Design Principles for the Information Architecture of a SMET Education Digital Library

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ABSTRACT

This implementation paper introduces principles for the information architecture of an educational digital library, principles that address the distinction between designing digital libraries for education and designing digital libraries for information retrieval in general. Design is a key element of any successful product. Good designers and their designs put technology into the hands of the user, making the product's focus comprehensible and tangible through design. As straightforward as this may appear, the design of learning technologies is often masked by the enabling technology. In fact, they often lack an explicitly stated instructional design methodology. While the technologies are important hurdles to overcome, we advocate learning systems that empower education-driven experiences rather than technology-driven experiences. This work describes a concept for a digital library for science, mathematics, engineering and technology education (SMETE), a library with an information architecture designed to meet learners' and educators' needs. Utilizing a constructivist model of learning, the authors present practical approaches to implementing the information architecture and its technology underpinnings. The authors propose the specifications for the information architecture and a visual design of a digital library for communicating learning to the audience. The design methodology indicates that a scenario-driven design technique sensitive to the contextual nature of learning offers a useful framework for tailoring technologies that help empower, not hinder, the educational sector.

Categories and Subject Descriptors

Computing Milieux - Computers and Education – Computer Users in Education

General Terms

Design, Human Factors

Keywords

Science, mathematics, engineering, technology, education, learning technology

1. INTRODUCTION

Instructional technology and 'e-learning' gain momentum daily as educators and educational policy-makers strive to incorporate Web-based learning strategies to improve education and achievement. In the United States, this momentum undoubtedly benefits from former President Clinton's initiatives on closing the digital divide advocated by the President's Information Technology Advisory Committee[1]. Congress has commissioned a Web-based education commission[2] to set policy for leveraging the Internet as a vehicle for education. The IEEE Learning Standards Technology Committee[3] works to develop standards and specifications to facilitate computer implementations of education and training components and systems.

However, the focus, whether in government, industry or academia, seems placed squarely on advancing the "technology" part of instructional technology rather than "instruction." Learning technologies could be characterized as technology-focused, that is, focused on the enabling technologies rather than tailoring their design to local educational practices. The bulk of the current set of learning technologies deliver tools needed to create, deliver, and manage on-line courses. More emphasis and effort is placed on full-featured learning management systems and ever more complex instructional technology systems incorporating more content and more capabilities.

Anecdotal evidence suggests that teachers and students are often frustrated by these systems. The need exists for systems that place instruction at the core of design and technical functionality, to distinguish them from systems that merely contain educational content but whose design and technical functionality is indistinguishable from a wide-array of others. We advocate a contextual design approach focused particularly on applying current learning research to instructional technology.

A prototype platform and portal for a new instructional system based on this approach is being built for the science, mathematics, engineering and technology education (SMETE) community. [11] The mission of this instructional system is to create an environment in which educators and students work together as active learners – a public space for the teaching and learning of science, mathematics, engineering and technology as an integrative study.

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[1] http://www.ccic.gov/ac/

[2] http://www.hpcnet.org/webcommission

[3] http://ltsc.ieee.org/

The foundation of this instructional system is a digital library of learning object resources. The digital library offers direct access to and delivery of instructional resources through the establishment of a federation of representative SMETE digital libraries. The digital library promotes learning through personal ownership and management of the learning process while connecting the learner with the content and communities of learners and educators. Content and services provided through the digital library will generally include multimedia courseware, digital problem sets and exercises, educational software applications, related articles and journals, and instructional technology services for educators and students, both commercial and non-commercial – all organized and labeled for the purpose of education and instruction.

Layered on top of the content are various tools, such as search tools, learning object management tools, and community-building tools, which leverage the educational content. These tools will permit users to learn, connect and manage their personal educational portfolio. The digital library seeks to connect communities of educators and learners to a rich set of pedagogical resources for SMET education. Educators engage intelligently in public discourse and debate about matters of technical importance. This combination of SMETE contents, services, and tools positions the digital library as a 'learning space' for learning science, mathematics, engineering and technology.

