The Development of a National Science, Mathematics, Engineering and Technology Education Digital Library

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Abstract: The emergence of the World Wide Web (WWW) in the early 1990's as a viable means for national and international sharing and re-use of education materials fundamentally changed our view of the way education and learning can be delivered. Internet-mediated learning environments provide mechanisms for the learner to be *anyone, anywhere, at anytime*. Although educators are developing an enormous quantity of materials for use through the Web, potential users face a daunting challenge when it comes to locating them, evaluating their quality and using them effectively. Understanding and overcoming this challenge is crucial if we are to fully exploit the opportunity to improve learning that these new resources have created

We are leading the development of an alliance to develop a National Science, Mathematics, Engineering and Technology Education (SMETE) Digital Library at www.smete.org. This *digital learning community* will provide access to a variety of digital learning resources and services from a federation of partners. It will serve a community of learners and instructors across the full range of SMETE disciplines and serve users from pre-college to undergraduates to life-long learners.

Keywords: digital library, technology-enhanced teaching and learning, science education, mathematics education, engineering education, technology education, learning objects

1.0 Introduction

The World Wide Web and networked information technologies provide an unprecedented opportunity to develop a comprehensive infrastructure to support and facilitate educational initiatives in science, mathematics, engineering and technology (SMET). Internet-mediated learning environments provide mechanisms for the learner to be *anyone, anywhere, at anytime*. Although educators are now developing an enormous quantity of materials for use through the Web, their potential users face a daunting challenge when it comes to locating them, evaluating their quality and using them effectively. Understanding and overcoming this challenge is crucial if we are to fully exploit the opportunity to improve learning that these new resources have created [1].

In response to these problems, two key National Science Foundation (NSF) reports, "Systemic Engineering Education Reform: An Action Agenda" [2] and "Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology" [3], urge the formation of a national resource to provide access to quality learning objects and to disseminate successful educational practices in science, mathematics, engineering and technology education (SMETE).

The broad vision of this national resource, a *digital learning community* for educators and learners, requires an integrated, multi-disciplinary view of science, mathematics, engineering and technology education. Since the early 1990's, NEEDS—The National Engineering Education Delivery System (see www.needs.org) has provided this vision for the engineering education community. Based on the experience in developing NEEDS, we have formed an Alliance with over 20 partners, which include professional societies, academic institutions and commercial e-learning companies, to take the lead in developing a comprehensive resource for SMET education at www.smete.org. The Alliance is branded SMETE.ORG.

This national resource has often been described as a 'digital library.' We believe our vision goes beyond the traditional academic library in digital form [4]. We envision this national resource serving a community of learners in science, mathematics, engineering and technology education that encompasses faculty, students and life-long learners. We see community members interacting with one another to develop, locate, use and recommend to each other resources to enhance learning. We refer to this national resource as a *digital learning community*, in which community members, both novices and experts in technology enhanced learning, work together to improve science,

mathematics, engineering and technology education in their classrooms, in their coursework, across disciplines and with each other [5].

This paper articulates an evolving community vision for the development of a national digital library for SMETE. It addresses the development of vital services and user studies and highlight "lessons learned" from NEEDS. We outline some of the key open issues in developing a national digital library for SMETE and our progress to date. Finally, we propose some areas of international collaboration.

2.0 Background on NEEDS

NEEDS provides a resource where both instructors and learners can search, access, and download digital learning resources over the World Wide Web in science, mathematics, engineering and technology. NEEDS grew out of Synthesis: A National Engineering Education Coalition's determination to share and reuse the instructional technologies developed in support of the coalition's curricular goals [4, 6].

NEEDS has evolved with changes in technology; from its debut in the early 1990's as a "text-based search engine over a centralized library catalog with pointers to digital course material" accessible via telnet [7] to its transition to the Web in 1994 to the current system, NEEDS continues to provide its users with the services to meet their needs. NEEDS has developed and implemented key elements in a reliable, distributed, scalable system architecture, including: redundant Web servers; an integrated database with WWW-based searching and downloading, utilizing state-of-the-art database and information technologies; and an indirection system to support multiple, nationally-distributed archive servers for courseware download [4, 6].

NEEDS is expanding its services to include more user-centered support mechanisms, such as "Amazon.com"-like user comments and reviews. The services and features under development are designed to allow NEEDS to continue to meet the needs of diverse user groups—some may use it to locate resources, others may use it to find like-minded educational innovators, while still others may simply want to get a glimpse of how to integrate technology and learning. NEEDS also supports a multi-tier evaluation system [8–10] including a national award competition—the *Premier Award for Excellence in Engineering Education Courseware*.

