Complete working group reports are available on the web at www.smete.org]

A. GOVERNANCE

The governance structure is the "glue" that ensures that the NSDL functions as a whole greater than its parts. It provides leadership while consistently monitoring the environment to identify best practices, promoting interoperability, ensuring persistence, and envisioning new directions.

The governance structure must allow for inclusion, representation, and empowerment of all groups willing to contribute to the overall mission of the NSDL.

A strong governance structure is essential to the success of the NSDL because it:

- enables coordination and collaboration between NSDL member entities and creates the public sphere where users can find their voice in the development of this public resource;
- can help balance educational and technological library goals and the interests of various components of the library (technology, education, collections, and services);
- provides the central entity that can be charged to maintain the vision of the whole library and its future, and that encourages the development of the NSDL based on this vision;
- creates opportunities for member entities to share resources to solve a problem (or by targeting new resources to members for this purpose);
- shortens the time between the recognition of a problem or opportunity and an effective response;
- enables evaluation of the entire NSDL and its impact on learning;
- establishes the structure required to secure persistence and stability for the NSDL as a recognizable institution;
- lays the foundation for the financial and legal transactions necessary for the NSDL to function as an institution; and
- provides a collective voice for the NSDL community representing its goals, accomplishments, needs and vision.

This need for cooperation raises both social and technical challenges. The Governance Working Group is focused on developing a structure for cooperation, coordination, and decision-making among the project participants, both for the short term of the currently funded projects as well as the long term for the on-going NSDL.

In the longer term, governance must be capable of:

- dealing with the diversity of communities participating in the NSDL—with the explicit recognition of the needs of multiple users and with contributors that will not all be NSF funded;
- coping with rapid changes in the technological infrastructure and predicted growth; and
- meeting the financial and legal issues that are implied by the existence of any formal institution.

Key values in the governance model proposed are:

- federation and interoperability;
- participatory collaboration; and
- flexibility and responsiveness as needed to allow NSDL to evolve in a rapidly changing, dynamic environment.

The interim governance structure described above was adopted by the initial awardees of NSDL funding. The intention is for the interim governance structure to exist for the next year. In the second year, a longer-term structure will be established. Recognition was given to the fact that the structure might also change as the result of a new CIS funding in 2001.

Multiple elements were identified as key to the development of a long-term governance model:

- identify stakeholders in terms of existing groups and people;
- formalize categories of membership listing rights and obligations (benefits/costs);
- develop a vision and mission based on stakeholder requirements;
- establish form of governance that appropriately balances interests;
- devise and codify defining elements in a constitution and details in a set of bylaws; and
- determine appropriate legal entity(s) to accomplish existing goals.

B. COMMUNITY, EDUCATION AND PEDAGOGY

The NSDL will include numerous intersecting communities working together towards the common goal of excellence in SMET education. Each community will contribute the knowledge base, methodologies and related resources that distinguish these many fields of scholarship. There is great strength in the diversity in the resources of existing communities, and these self-defined communities will be encouraged to do what each “does best” in the NSDL framework. In addition, new digital technologies will allow, and even require, building of new communities not heretofore possible, or re-purposing of existing communities to best adapt to and utilize new technologies as they materialize. Tremendous value accrues to the overall enterprise through the synergistic relations and connections between and among these self-defined and self-organized groups. The technical and social infrastructure of the NSDL must recognize and value the attributes that are intrinsic to communities that already exist. At the same time, the communication networks afforded by the NSDL make it possible (and desirable) for connections to be made, and relationships established, to form new types of communities among contributors to and users of the NSDL. The NSDL must be positioned to simultaneously address the current needs and interests of existing communities, and to be flexible enough to anticipate and respond to the emerging needs of new communities.

A community is required because there is a critical need for people to rapidly and reliably learn and use new knowledge, which can no longer be achieved and sustained by traditional mechanisms. A community can meet this need by providing and sustaining teaching-learning resources for education. To build a NSDL that is both useful and used, it is essential that the

voices of all communities be heard when developing technical and social infrastructures. Community input is required to plan and develop the resources, tools, interfaces, and communication networks that will support SMET education for all. In addition, NSDL must actively support sharing between and among its diverse communities, provide the opportunity for new communities to emerge, and to help communities discover connections and establish relations for the benefit of all.

This community, simply stated, comprises all interested parties concerned about, and committed to, improving SMET education at all levels. The NSDL community is an aggregate of many existing and intersecting communities, including:

- disciplinary groups;
- educational groups;
- technology and information science groups;
- special interest groups (e.g., policy makers, journalists, commercial sector); and
- learners of all kinds—students and citizens-at-large.

This concept of the NSDL is now possible because of the convergence of a) the public's demand for improvement of science education; b) technological advances that afford low cost and easy access to powerful, asynchronous communication and information management tools that enable people to create and sustain diverse communities; and c) the resolve of federal agencies to support research and development in this area (e.g., the Digital Library Initiative). There is the immediate, practical benefit that the NSDL offers in support of SMET education through the development of collections of educational resources, sharing of "best practices," establishment of communication networks, and in the development of other services. In addition, the NSDL provides a framework to support SMET education in two important new dimensions: horizontal and vertical integration of SMET education across all disciplines and at all levels (and venues) of instruction.

