Moving Digital Libraries into the Student Learning Space: The GetSmart Experience

BYRON B. MARSHALL, Oregon State University, Corvallis
HSINCHUN CHEN, University of Arizona, Tucson
RAO SHEN AND EDWARD A. FOX, Virginia Polytechnic Institute and State University, Blacksburg

The GetSmart system was built to support theoretically sound learning processes in a digital library environment by integrating course management, digital library, and concept mapping components to support a constructivist, six-step, information search process. In the fall of 2002 more than 100 students created 1400 concept maps as part of selected computing classes offered at the University of Arizona and Virginia Tech. Those students conducted searches, obtained course information, created concept maps, collaborated in acquiring knowledge, and presented their knowledge representations. This article connects the design elements of the GetSmart system to targeted concept-map-based learning processes, describes our system and research testbed, and analyzes our system usage logs. Results suggest that students did in fact use the tools in an integrated fashion, combining knowledge representation and search activities. After concept mapping was included in the curriculum, we observed improvement in students' online quiz scores. Further, we observed that students in groups collaboratively constructed concept maps with multiple group members viewing and updating map details.

Categories and Subject Descriptors: K.3.2 [**Computers and Education**]: Computer and Information Science Education

General Terms: Human Factors

Additional Key Words and Phrases: Concept maps, digital libraries, education

1. INTRODUCTION

Over the last decade the steady advance of computer and network technologies has radically changed the potential for support of schooling [Honey et al.1999]. Communication and computing technology can facilitate parent involvement and provide access to a wide variety of quality educational resources. Two of the key technological pieces are digital libraries and the internet. These technologies are making more and more resources available for instruction, but their effectiveness is often debated. Further, even if electronic resources can help achieve positive learning outcomes, technologies by themselves rarely have substantial impact on teaching and learning.

The National Science Foundation (NSF) through the National Science Digital Library (NSDL, www.nsdl.org) is creating a place where students and educators can find except-

This work was supported by NSF National STEM Education Digital Library: "Intelligent Collection Services for and about Educators and Students: Logging, Spidering, Analysis and Visualization" Award DUE-0121741, Program 7444, Sept. 2001 to Aug.2003.
Authors' addresses: B.B. Marshall (contact author), Oregon State University, Accounting, Finance, and Information Management, Corvallis, OR 97331**;** email: **byron.marshall@bus.oregonstate.edu;** H. Chen, University of Arizona, Management Information Systems, Tucson, AZ 85721**;** R. Shen and E.A. Fox, Virginia Polytechnic Institute and State University, Computer Science, Blacksburg, VA 24061.

ional science education resources. Exemplary resources and services have been and continue to be developed and interconnected to meet this goal. NSDL is built on a solid base of digital library technology research [Lagoze et al. 2002] and has funded numerous education-related initiatives [NSF 2005]. Collecting, indexing, and hosting high-quality collections represent major contributions to the educational landscape. NSDL is expanding as a center of educational innovation in digital libraries [NSF 2004]. Crafting effective learning-support tools is an important part of this expansion.

As they search for information, students go through a complex set of processes [Kuhlthau 1997]. GetSmart is an NSDL project aimed at enhancing digital library support for these learning processes. GetSmart's key notion is the integration of knowledge construction, digital library, and course management tools to support the information search process [Marshall et al. 2003]. Course management tools support class administration, while digital library tools help connect students and resources. Further, the concept-mapping tool facilitates knowledge representation, which directly impacts student thinking, learning, and sharing processes. Concept mapping in education is supported by solid theoretical foundations and a significant body of empirical evaluation [Novak and Gowin 1984; Novak 1998; Chmielewski and Dansereau. 1998; Herl et al.1999; Lambiotte et al. 1993; McCagg and Dansereau 1991; O'Donnell et al. 2002]. The next section reviews the relevant literature that is the foundation of GetSmart design. Later sections frame our research questions, describe system components, report on usage, and discuss operational experiences in using the system in a computing education environment. The article concludes with a look at future directions.