3.0 Developing a National SMETE Digital Library

Since 1996 the National Science Foundation has studied the development of a national digital library for science, mathematics, engineering and technology education. With the recent program announcement of the National SMETE Digital Library program in 2000 and 2001 [11,24] and preliminary funding under the Digital Libraries Initiative-Phase 2, NSF has begun to develop this national resource. This program is envisioned as a federation of services and collections that function together to provide *seamless* access to the wealth of teaching and learning materials under development. Most importantly it will be driven by, facilitate and promote change in SMET educational innovations. From its debut as the 'Library of Undergraduate Science Education (LIBUSE)' concept in 1996 to the NSDL program of today, NEEDS has provided leadership in the development of this national resource for the community of learners in SMETE [12–14].

SMETE.ORG is leading the development of an alliance to build the National SMETE Digital Library (NSDL) at www.smete.org. The alliance is a web of partnerships encompassing disciplinary collections, researchers, commercial and non-profit education organizations, and industry. Our vision for the national digital library for science, mathematics, engineering, and technology education is one of a diverse and dynamic learning community. Our goal is to establish a national digital library for SMETE that is much more than a static information repository. The alliance intends to create a dynamic learning community that promotes and supports SMET education in the 21st century by providing a broad and deep infrastructure of disciplines, collections, services and targeted research to serve a community of learners in science, mathematics, engineering and technology education. The NSDL must be a place where members of the community of learners interact with one another to develop, locate, use and discuss digital resources that enhance teaching and learning. The SMETE community needs services and resources to support both novices and experts in technology-enhanced learning in their classrooms, in their coursework, across disciplines and with each other.

3.1 Multidisciplinary Partnerships

Our background in engineering education (through NEEDS and the Synthesis Coalition) has shown the value in developing multi-disciplinary teams and strong partnerships among diverse organizations. We are leading the development of an alliance that will demonstrate a federation of collection and service providers in a National SMETE Digital Library at www.smete.org. Ultimately a wide variety of partners will be necessary; some will provide access to collections while others will provide services or the core infrastructure about which the federation is developed. Additionally a breadth and depth of partners is necessary to provide the rich user experience

envisioned for the national digital library for SMETE. Alliance partners, such as the Math Forum (see www.mathforum.com) and the Eisenhower National Clearinghouse for Science and Mathematics (see www.enc.org), are working within their own communities to determine the services and features necessary to provide value to their users. The challenge will be bringing these partners together to determine core services and features common to the National SMETE Digital Library. In addition we must plan for identifying and adding additional partners to support the broad reach of the sciences, mathematics, engineering and technology.

3.2 Standards and Protocols for Resource Description and Interoperability

Building upon our experience with NEEDS, we know that standards and protocols are the glue that will allow us to build a *seamless* National SMETE Digital Library at www.smete.org. Standards will provide mechanisms for sharing metadata about resources, and protocols will provide the means to accomplish interoperability between federated systems. The Institute for Electrical and Electronics Engineers (IEEE) is in the process of working with the community-at-large to develop standards for learning technologies in Working Group P.1484 (see ltsc.ieee.org). Also, the digital library research community and general library communities have developed standards for interoperability that we can adopt or adapt to suit the needs of a national digital library for SMETE.

From its inception, NEEDS has placed a high degree of importance on standards. In October 1991, NEEDS convened a standards advisory group to examine and recommend existing and developing standards for describing resources in a networked environment in order to allow access to all users [15–16]. From the use of the USMARC standard for the bibliographic cataloging of our resources [16] to the adoption of emerging learning object metadata standards of today—the IMS Metadata Specification version 1.0 and the proposed IEEE Learning Object Metadata standard [17–18]—NEEDS has been at the forefront in describing networked learning resources. This adherence to open, international standards continues with SMETE.ORG.

To accomplish the interoperability required of a federation of collection and service providers, we can look to the work being developed by digital library researchers and apply it to the SMETE domain. The Dienst and Waters protocols are in use today in the Networked Computer Science Technical Report Library (see www.ncstrl.org). The Networked Digital Library of Theses and Dissertations (see www.ndltd.org) in Computer Science is also experimenting with protocols to perform federated searches over its distributed collection [19]. Researchers at Stanford University are developing a Simple Digital Library Interoperability Protocol (SDLIP) in use locally within their digital library and in conjunction with the digital library research project at the University of California at Berkeley [20–22]. These three examples combined with standards such as Z39.50 and the use of extensible markup language to encapsulate searches [23] are some of the areas we will be exploring as we develop specifications for interoperability in the National SMETE Digital Library. To date, we have developed a prototype federated search specifications to enable the discovery of learning resources from distributed digital library collections.