The NSDL provides opportunities to develop a new SMET education community that is interdisciplinary in nature. There is intrinsic value in recognizing and accentuating the connections among the knowledge bases, skills, and methodologies employed by the contributing disciplinary communities. The NSDL can make a substantive contribution towards bridging current disciplinary boundaries. A NSDL that effectively integrates concepts, knowledge and methods across the SMET disciplines will be a much greater resource than a collection of discipline-specific libraries.

The NSDL also provides opportunities to integrate K-16 and informal education. The information and communication systems of the NSDL will provide a spectrum of educational opportunities for all learners—"from K to gray." Individualized learning paths will become possible in response to personalized needs, interests, and capabilities. Learners will be able to pursue topics of interest to any desired level of sophistication. To realize this goal will require contributions and cooperation from many diverse communities—providers of content (e.g. researchers), developers of instructional materials, instructors, and learners themselves.

And, the NSDL can foster new types of relationships:

- between teachers and students (e.g., through the development of tools to promote and support robust and persistent communication and collaboration);
- between teachers and content authors (e.g., through the development of tools to enable teachers to communicate instructional/content needs and for content authors to communicate with teachers to better understand their instructional needs);
- between students and content authors (e.g., tools to enable students to communicate instructional/content needs and to enable content authors to communicate with students about instructional needs);
- between teachers and the NSDL (e.g., tools to enable teacher annotation of content, from a particular community/cultural perspective and that enable teachers to assemble instruction from existing learning objects, annotate, and submit as new collection item);
- between students and the NSDL (e.g., tools to enable student annotation of content, from a particular community/cultural perspective and to enable student personalization of content);
- between content authors and the NSDL (e.g., mechanisms and incentives for content authors to develop and distribute new instructional resources to broad audiences through the NSDL, with benefits accruing to the NSDL by accessing new instructional resources and attendant technologies).

The technological advances in communication and coordination also enable new types of communal relationships to meet educational goals:

- content developers can be the teachers and students themselves due to the access and usability of development tools and the ease of reusing, re-purposing, reintegrating, and revising existing digital materials;
- cooperative participation in the development and design of the digital teaching-learning resources allows for full participation of diverse populations in the educational process;
- asynchronous access to content enables teachers and learners to learn and teach at the pace needed to optimize learning opportunities. It is now possible to develop personalized learning plans according to the needs, opportunities, and challenges of all students and teachers;
- the remaining physical and economic constraints have minimal impact on the ability to access vast amounts of digital materials related to both content and pedagogy;
- interactive multimedia content (vs. static text and pictures) enable students and teachers to integrate critical thinking pedagogy (supporting problem solving, inquiry, and discovery) into the content rather than making it an optional add-on to the content, and

instructional materials may be utilized in a non-linear fashion to meet personal and local needs, and to create and take advantage of the “teachable moment”;

- user-friendly, accessible tools (computers and printers) translate digital materials into customized printed materials that in turn can be integrated into traditional teaching-learning-administrative practices. Consequently, teachers can update their curriculum and pedagogy in a timely, inexpensive, and customized ways to serve the learning needs of their students.

To build a NSDL that is both useful and used, it is essential that the community voice be heard to develop supporting technical and social infrastructures. Community input is required to plan and develop the resources, tools, interfaces, and communication networks that will support SMET education for all. In addition, NSDL must actively support sharing between and among its diverse communities, provide the opportunity for new communities to emerge, and to help communities discover connections and establish relations for the benefit of all.

C. COLLECTIONS

Collections, the content that people use, are central to the existence, utility and reputation of digital libraries. Collaboration with the Services, Standards and Technology Working Groups are key to building usable collections. Quality collections, metadata and associated services, which enable the formation of dynamic learning communities, will establish the fundamental identity of the NSDL.

Any collection may be considered for inclusion in the NSDL that meets the following broad filters:

- relevance to any aspect of science, mathematics, engineering, and technology education;
- conforms to NSDL Intellectual Property Policy (to be developed); and
- basic integrity filter (e.g., no blatant errors of fact; no blatant political, religious, or commercial message; no blatant technical failures of the digital resource).

Collections of digital materials that meet the broad filters above will reflect several different types of collections, including:

- *Federated Collections* (e.g., DLESE and SMETE.ORG). In this type of collection, the conventional approach to interoperability is for a group of organizations to agree that their services will be built to certain specifications (which are often selected from formal standards).
- *Harvested Collections*. Each digital library makes minimal metadata about its collections available in a simple exchange format. This metadata can be accumulated by members of the federation and built into services such as information discovery or reference linking.