Direct access to a broad collection of SMET educational content and services presents simultaneously an opportunity and a source of frustration for the learner and educator. In order to conceptualize and design a new instructional system, instructional considerations, not technology, must take center stage. Utilizing a constructivist view of learning, we outline the specifications for an information architecture for the presentation of educational resources in a manner that communicates education and instruction to the educational user. Under this viewpoint, 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. Whoever the user may be, the objective is the same: to assemble educational resources for the purpose of learning. The essence of the information architecture is to devise interactions that let users achieve this goal.

Information architecture [14] deals with the design of organization, labeling, navigation, and searching systems to help people find and manage information. This implementation paper introduces the grounding principles for the information architecture based on instructional considerations for each of the objectives of information architecture, that is, organization, labeling, navigation and searching. Based on the principles, we formulate an information architecture that supports these principles. The principles are based primarily on constructivist theories of learning with reference to information processing [1] as a model of mental cognitive tasks [7]. A visual concept and reference technical implementation that exemplifies the information architecture is presented. The paper concludes with plans for an assessment of the effectiveness of the architecture in meeting the design principles.

2. Learning: A Constructivist Viewpoint

A prevailing theory of learning, constructivism, asserts that learning is based on students "constructing" their own knowledge by testing ideas and approaches based on their prior knowledge and experience, applying these to a new situation, and integrating the new knowledge gained with pre-existing intellectual constructs. [8] Information access environments, such as an educational digital library, offer students and educators opportunity to gain access to these "pre-existing intellectual constructs." Unfortunately, giving them unstructured access to the digital library is similar to an unguided visit to a "bricks and mortar" library. Pedagogical structure is necessary for learning and education to happen. Deciding which resources to use, and what information to extract, that is, altering, rearranging or recomposing information, are among the numerous information processing tasks [13] associated with constructing mental models [8] that could be better left up to the educational user. The tasks of the digital library are to find the learning resources, supply useful tips on applying them to current learning goals, and surface information that would aid in the decision to incorporate the learning elements. The following sections propose principles for applying pedagogical structure to the information architecture of an educational digital library in support of this constructivist view of learning.

2.1 Information Organization

Separating content and context, or content and learning processes, affords learners the flexibility of applying learning objects towards different instructional strategies to teach the same or related subject matter. One of the primary challenges of information organization for education is the uncertainty in knowing the cognitive models of the learner or educator. Studies in generative learning theory for science and technology [11] posit that learning is not necessarily limited to the manipulation of existing cognitive structures but rather begets new associations for the learner. We are led then to the following principle.

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.

2.2 Information Labeling

Using appropriate instructional strategies for a particular level of learning and incorporating necessary conditions for learning presentation are significant components of success associated with a specific instructional delivery mechanism. The effectiveness of the learning resource hinges on the type of learning undertaken, whether the pedagogical style is inquiry-based, project-based, peer-based, or model-based, among others. This leads to the second principle specification.

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

2.3 Information Navigation

Few would argue that the best possible instruction involves individualized treatments that differ in structure and completeness depending on the learning goals and ability of the learner. Research has shown that curriculum with highly structured treatments seem to help students with low ability but hinder those with high abilities. [3] The navigation scheme of the digital library acts as a proxy for curriculum in so far as how the digital library guides users through the task of finding learning elements. The implication for the information architecture then is to balance prescriptive navigation while allowing users ability to explore. Two individuals using the same navigation should be guided to only the specific information that a particular learner wants or needs in the appropriate manner and at the appropriate time.

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

2.4 Information Search

A popular approach to implement digital library search services is to utilize an existing full-text information retrieval system such as Google. The primary deficiency, though, is that these systems lack sufficient context for learning. The question that needs to be asked is how to formulate a search that aids in personal learning. The difference between finding a learning resource and doing research for developing course curriculum versus merely conducting an information retrieval task lies in the interpretation of relevance. Relevance in the sense of learning is much more complex than as treated by standard information retrieval methods. A search for "solar system" could return numerous relevant documents with high precision, defined in information retrieval terms, but not contain information addressable by a class of high school physics students performing an inquiry-based study of orbital patterns nor would it be useful for providing information relevant to the specific learning context.