2. BACKGROUND

2.1 The Information Search Process

A variety of learning theories have been proposed to describe how people acquire knowledge and to suggest improved methods for education. As they relate to online learning environments, these theories can be organized into three groups: behaviorism, cognitivism, and contructivism [Mishra 2002]. While behaviorism and cognitivism are still viable perspectives with important implications for education, constructivism has been identified as a useful paradigm in the development and evaluation of online learning environments [Oliver 1999; Hung 2001; Hung and Nichani 2001]. Constructivism focuses on the process by which people acquire knowledge. The constructivist model of learning emphasizes three main ideas [Dalgarno 2001] which are important in a digital library context. First, there is no single "correct" representation of knowledge; second, people learn through active exploration, where exploration uncovers inconsistencies between experience and current understanding; third, learning occurs in a social context.

Kuhlthau [1991] combined constructivist learning ideals and experience in the library domain to create a six-step information search process model, according to Kuhlthau [1997]: "*A basic principle for learning from digital libraries is to take charge of your own constructive process. In the digital library environment, it is important for students to actively seek to formulate a focused perspective that will guide their choices of what is pertinent and useful to them from the vast resources that may be generally relevant to the overall problem*." An effective learning/digital library environment should support learners as they progress through six search steps: initiation, selection, exploration, formulation, collection, and presentation.

The first three stages of Kuhlthau's process emphasize the identification and clarification of a topic. First, the initiation phase begins when a problem is introduced. Students are often puzzled. They wonder "What does the teacher want?" "What do I know?" and "What do I want to learn?" Second, in the selection stage, a general area for investigation is identified. Students generally have a sense of optimism regarding the accomplishment of the task, although those who do not select quickly may become anxious. The third stage, "exploration," is identified as the most difficult part of the process. The goal here is to form a focus. This requires reading, reflecting, and identifying a personal perspective or focus for the work. Exploration has many cognitive requirements similar to browsing tasks, often used in (testing) digital library and information retrieval systems.

The last three steps in the search process involve organizing information into a coherent structure. The formulation stage is identified as conceptually the most important step in the process. The student formulates a personal perspective or sense of meaning from the encountered information. A guiding idea or theme emerges which is used to construct a story or narrative. This formulation will guide the student in selecting appropriate information. In the collection phase information is gathered to support the chosen focus. During the final stage, presentation, the ideas, focus, and collected resources are organized for sharing. Collection tasks are similar to tasks used to measure the effectiveness of information retrieval tools. But while formulation and presentation tools (e.g., PowerPoint) are widely used, they are generally separate from search tools and course management tools.

2.2 Existing Tools to Support E-Learning

Many tools have been developed to support e-learning processes, including course management systems (CMS), digital libraries, and knowledge representation applications. While each class of tools has demonstrated educational value, they are usually presented to students independently, with no attempt to achieve integration. In this section we briefly describe a few such tools and connect them to the key parts of the information search process.

Blackboard and WebCT are two leading course management tools used in higher education. They offer a variety of modules emphasizing the presentation of course materials, facilitation of instructor-student and student-student communication, student evaluation, class administration, and (frequently) the ability to include additional modules. While both systems admirably support many course management functions, neither seems designed to directly support the information search process that Kuhlthau describes. We believe that two major pieces are missing: (1) although the search course material is a readily available CMS capability, the ability to attach to external digital library resources is not; (2) a knowledge representation tool (such as a concept mapping tool) is not commonly available, although a portfolio feature has recently been added to WebCT that allows student work to be collected for review. Thus, while existing tools do seem to provide support for initiation, selection, and presentation, they neglect the formulation and collection phases.

While curriculum tools support class functions, digital library tools support the selection, formulation, and collection phases of the information search process by helping users find the right information amidst a huge amount of digital material. A number of digital library research projects focus on learner needs. For example, the University of Michigan Digital Library (UMDL) project is a learner-oriented initiative [Soloway et al. 2000], and CITIDEL (www.citidel.org) records user search activity to support effective search strategies [Perugini et al.2004]. Recently funded NSDL projects include "Creating Interactive Educational Activity Templates for Digital Libraries," "PRISMS- Phenomena and Representations for the Instruction of Science in Middle Schools," "The

Computational Science Education Reference Desk," "CoMPASS-DL: Design and Use of a Concept Map Interface for Helping Middle School Students Navigate Digital Libraries," and "Personal Collections: Enhancing the Utility of the NSDL" [NSF 2005]. These projects reflect the need for better learning support. Concerted effort is also underway to systematically evaluate the effectiveness of digital library tools in a manner which lends itself to improved design [Sumner and Marlino 2004]. Still, much needs to be done. One recent UMDL study recognized that even well-intentioned, kid-oriented search engines have difficulties related to learning support because they: (1) return too many hits; (2) provide no place to store results; and (3) provide no thesaurus [Soloway et al. 2000].