- *Gathered Collections*. Each digital library makes minimal metadata about its collections available in a simple exchange format. This metadata can be accumulated by members of the federation and built into services such as information discovery or reference linking.
- *User Contributed Collections*. Collections contributed by the community of users that meet the basic filters mentioned above. The major critical issue is how to make the collections available to users under one umbrella.

Decisions need to be made in the following areas in order to develop an NSDL collection as an aggregate of all the associated digital library collections. Decisions have been made in many of these areas for the current collections projects:

1. Nature and definition of the collections and the resources within collections:
 - defining scope and balance of collections, for completeness and robustness;
 - describing types of materials to be collected;
 - defining what constitutes an "object" or a "collection"; this is done within each NSDL collection;
 - maintaining individual collection identities;
 - describing how individual collections relate to each other and to NSDL as a whole; and
 - developing interoperability between collections (i.e., how individual collections are searched and accessed as part of NSDL).
2. Metadata:
 - varying levels of granularity used for description of objects in collections;
 - structure and organization of information; and
 - collection contributors.
3. Quality collections:
 - assurance of quality, authority, validation; and
 - review systems, filtering systems-these vary among the collections.
4. Archiving or persistence issues:
 - persistence and integrity of item level resources;
 - archiving collections that no longer are supported by the creator; and
 - de-accessioning/removing resources, removing collections.
5. Collection building tools and processes:
 - process of collecting;
 - process of contributing; and
 - process of reviewing.
6. Intellectual Property and Commercial providers policy issues:
 - digital rights management.

The immediate short-term goals of the Collections Working Group are to:

- Create a document that articulates a collection development policy so contributors and users understand the relevance of individual collections to the overall NSDL. This scope document should include the content scope, which is any type of digital resource that can be used or reused/purposed to facilitate learning in science, mathematics, engineering, and technology. Target users and providers are the science, mathematics, engineering, and technology educators and learners (which includes the research community) and creators of science, mathematics, engineering, and technology content and services.
- Provide collection support structure for new contributors.
- Help describe a set of services necessary to support developing collections (templates for collection development policies, frameworks for describing resources that support discovery)
- Establish a registry data template for users, harvesters, collection developers, resource developers, and collection producers to contribute to collections.
- Promote development of high-quality, relevant collections.
- Work with Standards Working Group to match appropriate metadata with content.
- Work with Evaluation Working Group to assess the quality, usability, and usefulness of resources.
- Work with collection developers to improve usability.
- Periodically assess individual collections for completeness, robustness and relevance.
- Assess NSDL Collection to identify gaps and development areas.
- Develop methodologies for monitoring and analyzing collection use for future collection building and collection scope and policy revision.

D. STANDARDS

While many standards are necessary for the successful functioning of a digital library, the Standards Working Group is focusing first on “metadata.” Metadata, literally “data about data,” is descriptive information about a resource. For example, the card catalog in a public library is a collection of metadata, including information about the author, title, subject, and publication date of the books and other resources in the library. Metadata facilitates the identification of relevant items very quickly without requiring the examination of all items available. The Standards Working Group has identified a general metadata approach for resources within the NSDL that

should help people and computers find relevant resources by searching – as opposed to browsing the entire digital library until they find the right one.

The approach taken by the Standards Working Group relies on recognized metadata standards that can be used across diverse types of information, standards that will be maintained according to open processes. We understand that this approach does not necessarily take advantage of all the metadata used by the various NSDL collections. Instead, it focuses on what is generally “discoverable” across the various domains represented by the numerous NSDL projects.

As the NSDL effort involves the implementation of relatively new protocols and models for harvesting and managing metadata, it provides a potent test bed for advanced metadata research. The Standards Working Group expects not only to provide answers to NSDL projects, but also to pose questions to the research community, especially in the following areas:

- metadata harvesting, including associated protocols;
- technical requirements for wrappers;
- syntactic bindings and schema; and
- metadata elements for support of education and training.

The Standards Working Group has set the following as goals.

- Consider and specify the metadata standard that best facilitates discovery of resources in the NSDL.
- Provide a mechanism within the metadata for referencing quality and educational standards describing resources in the NSDL.
- Work with the Evaluation Working Group to ensure that metadata usefulness is included in evaluative studies of NSDL.
- Explore ways to provide consulting services to NSDL projects seeking to use metadata for the first time or improve their use of metadata.

In the near term, the Standards Working Group will consider:

- technical interoperability standards for syntactic bindings and schema;
- strategies for management of metadata records that change over time (e.g., version descriptions for the same object); and
- strategies for managing changes to the specified set of metadata to which we will map.

E. SERVICES

The Services Working Group is an essential component of the NSDL, supporting its key motivations of enhancing learning and teaching, providing value to knowledge-seeking users in the education community, and developing a production system that will debut in September 2002. The Services Working Group is distinct from the NSDL Program Services funding track, although some participants may play a role in both groups. The Services Working Group envisions a role that not only collaborates with other working groups but also administers unique

responsibilities. The collaboration role may extend to providing services that facilitate communication between working groups as well as addressing needs that involve the purview of more than one group. The Services Working group will also address issues that do not cross cut (e.g., define and possibly providing usage enhancement services that are not met by any existing NSDL participant). All activities of the Services Working Group should reinforce and enable the distributed nature of the NSDL as well as facilitate users' experience.