Educational objectives should be searchable and listed in the search results. The extent to which a learning element is relevant correlates with how the learning element achieves a learning goal. This leads to the following principle.

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

3. Methodology

This information design methodology follows along the principles of "contextual design." [2] Contextual design suggests that systems development should follow a deep understanding of the users' work, thereby explicitly defining the interaction of the users with the system. We utilized several tactics for obtaining this task information: 1) a review of user needs provided by case studies and user scenarios; 2) a simple benchmark of two existing, prototypical educational digital libraries; and 3) user personas and task modeling.

3.1 Analysis of Existing User Studies

An important first step in this process is gaining knowledge of the educational objectives of learners and educators and what tasks they would undertake in the digital library to achieve their objectives. This knowledge was gathered from a review of use scenarios from an evaluative case study of users [9] in the National Engineering Education Delivery System (NEEDS) [10] and user scenarios[4] developed by the Digital Library for Earth Systems Education (DLESE). Both of these studies centered on identifying and clarifying users' (end-users such as learners and educators as opposed to catalogers and authors) needs regarding the functionality and behavior of an educational digital library and prototypical tasks in utilizing the digital library's resources.

The major findings from the above studies were:

- When users search for instructional materials (learning objects), they want to find materials that are useful and meet their needs. For educators, "useful" materials include labs, exercises, lecture notes and primary materials. Educators also noted the desire for quality standards and peer review as a filtering mechanism. For students, useful materials were resources for papers or research.
- Faculty noted the importance of instructional and pedagogical labeling to understand successful courses and learning experiences.
- Given the broad array of disciplines represented by the resources of the digital library, both students and educators noted the need for cross-references to information that cuts across the disciplines. Tools such as glossaries and thesauri could ease the referencing of such material.
- Both students and educators emphasized community as an integral component in the learning process.

Based on these findings, we identified the following high-level user needs:

- Information Organization
  - Methods to organize the materials around personal context(s) rather than a prescriptive context.
  - Community resources for social network building in particular to assist in discussion and synthesis of learning resources.
- Information Labeling
  - Educational labels to describe learning resources.
- Information Navigation
  - Learner information profile to improve adaptation of learning elements towards educational goals.
- Information Search
  - Learning descriptors as search filters.

3.2 Benchmarks of Existing Educational Digital Libraries

For the second phase, we compared the information organization, labeling, navigation and search of NEEDS and MERLOT[5], two widely used educational digital libraries, on the high-level needs shown in Table 1.

Table 1 Comparison of educational digital libraries

	NEEDS	MERLOT
Information Organization		
Methods to organize the materials around personal context(s) rather than a prescriptive context.	No	No
Community resources for social network building in particular to assist in discussion and synthesis of learning resources.	Yes	No
Information Labeling		
Educational labels to describe learning resources.	Yes	Yes
Information Navigation		
Learner information profile to improve adaptation of learning elements towards educational goals.	No	No
Information Search		
Learning descriptors as search filters.	Yes	Yes

[4] Available at http://www.dlese.org/usecases/forum.html.

[5] http://www.merlot.org/

3.3 User Personas and Task Scenarios

Finally, we developed user personas and task scenarios these users might potentially undertake to reach their learning objectives. We noted that finding learning resources using this digital library represents but one of many tasks that a user might undertake to satisfy their learning objectives. Further, we thought through how the digital library might complement the user's existing learning environment rather than supplant it with a virtual learning environment. That is, the digital library should enhance overall learner and educator productivity rather than enhance just the ability to search and retrieve learning resources.

Examples of the user personas are:

1) Sally is a 10th-grade student at an inner-city high school. Sally's favorite course is biology and would like to become a doctor or veterinarian.
2) Tom has taught general science in junior high for over 10 years and would like to be rejuvenated. He has started to attend professional development workshops where he has been introduced to new pedagogical techniques for teaching science.

Tasks these personas might undertake include:

Student:

The student has a homework assignment on "electrons." To complete the assignment, the student begins by browsing through the digital library collection of materials appropriate for K-12 general science and mathematics education on "electron configuration."

A student has just gone on a field trip to an observatory. The student learns about solar winds and their effect on radio transmission. The student is not able to find materials on solar winds and thus posts a question to a "science buddy" about solar winds.