Another type of learning tool helps learners visually review, capture, or develop knowledge. Curriculum tools commonly use a text-based syllabus approach to describing course content. This approach often fails to delineate the relationship of concepts and skills in one course to those covered in another. It fails to show the knowledge base that a learner will have acquired at the end of his or her course of study. A visualization tool can help both learners and instructors engage in an active learning process when they construct spatial-semantic displays of the knowledge, concepts, and skills that the learner possesses and acquires [Saad and Zaghloul 2002]. Concept mapping is one such knowledge visualization tool, which can provide both a "course map" view of instructional topics and a methodology to support personal knowledge acquisition. This process of building a personal knowledge representation aligns closely with the formulation stage of the information search process.

2.3 Concept Mapping

Concept maps are visual, semantic, node-link representations of knowledge that allow students to formulate and present information from a personal perspective. Concept mapping for education was introduced as a technique to support meaningful learning [Novak and Gowin 1984; Ausubel 1968]. When making a concept map, a learner begins by extracting key ideas and expressing key relations between those ideas. The resulting chart representing a student's knowledge can be used to guide various instructional activities. Novak and Gowin [1984] identify four key learning processes: (1) new concept learning, (2) subsumption, (3) progressive differentiation, and (4) integrative reconciliation. Each process finds significant expression in the concept mapping process [Novak 1998]. In concept mapping, a learner begins with the selection of key concepts, hierarchically organizes those concepts, differentiates between them, and expresses more complex cross-hierarchical relations.

Empirical studies support the theoretical conclusions about concept mapping as an educational technique. Spatial-semantic representations such as concept maps have evolved as alternatives to textual, linear information representations. Concept maps are flexible enough to represent a wide variety of relationships and structures. Citing many previous studies, Chmielewski and Dansereau [1998] note that these representations can be the basis of effective study and learning strategies. Spatial-semantic displays have been found effective (1) in cooperative interactions, (2) as pre- and poststudy aids, (3) as a substitute for traditional text, and (4) for updating and editing knowledge. While concept maps are similar to other formal node-link knowledge structures such as conceptual graphs (described by Sowa [1984]), ontologies, or semantic networks, the educational context requires a high degree of flexibility. Kremer [1984] notes that concept maps are informal. Informality includes organizational variations, node name differences, and link type variations. Although using a closed list of nodes and links has some positive benefits [Herl et al.1999; Lambiotte et al. 1989; McClure et al.1999], most current concept mapping tools allow users to choose their own concept and link names [Oughton and Reed 1999].

CMap and WebMap are two frequently cited concept-mapping tools. CMap was developed by the IHMC (Institute of Human and Machine Cognition) at the University of West Florida. Users can share concept maps through the internet by using CMap's synchronous communication component [Hamilton 2001]. IHMC researchers also combine CMap with case-based reasoning to support knowledge access, reuse, and capture [Canas et al. 1999]; WebMap was developed at the Knowledge Science Institute at the University of Calgary [Gaines 1995]. Gaines and Shaw [1995] proposed that concept maps be regarded as basic components of any hypermedia system, complementing text and images with formal and semi-formal active diagrams. They illustrated a number of concept-mapping applications, including active documents, artificial intelligence, concurrent engineering, education, and hypermedia indexing.

Concept mapping has also received special attention in connection with collaborative activities. Kremer and Gaines [1994] demonstrated the use of concept maps in coordinating the knowledge processes of geographically dispersed communities. Komis et al. [2002] studied the use of collaborative concept mapping and found that students involved in concept mapping exercises achieved both good results and exhibited high levels of task-focused behavior. Regev [2000] considers concept maps a primary metaphor for a collaborative virtual environment. Emphasis on the value of concept maps for collaboration and the constructivist notion that knowledge is gained in a social context suggest the potential of concept mapping as an appropriate tool for an integrated learning environment.