The Services track brings together 10 unique projects that form the core of services NSDL will offer to patrons and project participants. The activities of the projects in the Services track cannot, however, address every possible service the NSDL will need to debut effectively. Building upon these core services, however, the Services Working Group can advise other working groups and the NSF on necessary and missing services. Through these duties, both the Services track projects and the Services Working Group provide necessary adhesion interwoven between users, collection providers and CIS. Services can hold the layers of the NSDL together and provide visible "icing on the cake" services to patrons.

As a collaborator, Services will need to work closely with the Evaluation, Community/Education/Pedagogy, Standards, Technical Infrastructure, and Collections Working Groups to identify additional services needed. These points of collaboration can occur in all stages of service development: identifying services needed, designing services to reflect recommendations and specifications, implementing services, and evaluating services' efficacy. Collaborations with other working groups include:

- Technical Infrastructure should work with Services to develop an inventory of services required to debut the NSDL in 2002. Comparing this list to funded services, gaps should be identified. Then, requirements for third party providers should be developed. Finally, providers of needed services should be sought. The Technical Infrastructure Working Group may wish to work with the Services Working Group to develop operational guidelines that will accommodate NSDL growth and progress.
- Collections and Services may work together to identify specific services needed to allow users best access to NSDL collections. These services may include creation of an inventory of currently accessible resources paying particular attention to the ratio between free and fee-based resources, identification of new sources of material to address gaps in the collections, articulation of requirements a collection or service provider must have met in order to participate when the door opens in September 2002, and providing information services to respond to queries from potential collection providers. Due to the dynamic and federated structure of the NSDL, services that collect info about re-purposing of objects and enable the combination of materials from multiple collections should be explored.
- Community/Education/Pedagogy will require specific services to support community development and to enable further dialogue about the purpose and impact of the NSDL (e.g., patron forums, email lists, chats, user reviews, etc.). Perhaps the first priority of this collaboration is to examine services relating to garnering community interest. The Services Working Group would like to assist with identifying distinct user groups, paying

special attention to the NSDL's mission to appeal to diverse user groups and address issues of technology disenfranchisement. In addition to taking part in outreach activities, priority should be given to cultural usability issues such as Web Accessibility Initiative usability standards, classification by Native American schemas, and multilingual support.

- Standards will require services to resolve issues relating to the collection of personal data as a way to customize information delivery and better help NSDL to meet user needs. Adoption of a particular set of metadata standards for federated collection will enable a suite of services. If deemed appropriate, the Services Working Group will serve as liaison to non-member collections inquiring about NSDL metadata standards and crosswalks. Many requisite standards will be developed as core services: harvesting, persistence, protocol mediation. These services most likely fall within the realm of Technical Infrastructure and/or CIS.
- Evaluation may call upon the Services Working Group to develop strategies to assess market viability and quality of services provided as well as measures of patron satisfaction. If commercial services are perceived as having more value than the NSDL, sources of that value need to be identified and recommendations need to be made to appropriate NSDL entities. Internal evaluation of NSDL should identify gaps in services and recommend ways to address gaps. The results of this gap analysis may form the basis for discussion with Technical Infrastructure regarding recommendations for funding of new services. Likewise, Evaluation and Services may work together to interpret the output of user evaluations and how this is fed back into system design.
- Services add value for NSDL patrons and make use of the NSDL distinct from and preferred to similar tools. As an advocate for users, the Services Working Group should lead efforts that aid the user experience and maintain a high level of service quality. These efforts must include services that support teaching and learning with the various data types included in the NSDL. The service tradition of the physical library is still appropriate and may even be more important in the NSDL than in other tools; services allow a traditional library to go beyond a repository. In the traditional library, the most valuable services involve patrons interacting with librarians. Patrons may need assistance in selecting information, with seeking informal information, and with connecting with other users. The protection, continuation, and facilitation of these social interactions may allow the NSDL to remain distinct from other digital library resources.

One element of the traditional library that will require serious attention is the existence of the NSDL help desk or "Virtual Reference Desk." At this point, no project or group has been given the responsibility of fielding user inquiries about content, use, or basic navigation. Since the NSDL has an intended initial audience of all levels of students and instructors, one of its applications is the enhancement of independent learning. The NSDL will need to be sure that basic elements of the user experience are not neglected. For many patrons, dynamic materials and various media types may be unfamiliar. Teaching and learning tools for this media should be developed. Also, given that the NSDL is a new tool, some patrons may not be clear about its purpose and scope. Consideration should be given to having the Services Working Group aid in the development of user tutorials and training modules that are designed to enhance user

experience. In some instances and for some communities (e.g., K-12 teachers), outreach services in the form of training workshops may need to be provided.