Teacher:

A teacher is preparing a new lesson plan for a general science class. The teacher finds curriculum material. Instead of printing them out, he directs his students to the material on-line where they can work together on some experiments. An example of this on-line personal collection is shown in Figure 1.

A teacher wants to share her experience using a "mathlet" for plotting equations. The teacher uses the Comments and Reviews feature, shown in Figure 3, to attach a teaching use comment with the learning resource. The comment is sent to the author.

4. The Architecture

The primary driver for the information architecture of an education digital library is to facilitate a better way to accommodate the task of retrieving learning objects that can be re-used for learning. A reference information architecture for a SMETE digital library, available for preview at http://www.smete.org/, is presented.

4.1 Information Organization

The challenge here is to develop a personal collection or learning portfolio to keep track of materials found, not necessarily for convenience, but rather to assist the learner or educator in conceptualizing the material in a manner conducive to individual learning. Further, the collection can be shared to engage discussion between the user and the author(s) or contributor(s) of the resource as well as with others interested in learning about the same subject matter using the same learning object. The learning portfolio shown in Figure 1 is both a radiant experience and focal point for organizing material. As a secondary purpose, it allows the user to navigate through the space of digital library resources in a concept space that is defined by the user.

The folder metaphor is just one interface currently under development to assist users in organizing learning resources. Other interfaces, including concept maps [3] in which users create their own concept maps and organize materials according to the map, are currently under consideration.

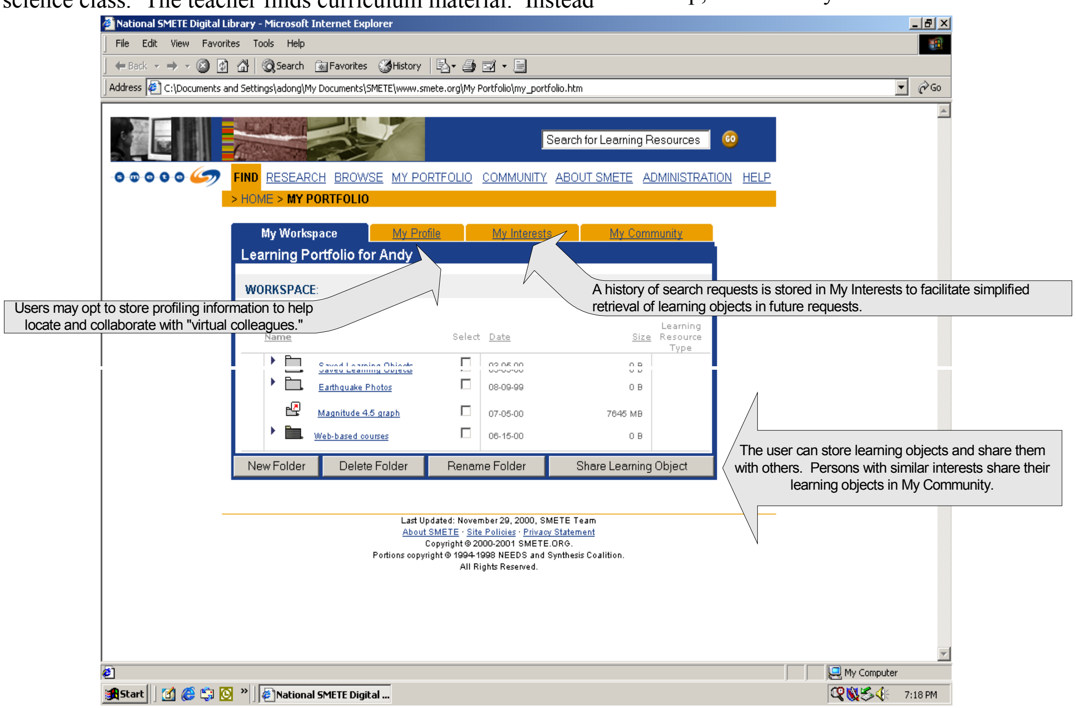

Figure 1 The My Portfolio service is a radiant experience and focal point for organizing material. The user is able to create a personal conceptual model of learning resources and share that model with others.