Current standards efforts IEEE Learning Object Metadata Working Group P1484.12 (see ltsc.ieee.org/wg12), and the work of various international groups such as IMS (see www.imsproject.org) and ARIADNE (see ariadne.unil.ch), have focused on describing the content of the learning resource. SMETE.ORG is in the process of adopting these emerging standards and continues to follow their development. We are committed to implementing and participating in the development of standards and specifications for metadata and content description. We feel it is important to be a key player in the development of these items. We bring ten years of experience in running a production system that takes advantage of these standards and specifications [5].

3.3 Community of Learners

If standards and protocols are the glue that holds the technical infrastructure in place, then community provides the threads to weave content and pedagogy into learning and teaching. We know that for any effort to be successful, the resources we develop for a national digital library for SMETE, must be built around and support a community of use and practice. Thus, the *digital learning community* of the National SMETE Digital Library at www.smete.org, to reflect some of the best qualities of real life communities, should be persistently interactive, mutually supportive, and provide its members with mechanisms to adapt and build on the work of others to strengthen SMET educational programs [1].

The long-term vision of our community building efforts is to facilitate users searching for both content as well as educational concepts (e.g., geometry or problem-based learning). We also want to help users answer the question, "How do I use these learning resources once I've found them?" This evolution to support communities of learners emphasizes interactivity, user-to-user communication and community building. Two steps we have already initiated are allowing users to post reviews (i.e., "Amazon.com"-like reviews) and participate in focused discussion groups (e.g., "how to revitalize freshman design?"). It may be possible, however, to go further; we envision "pedagogical metadata" that better encapsulate or package the pedagogical applications of a learning resource [5].

3.4 Towards the Future

As we look toward the future, we see the growing need for work to be done in several key areas. We see the need to continue to develop disciplinary and cross-disciplinary subject thesauri to better describe learning resources. These subject hierarchies will allow the user to both browse for learning resources he/she may be looking for as well as assist searchers in finding related materials (greatly improving discoverability of resources). Groups such as the American Mathematics Metadata Task Force (see www.ammtf.org), and some of our early efforts with NEEDS in engineering, already have initiated development of discipline-based subject hierarchies.

We also see the need to develop taxonomies to better encapsulate the context in which a learning resource is used. Finding the materials is only a small part of the challenge facing educators and learners today; knowing what to do with the materials poses tougher challenges. Current collection providers have provided the first part of the needed solution—tagging the basic description of the content and technical requirements of the resource. In some cases, for example by the Math Forum and NEEDS, collection providers have taken initial steps in describing the much-needed part that of pedagogical application of the resource. However, current efforts in metadata tend to provide only a macro-level view of the pedagogical application of a learning resource. What's needed is a micro-level, or more granular, view of how to use a particular resource. We envision collection providers continuing to provide the basic tagging of the content of a resource. However, we also see them working to develop an author/instructor completed "short form" that describes the pedagogical application of a resource. From this "short form," we envision being able to extract a much richer set of descriptions about possible applications of the learning object. This "short form" combined with culling discussions about resources we feel will ultimately allow us to provide a better description of the context in which to use learning objects [5].

4.0 Progress

Over the past year, we have made progress towards developing a prototype digital learning community for science, mathematics, engineering and technology education. The prototype is currently available for review at beta.smete.org as shown in Figure 1. Some of the key features of the prototype include the ability to search for learning resources using pedagogical identifiers, searching over multiple collections including distributed educational digital library collections provided by SMETE.ORG Alliance members, supplementing learning objects with books and scholarly journal articles through a Z39.50 gateway, and a collaborative filtering mechanism to autonomously recommend learning objects based on prior expressed educational needs. Some services still under development include the ability to build a personalized collection based on learning objects located in the digital library, to form ad-hoc communities based around educational issues and learning objects, and to attach personal, and potentially shareable, comments on learning objects. We expect to have a fully functional prototype by the Fall 2001 at www.smete.org.