It is valuable to remember that the NSDL is more than a "digitized" library. The NSDL exposes its users to vast holdings of digital information resources, such as the terabytes of data stored at government archives. Some of these resources include data sets that require visualization and analysis in order to be used. Today the data are delivered via the Internet mostly through derived images, which still require interpretation. Soon technologies will extend the visualization of these data to the user's desktop. This delivery capability presupposes that the user will know what to do with these data. One of the services implicit in the NSDL as a digital library is the promotion of public "data literacy." NSDL users will need to acquire the ability to visualize and analyze digital resources made publicly available through the NSDL. The Services track should promote data literacy through software tools that bring data visualization and analysis capability to the user, and through informational and instructional content development about digital data and information interpretation and use. The NSDL, as a next-generation of digital libraries, will need to facilitate and accommodate the new generation of data-savvy library users.

F. EVALUATION

The Evaluation Working Group considers evaluation broadly, and sees it as an activity that impacts most if not all of the functions of the NSDL. In particular, formative evaluation addresses the planning and implementation aspects of the NSDL, from assessing the needs of potential users, to designing the user interface and testing it with users. Additionally, evaluation addresses the impact of the project more broadly from the specific user, to a system of users, to its impact on SMET education at all levels of education: secondary and post secondary, formal and informal. Driven by stakeholders and participants interests, evaluation activities also relate to selection of the library's holdings and evaluation of their quality. Finally, evaluation must examine the impact of the library on student learning. In these many roles, evaluation must be an integral part of the CIS from earliest design stages through development and operation of the NSDL.

We anticipate that evaluation of the NSDL will by necessity be multi-method in nature. Methods (e.g., focus groups, survey, interview, and observation) will all be employed in order to respond to various evaluation needs and questions. Evaluation should build on the existing though nascent evaluation efforts already undertaken under the auspices of NSF DLI - 2 funding and other funding supporting digital library efforts.

The purpose of the Evaluation Working Group is to ensure that participatory and stakeholder evaluation principles are integrated into the development and implementation of the NSDL. In particular, the goals of the working group are to:

- disseminate evaluation resources and findings from existing digital library and related projects;
- facilitate sharing of evaluation instruments, methods, procedures, and expertise across NSDL projects;
- educate NSDL participants about implementing evaluation;

- help working groups (Collections, Standards, Services, etc.) to implement evaluations to help further their own work (e.g., assess the quality, usability, and usefulness of resources or services);
- facilitate formative (and summative) evaluation across NSDL participants;
- support NSDL participants' evaluation efforts by supplying expert consultation;
- recommend/develop planning processes, methods, tools, and guiding principles for an NSDL evaluation; and
- conduct a meta-evaluation that addresses the NSDL as a whole.

Given the breadth and scope of the NSDL, it will be necessary to develop a meta-evaluation model for the entire enterprise. Meta-analysis refers to a process by which common measures are identified and tracked across various studies, reports, and research projects. We have adopted this framework as a means for integrating the data collected from multiple projects in order to create an overall picture of the NSDL and as the basis from which to think about identifying best practices in a SME&T education digital library. Five levels have been identified for this evaluation model:

1. documentation
2. formative
3. worth of objectives
4. immediate impact
5. long-term impact

The process of evaluation and meta-evaluation will require creation of a central resource to support the work of digital library evaluation. Evaluation of digital libraries is a new focus for educational evaluation and as such will require new methods, new tools, and new combinations of existing evaluation methods and tools be utilized in an effective evaluation of this innovation. As such, the working group identified two priorities for the NSDL:

- create an organizational structure to coordinate the evaluation efforts of the NSDL in relation to individual digital library projects; and
- establish mechanisms to support evaluation efforts of individual digital library projects by initiating a center that collects and disseminate evaluation resources. This center would also promote formative peer/expert reviews for participating digital library projects.

Through the evaluation process, indicators of success will be identified through documentation or measurement of:

- effectiveness of collaboration across and among the NSDL member libraries;
- impact on and use by the SMET education community;
- impact on changes in teaching and evaluation practices; and
- impact on changes in student learning.

G. TECHNOLOGY

The overarching technical purpose of the Core Integration System is to provide a framework on which the various components of the NSDL will coalesce to form a powerful and coherent educational resource for the nation. To this end, the principal goals are:

- *Collection building.* Help contributors with small or large collections and digital libraries integrate their resources into NSDL, with selectable levels of interoperability.
- *Services.* Identify the core capabilities required to implement user services, and build coherent services for users that unify the resources provided by the individual collections and digital libraries.
- *Portals.* Tailor the presentation of these services to suit the requirements of different users and groups of users.
- *Scientific education quality.* Ensure that high-level scientific and educational concepts and standards may be embodied in the structure of the library.

The architectural drivers used to guide analysis of the quality attributes of the architecture are:

- strong federation and interoperability resources;
- learner and educator productivity mechanisms; and
- ability to evolve.