4.2 Information Labeling

The key goal in information labeling is supporting the discovery of education resources rather than merely supporting the discovery of resources in general. The search results (Figure 2) surface educational use indicators such as age group, learning resource type and learning context through the use of the IEEE Learning Object Metadata (LOM). [6] While the LOM, and similarly the Dublin Core metadata in the description of educational resources [5], do not currently make semantically identifiable statements about the pedagogical aspects of a learning resource, information indicating how the learning resource can be integrated into a curriculum can be made available through the use of domain-specific 'best practices' vocabulary. In the LOM, the tags Educational.LearningResourceType, Educational.TypicalAgeRange and Educational.TypicalLearningTime offer teaching and learning information that may aid in the discovery, retrieval and eventual use of the learning resource when populated with appropriate controlled vocabulary. That is, by labeling learning resources with information about how they might be used, the labeling supports better learning through better instructional design.

These domain-specific vocabularies for describing the educational use of learning resources are being developed in various communities. The Mathematics Association of America has completed a subject thesaurus for mathematical concepts and the Eisenhower National Clearinghouse has completed a taxonomy of mathematical concepts for K-12 education. These thesauri are being integrated into the information labeling of this educational digital library.

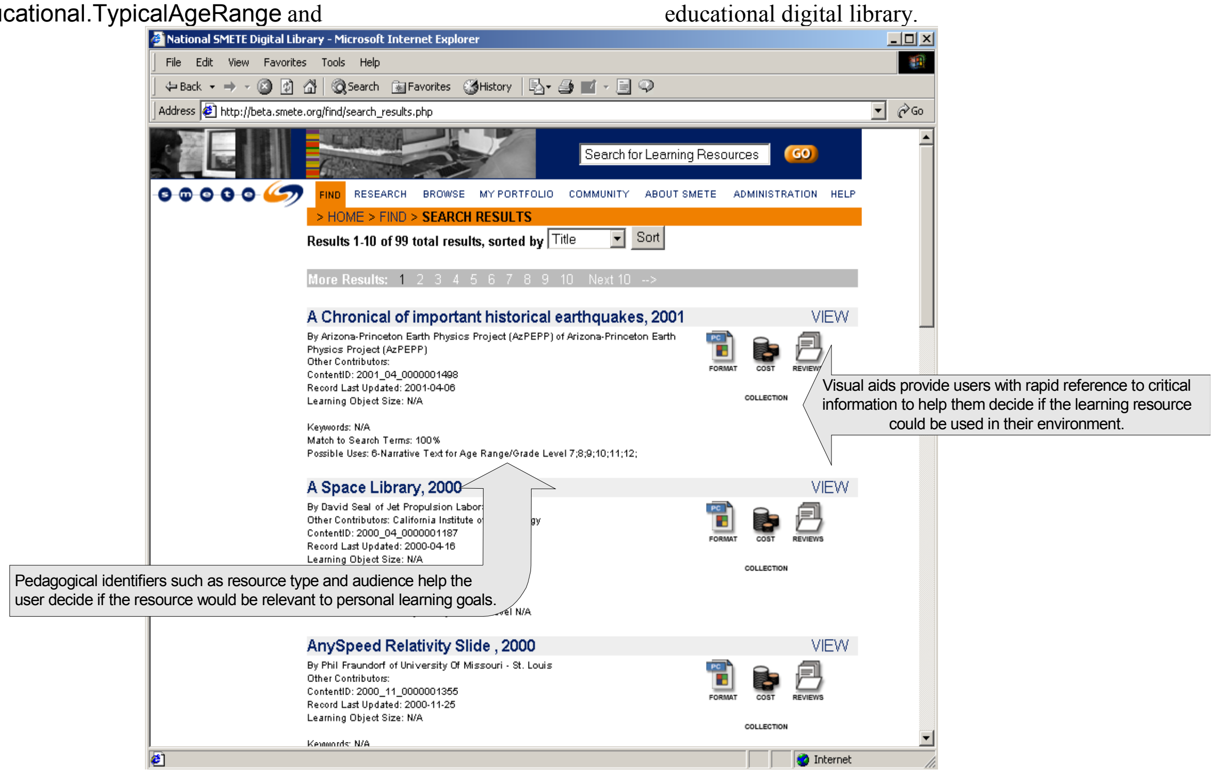

Figure 2 The search results indicate information to help decide if the learning resource would be relevant and useful to learning goals by surfacing educational identifiers. Equally important is Cost, which can restrict access to the resource.