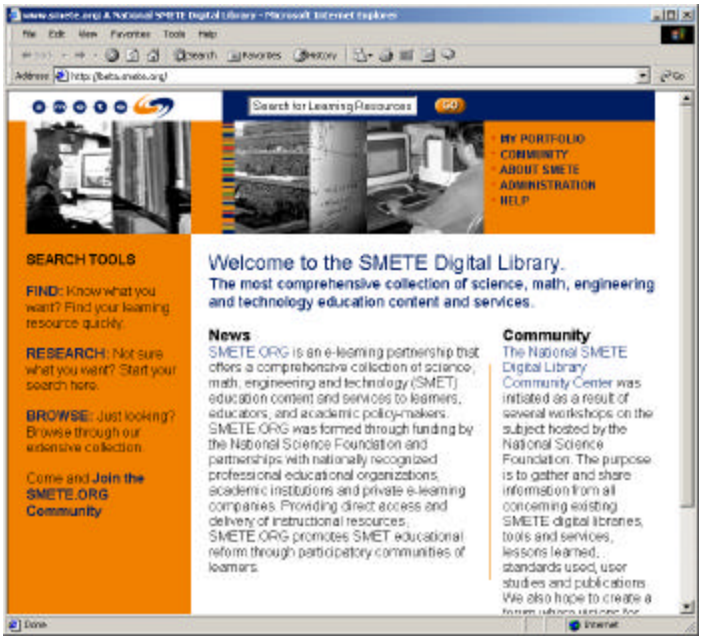

Figure 1 Prototype Portal at http://beta.smete.org/

One of the major advances made by the SMETE.ORG Alliance is the introduction of design principles for the information architecture of an educational digital library, principles that address the distinction between designing a digital library for education versus designing a digital library for information retrieval in general [25]. These principles are:

Principle 1: Organize information to provide opportunities for students and educators to create, synthesize, manipulate or debate content rather than merely to passively receive instruction.

Principle 2: Label resources with pedagogical identifiers such as age group, teaching method, and academic standards to indicate educational uses.

Principle 3: Guide the collection and adaptation of learning elements towards individual learning goals.

Principle 4: Optimize search to meet the interests, knowledge, understanding, abilities, and experiences of the users in their roles as educators or students.

The essence of the information architecture and the design principles is to devise interactions that let users achieve the goal of using the resources of the digital library for the purpose of learning. Figure 2 illustrates a sample record for a learning object and implementations of some of the principles described above. End-users can get tips on how to use the learning resource, add shareable comments on the learning object and review others' comments. The information design of the digital library should increase students' responsibility for their own learning; they take control of their actions and interactions and organize their own time for learning. At the same time, the design should empower the educator to guide the student through this educational path. The primary impact we envision for the digital library to have on teaching and learning is to actively engage the participants in the creation of shared conceptual understanding of science, math, engineering and technology as an integrated study.

Figure 2 Learning Object Catalog Record

5.0 Areas for International Collaboration

As the SMETE.ORG Alliance progresses towards an operational National SMETE Digital Library, we look towards expanding our partnership across international borders. In particular, we seek to establish partnerships with international agencies and organizations spearheading educational digital library initiatives in the areas of science, mathematics, engineering and technology education. We desire to expand our understanding of the teaching of the SMET disciplines and the potential impact of digital learning resources and digital learning communities on these teaching methods. Sharing our mutual lessons learned in developing educational digital libraries serving diverse communities of users will ultimately enhance the ability of all educational digital libraries to serve the broadest array of users. Furthermore, we would like to continue to collaborate with international agencies in the development of standards for the discovery of learning resources to enable interoperability among international education digital libraries in the SMET disciplines. Just as the Z39.50 protocol opened up access to bibliographic resources across international library collections, we seek to continue on this model of international cooperation in the area of educational digital library interoperability. We already work closely with the IMS Consortium and the Dublin Core Initiative working group developing a metadata element set for the discovery of education resources. These standards will help to assure that learners can have access to the best learning resources, anywhere, anytime, while respecting the intellectual property rights of the authors and providers of the learning resources.

6.0 Summary

The frenetic pace of change in information technologies has exacerbated the age-old problem of finding information. With everyone a "publisher" in this new information age, the volume of materials is drastically increasing. Even if we "just" limit ourselves to engineering education, the volume is enormous. SMETE.ORG and alliance partners are developing a new vision, a *digital learning community* that extends beyond a single discipline. We are working to develop a National SMETE Digital Library at www.smete.org, encompassing a federation of collection and service providers to support the learning and teaching needs of a broad community of learners in the sciences, mathematics, engineering and technology education.

In this early stage of development, we are focusing our evaluation efforts on identifying user needs in order to ensure that the library design reflects those needs. The needs assessments have been instrumental in the design of our site and are essential to developing an accessible library that does not exacerbate the growing digital divide. To better understand the needs of our diverse community of users we conducted in-person focus groups and, this year, will implement on-line focus groups. We also continue to survey our registered users on a regular basis as well as specified samples within the larger population. To examine the short and long term impacts of SMETE.ORG, we will conduct more in-depth studies that focus on the expected outcomes associated with our goals. These studies will include tracking usage statistics and patterns across, between and among specific user communities as well as for the library as a whole. Metrics associated with expected outcomes for teachers, students and in some cases courses, curricula and schools may be examined. Particular attention will be focused on the impact on student learning. Studying the immediate and long-term impact of the library is a complex project requiring expertise from various different disciplines. Collection of use data is currently underway, and planning has begun with regards to long-term longitudinal studies.

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