This plan envisions the NSDL as a federation of heterogeneous, small or large collections and digital libraries, each of which potentially serves as a portal or gateway to the NSDL. This multiplicity of means for entering NSDL permits an unlimited variety of specialized services and tailored views onto the library's contents. The implication of this design is the absence of centrally prescribed user-level functionality. Indeed, the functional characteristics of NSDL are defined in large part to be the aggregated capabilities created by the many contributors to NSDL (with or without NSF funding). The technical infrastructure of the NSDL should be capable of supporting multiple portals with full access to all NSDL resources. While policy or consumer choice may result in a single "super-portal," this should not be dictated by the underlying technical infrastructure.

Given the distributed nature of NSDL components, it is essential that the technical infrastructure support interoperability at many levels. The term interoperability refers to the challenge of building coherent services for users, when the individual components are technically different and managed by different organizations. This requires cooperation at three levels: technical, content and organizational. Technical agreements cover formats, protocols, security systems so that messages, information discovery queries, metadata, and data can be exchanged, etc. Content agreements cover the data and metadata, and include semantic agreements on the interpretation of the messages. Organizational agreements cover the ground rules for access, for changing collections and services, payment, authentication, etc.

For collection building, there appear to be three approaches to interoperability:

1. *Federation*. The conventional approach to interoperability is for a group of organizations to agree that their services will be built to certain specifications (which are often selected from formal standards).
2. *Harvesting*. Each digital library makes minimal metadata about its collections available in a simple exchange format. This metadata can be accumulated by members of the federation and built into services such as information discovery or reference linking.
3. *Gathering*. If the various organizations are not prepared to cooperate in any formal manner, a base level of interoperability is still possible by gathering openly accessible information. The premier examples are the web search engines.

The technical infrastructure of NSDL must also support an array of services. The following list is a summary of the major services that are desired for the NSDL.

Information discovery: This includes both searching and browsing. Searching is one of the primary services that the NSDL must provide. Moreover, the search capabilities must be suitable for the NSDL's various levels of science education. Searching for learning resources is likely to include:

- free-text (keywords);
- metadata fields, e.g., learning objects metadata, Dublin Core, pedagogical, and domain specific subject headings;
- mechanisms to deliver scientific and instructional content or references to such content; and
- enrichment of search through subject thesauri and controlled vocabulary

Access to the NSDL is likely to be through a combination of searching and browsing. Browsing will be possible both through the metadata records and through the contents of repositories.

Catalogs and indexes are tools for information discovery. To build them, the NSDL working groups will need to collaboratively define standards for information discovery queries, metadata delivery, and data delivery. Additionally, the NSDL will need to provide:

- specifications for, and methods to register, metadata that adheres to core standards about resources;
- methods to submit pointers to metadata for harvesting;
- methods to suggest resource for cataloging through crawling;
- tools for creating crosswalk(s) to core metadata standards; and
- tools for tagging collections according to core metadata standards.

Other related services include:

- archive metadata to distributed sites;
- publish search interface(s) including query format(s) and response format(s);
- publish metadata interface mappings;

- metadata retrieval engine(s); and
- publish source metadata (i.e., information about collections).

The specification of metadata standards must include the definitions of the fields, the semantics of information in those fields, and the syntax of encoding schemes (e.g., XML or RDF) for NSDL digital library. In most circumstances, standard metadata schemes will be used. The NSDL will need to hold static information from each NSDL digital library partner as well as develop mechanisms for accommodating changing standards as the NSDL evolves.

To support the integrative study of science, mathematics, engineering, and technology, the NSDL should include services for the integration of metadata across multiple and cross curricula, including:

- services to describe the NSDL 'collection of collections' (meta-catalog);
- synonyms (controlled vocabulary) to describe the semantic unification of collections;
- meta thesauri and attributes for a knowledge management framework;
- semantic registry for attribute relationships; and
- data and metadata for annotations and discussions in general, e.g., quality review, informal feedback.

In the longer term, the NSDL infrastructure will need to expand this integration of metadata into a full knowledge management service. This would support, for example, federation of collections achieved by mapping from a concept space to the attributes chosen by a particular collection. The mapping could be done independently of the legacy collection, but does require consensus between the NSDL community and the scientific disciplines on an appropriate set of concepts. In practice, we would expect each scientific discipline to define its own concepts. This is a generalization of crosswalks to work from attribute space to concept space.

Content Delivery. The NSDL must be able to deliver all forms and formats of scientific and educational materials to every category of user, knowing that the level of expertise and the technical resources available to users differ enormously. In particular, the NSDL architecture must provide:

- mechanisms to deliver scientific and instructional content or pointers to instructional content on remote digital library repositories to users; and
- repository services for storage and archiving of resources

Curatorial services are required for archiving and maintaining collections over long periods of time, including 'out-of-print' scientific collections or legacy learning resources.

Access Control. The NSDL must provide services to control access to materials, including both authentication and authorization services. These include:

- identification and protection of non-free learning resources;
- identification of users with personalized access rights;
- authentication of user identity;

- creation of identity information for purpose of enabling access rights; and
- methods of authorization and access control.