4.3 Information Navigation

Since a learning object normally has several elements and requires instruction about the pedagogy, navigation (Figure 3) is required to guide users towards the adaptation and collection of learning objects associated with different learning goals. Navigation cues to "learning elements" lists the components of the learning object with a brief description of the elements associated with the learning object. Cues to "pedagogy" contain information on how the user might integrate the material into curriculum including references to past successful implementations.

Ad-hoc on-line communities for review and assessment integrated into the search results and learning objects, cross-linked by subject and description keyword(s), guide users towards debating and synthesizing learning materials in collaboration with others. By bringing in these discussions, learners and educators can capture issues and others' conceptual models to develop a shared view of the subject.

Figure 3 The learning object forms the nucleus of information from which users can learn how to incorporate the learning object, and add comments on their experience with the learning object.

4.4 Information Search

One of the important pieces of user feedback regarding the search mechanism of the NEEDS digital library was the confusion between "Search" and "Advanced Search," the former connoting usefulness to novice users of the digital library and the latter to advanced users. Instead, the difference between the two modes of search is really the level of filtering, with "Advanced Search" containing more learning descriptors as search filters. As such, we differentiate the search mechanisms in terms of assisting users find materials with potentially more relevance to their education levels, experience and knowledge.

A more relevant distinction to searching for learning resources is the level of knowledge the user has of the SMET concepts and how those concepts would typically be addressed. That is, an experienced person in a specific subject discipline might use the Find feature to locate a particular learning object whereas a beginning student in the field might utilize the Browse feature to locate learning objects within a more general subject category familiar to the student.

In the "Find" mode (Figure 4), users apply numerous learning descriptors to direct the search engine towards particular learning object(s). A typical "Find" search might be, "Find the courseware titled 'Interactive Frog Dissection.'" In "Research" mode, users conduct a broad search using subject headings, with the option of filtering the results by a set of learning descriptors. The "Research" mode also offers the capability to view courseware within a collection by subject headings, such as all "civil engineering" courseware from the "NEEDS" collection. In "Browse" mode, users conduct high-level subject searches unconstrained, necessarily, by any learning descriptors. Hierarchical browsing through subject keywords, visual browsing through an image database of multimedia learning elements, and browsing by teaching method assists the user in conceptualizing at a high level the type of resources available in the digital library. It is expected that users unfamiliar with a subject area would begin by browsing, eventually using some of the navigational aids and information labeling to inform more directed "Find" or "Research" to locate specific learning objects.