Community. A set of tools and resources for community interactions is required, including:

- community discussion tools in general, e.g., for discussion of learning elements;
- support formation of ad-hoc on-line learning communities; and
- archive discussions.

Services to Manage the NSDL. The NSDL architecture will include tools to manage and enhance the library. They include evaluation:

- implement tools and mechanisms for evaluating learning resources according to agreed standards;
- publish default evaluation standards; and
- publicize "best of SMETE" as references and benchmarks for evaluation;

They also include traffic management:

- collect and analyze data relating to users and use patterns; and
- implement a user tracking mechanism based on an agreed standard

Portals and User Interfaces. The technical infrastructure must support a multiplicity of portals and user interfaces. Given the need to support science education from “K to gray,” and communities ranging from pre-school students to teachers to researchers, the overall NSDL must clearly be able to accommodate a huge range of user experiences. Moreover, in order to build on the community of NSDL users, portals and user interfaces will need to be extensively customizable by community members seeking to present their own specialized view into the available materials. Finally, unique resources, such as interactive simulations, will almost by definition require unique user interfaces, which must be supported by the underlying technical infrastructure.

Scientific Education Quality. A number of dimensions affect to the issue of quality, including:

- quality of the scientific content;
- longevity, persistence, and archivability; and
- authenticity of material (e.g. it has not been fraudulently altered)

One problem is that there is no possibility of a clear, single rating for quality. Instead, quality is cumulative, based on a set of “endorsements” of varying types, including:

- curatorial – this type of endorsement is based on organizational integrity and reputation (e.g. the material is from the Encyclopedia Britannica);
- formal Review – this is the standard peer review process used in journal publication;

- informal feedback – this is user-level review of the type found at Epinions.com or the book reviews at Amazon.com; and/or
- statistical analysis – examples include citation analysis, frequency of web links, and other algorithmic rankings.

Functional Specifications. These technical requirements outline the basic system-level functional specifications that the overall NSDL should support (i.e., the baseline of the core NSDL). A summary of these functionalities includes:

1. Search

- Search for learning resources
 - free-text (keywords)
 - metadata fields, e.g., learning objects metadata, Dublin Core
 - pedagogical
 - domain-specific subject headings
- Enrichment of search through subject thesauri and controlled vocabulary
- Browse through contents of repository

1. Metadata

- Services to describe the NSDL 'collection of collections' (meta-catalog)
- Synonyms (controlled vocabulary) to describe the semantic unification of collections
- Meta thesaurus and attributes for a knowledge management framework
- Semantic registry for attribute relationships
- Metadata for annotations and discussions in general, e.g., quality review, informal feedback

2. Content Delivery

- Deliver instructional content or pointers to instructional content on remote digital library repositories to users
- Repository services for storage and archive of learning resources

3. Rights Management/Authentication

- Identification and protection of non-free learning resources
- Identification of users with personalized access rights
- Authentication of user identity
- Creation of identity information for purpose of enabling access rights

4. Cataloging

- Specify *minimal* core standards for metadata
- Method to register (upload) metadata that adheres to core standards
- Method to submit pointer to metadata for harvesting
- Method to suggest resource for cataloging through crawling
- Tools for creating crosswalk(s) to core metadata standards
- Tools for tagging collections according to core metadata standards

5. Community
 - Community discussion tools in general (e.g., for discussion and informal feedback of learning elements)
 - Support formation of ad-hoc on-line learning communities
 - Archiving of discussions
6. Evaluation
 - Implement tools and mechanisms for evaluating learning resources according to agreed standards
 - Publish default evaluation standards
 - Publicize "best of SMETE" as references and benchmarks for evaluation
 - Federated tools for structured annotation, e.g., formal feedback, endorsement
7. Traffic Management
 - Collect and analyze data relating to users and use patterns
 - Implement a user tracking mechanism based on an agreed standard
8. Curatorial
 - Archive 'out-of-print' collections or legacy learning resources
 - Support methods to 'archive' learning resource
 - Support analysis of "quality" of documents in collection through some form of document tagging or annotation
9. Systems Interoperability
 - Archive metadata to distributed sites
 - Publish search interface(s) including query format(s) and response format(s)
 - Publish metadata interface mappings
 - Metadata retrieval engine(s)
 - Publish source metadata, i.e., information about collections
 - Facilitate retrieval of learning objects and collections from distributed, remote repositories and vice-versa
 - Publish standard procedure for backup and disaster recovery
10. Systems Operation
 - Support distributed data access mechanisms, e.g. HTTP, FTP
 - Tools for bulk-loading collections and collections metadata into core
11. Governance
 - Tools to support governance of NSDL community
12. Education and Instruction
 - Create logical links to cross and multi-disciplinary collections
 - Clearinghouse for teacher training in SMET education

IX. NSDL Action Plan

Development of the comprehensive NSDL will require a phased approach from initial design to implementation. In the current, preliminary phase, six CIS awards have been made to *construct prototype portals, conduct initial tests of features and representative services, and report on the results of this work to NSF (NSF 00-44)*. Thirty-six other awards have been made to support development of collections, services, and targeted research. During this inaugural year, communication and governance mechanisms have been established to enable the 42 funded projects to develop a collective vision and strategy for developing an integrated library (e.g., Community Center at www.smete.org; Working Groups and Coordinating Committee authorized by the PIs of the original funded NSDL projects; this “white paper”). Funded projects are currently working independently to develop collections and services that will make the initial contributions to the distributed NSDL.

Phase I of construction of the NSDL is expected *to establish an operational digital library by September 2002 (NSF 01-55)*. During this phase, the social and technical infrastructure must be established to support the essential functions of the NSDL. Existing partners must be fully engaged in developing the governance, communication, and technical structures needed to integrate their funded projects into a working library. It is the sense of the current NSDL PIs and the Coordinating Committee that at this early stage a strong governing body empowered to formulate policy and coordinate efforts is essential. This body must work closely with a central office or CEO empowered to make operational decisions needed to implement the distributed CIS technical infrastructure and to support the integration of the distributed collection and service networks. New partners, including those who are granted awards in the next funding cycle for NSDL and other potential contributors, will be incorporated into this effort. A plan to evaluate the NSDL and its impacts on learning should be developed and baseline information collected. In this phase, the focus is on building an operational library and engaging additional library builders.

In Phase II of construction, the NSDL is expected *to enrich the scale, scope, and functionality of the digital library by expanding its network of resource collections and introducing new value-added services (NSF 01-55)*. During this phase, a workable library exists, and the emphasis will be on continued growth of the contributor and user bases. A broad-based governance structure will be emplaced, allowing community guidance of the NSDL, and balancing the full diversity of user needs. The CIS design must be flexible enough to allow for rapid growth of the library, incorporating new collections and services with ease. During this phase, it will become increasingly important to engage the education community in using the library, to implement evaluation metrics, and to support library users and contributors.

Completion of this action plan rests on three strategies:

1. A NSDL community emerges from the current funded efforts and fully supports community-based governance including collective decision-making and volunteer activities organized by the Coordinating Committee and working groups.

2. The Core Integration Services are successful in creating an expandable platform for integrating new collections and services, and in supporting outreach needed to engage both building partners and the SMET education user community.
3. Partners come forward who are willing to become part of the NSDL community and develop the full range of collections, services, and library programs needed for SMET education.

The action plan envisions that volunteer efforts to establish policy and collaboration will be coordinated by the governance structure. The CIS will support this work with both technical and human infrastructure. A broad, disseminated effort by funded partners developing activities such as educational applications, evaluation services and user support services will enable maximum flexibility and creativity in developing the library. This will be balanced by the guiding oversight of the governance structure that can both encourage growth in new directions and coordinate the adoption of guidelines and common approaches where necessary.

Planning and Prototype Design 2000-2001 (current activities)

Establish collective NSDL effort from 42 funded projects

- Develop collective vision among funded partners for NSDL construction (Interim Governance)
- Design Core Integration Services to meet needs of funded partners (Interim Governance including CIS partners)
- Implement Interim Governance to enable initial collaboration and decision making (Funded partners)
- Explore governance, business, and intellectual property models (Working Groups)
- Engage funded partners in initial discussions to enable integration of funded pieces (Working Groups).
- Funded projects initiate work on library pieces (Funded partners).
- Develop proposal strategy to fund needed pieces for initial working library (Interim Governance)

Phase I Construction of an Operational Library: 2001-2002

Establish Community –Based Governance and Core Integration System to enable integrated distributed library.

- Enable use of existing collections and services projects through core integration system (CIS and funded partners)
- Develop guidelines and tools for collaboration to enable broad participation in NSDL (Interim Governance, CIS, and service partners)
- Design and implement long-term community-based governance structure extending beyond funded partners (Governance working group and interim governance)

- Disseminate information about NSDL throughout the SMET education community to build NSDL community of users and contributors (CIS and funded partners)
- Design evaluation strategy (Working Groups, CIS and Interim Governance)
- Investigate intellectual property models and business plans (Working Groups)
- Identify gaps and develop an outreach strategy to develop needed partnerships (Working Groups, CIS and Interim Governance)

Phase 2: 2002-2005 Growing the NSDL

Operational Community-Based Governance and Core Integration Systems allows broad community involvement in building collections, services, and library programs.

- Fully implement broad-based community governance and encourage participation to guide NSDL (Governance)
- Incorporate new collections and services to rapidly grow to a full service library for all of SMET education (CIS and new partners)

Develop NSDL as a Learning Resource

- Develop and fund a meta-evaluation of NSDL building in user/contributor feedback and evaluation meta-data. (CIS and new partners)
- Develop maps of taxonomy and concepts relating various parts on NSDL (new partners)
- Support users and contributors with a help desk and library services (CIS and new partners)
- Develop programs engaging SMETE community in using and improving NSDL (Governance, CIS and new partners)