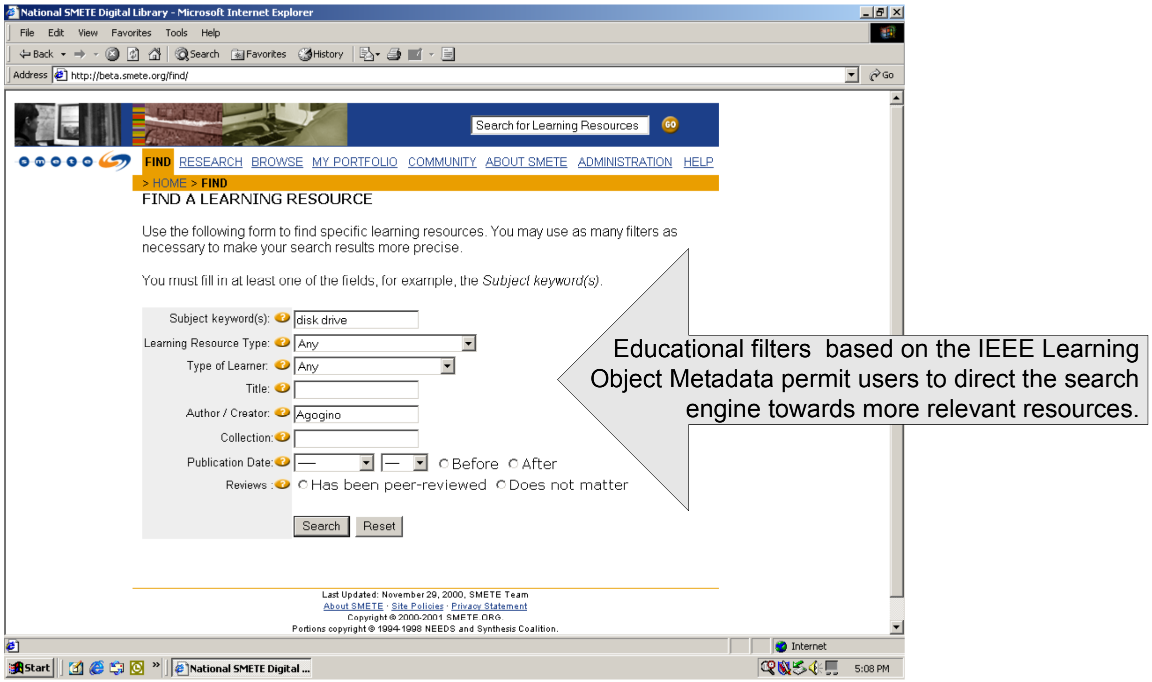

Figure 4 The Find page incorporates educational filters based on the IEEE Learning Object Metadata standard. These filters permit users to direct the search engine towards more relevant resources depending upon their educational needs.

5. Conclusions

The objective of this implementation paper was to investigate the support of learning through the resources of a digital library and then translate those needs to the design of an information architecture for an educational digital library. By focusing on the learning objectives of educational users, rather than how to enable a particular user interface or learning technology, the study establishes principles on how to introduce features that focus the digital library on its educational goals. By understanding the motivations that lead individual educators and learners to utilize the resources of an education digital library, we were able to obtain knowledge of how a larger population of learners and educators would use the digital library. The information architecture principles present guidelines on how to design an education digital library that better satisfies the information processing tasks associated with learning, particularly inquiry-based learning. These principles enabled the design of a digital library for networked information discovery and retrieval with education being the objective, a primary distinction from information retrieval in general.

Currently under parallel development is an Instructional Architect[6], an integrated Web-based development environment in which learning objects can be assembled into instruction with a method for enabling the spontaneous formation of new communities of users based on shared interests. Users may search for learning objects using the digital library presented in this paper and download them into the Instructional Architect system.

Assessment studies are currently being conducted on a lead-user group. The evaluation plan for the information architecture is organized loosely around three types of evaluation methods:

- Assessment of user needs
- Formative assessment focused on improving services and features
- Short and long term impacts of the digital library on the SMET educational community including students

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. Our next steps will center on implementing user studies of various users (e.g., students, faculty, K-12 teachers) interacting with the site. Here we will implement observation studies of users as well as coordinated surveys of users.

Questions guiding the user studies include:

- Do the users interact with the site as designed?
- Are the users satisfied with the site? Do they find it easy to navigate? Do users find useful materials? What hinders their use of the site?
- Do users prefer particular aspects of the interface design?

To examine the short and long term impacts, 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

[6] http://ia.usu.edu/

different disciplines. Collection of use data is currently underway, and planning has begun with regards to long-term studies.

The primary impact the digital library may have on teaching and learning is to actively engage the participants in the creation of shared conceptual understanding of science, mathematics, engineering and technology as an integrated study. By giving teachers and students access to learning resources across disciplines with the flexibility to incorporate them into their own personal educational goals, the digital library creates new learning opportunities for students and new ways to present materials for teachers.

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Acknowledgements

The National Science Foundation funded this research work under Grant #DUE-0085878 and program solicitation DUE #00-44 for the National SMETE Digital Library Program. The authors would like to acknowledge the members of the SMETE.ORG Alliance for their invaluable feedback during the development of the information architecture. This research is part of an ongoing collaboration to build a National SMETE Digital Library at www.smete.org.