Student evaluation is a widely studied application of a concept-mapping tool. Hundreds of studies have focused on technologies that can improve student test scores on memory and skills such as spelling and math by measuring pre- and post-test differences between control and experimental groups [Honey et al. 1999]. However, these studies generally do not address the larger challenges of creative and critical thinking. The effectiveness of educational techniques is difficult to evaluate, and some authors criticize the use of numeric or letter grade scores at all [Kinchin 2001]. While some attempt has been made to measure concept mapping's impact on learning as traditionally measured in standardized tests [Chen et al. 2001], most concept map evaluation techniques focus on educational objectives beyond the recall of specific facts [Herl et al. 1999]. Evaluating students using concept maps is an excellent but tedious and potentially inconsistent methodology [Kinchin 2001]. The advent of electronic concept-mapping tools promises to facilitate computer-supported evaluation of student concept maps, increasing their utility as part of a larger online learning environment.

3. RESEARCH QUESTIONS

To explore the value of combining CMS, digital library, and knowledge representation tools, we designed and tested the GetSmart system. This article expands on previously published work [Marshall et al. 2003] focusing on evidence for the educational value of our integrated system. GetSmart activity logs, student map results, and preference surveys are analyzed to address three questions:

- Will the integration of CMS, digital library, and knowledge representation components support the information search process?

- Does use of concept mapping improve academic performance in computer classes?
- How does the use of a concept mapping system impact collaboration?

4. RESEARCH TESTBED

We designed and tested the GetSmart system to explore the value of combining CMS, digital library, and knowledge representation tools. GetSmart includes four major components: (1) curriculum, (2) search, (3) concept map, and (4) learning progress. In general, the course-management component implements features readily available in existing CMS. The learning progress component only relates to concept mapping and search activities. The innovation in GetSmart is the inclusion of external search and personal knowledge representation tools designed to work in the context of curriculum features. The concept map data, user authorizations, and search histories are stored in a database; another database contains the index for course resources. The GetSmart architecture and system components are reported on in Marshall et al. [2003]. The following section in this article, Section 4.1, describes several targeted learning activities in a computer science education context; Section 4.2 highlights the components and use of the GetSmart System.

4.1 Targeted Learning Activities

Previously cited work suggests that the creation of concept maps by students promotes improved understanding of the material. To leverage this cognitive value, we designed GetSmart to support several learning activities:

(1) individual study of course materials;
(2) acquisition of additional information related to course topics; and
(3) preparation of group presentations.

Lectures, quizzes, and projects are generally intended to help students grasp the information in course materials. The GetSmart system is intended to support the review of previously presented materials by facilitating the creation of concept maps that express a student's understanding of key concepts and relationships. For example, we might expect a student in a data structures and algorithms class to depict various types of tree structures used in program, comparing their characteristics and usage. As previously noted in Novak [1998], to draw a concept map a student has to formulate a list of important concepts, arrange them hierarchically, and label relationships or interactions between the conceptual elements. Thus the first learning activity supported by GetSmart envisions a student creating a personal concept map of information gleaned from course materials. These materials are either linked on the course web site or provided separately in textbooks or lectures. We expect that creation of the concept map will help a student better understand the material, and that this better understanding will be reflected in quiz results and other measures of student learning. However, as noted in Section 3.2, we are not sure that improved learning will always be reflected in improved scores on traditional evaluation instruments.

A second important learning activity encourages students to go beyond the materials presented in class to create an expanded personal representation of course topics. To attach "resources" (annotations and URLs) to the nodes in a concept map a student has to identify and evaluate additional sources of information and fit them into a framework of understanding. For example, a student studying neural network (NN) programs might gain a better understanding by identifying several applications that might benefit from

NN analysis. Our search tools and links to instructor-selected materials are intended to help the student identify useful sources but, of course, many additional sources of information are available. For example, related books are important, and many students are quite familiar with internet search portals that provide access to a vast array of documents. We expect that some searching will be done within our system because the materials included in the local search are likely to be relevant in the information search. However we also expect that many useful resources will be attached to concepts in the system but identified using other manual or electronic processes.

As highlighted in our previous discussion of constructivist learning theory, a learner's understanding is often strongly affected by interactions with other people. To support this element, we expect that groups of students will be required to create and present concept-map representations of their topic. We hope that requiring the presentation of a group concept map will stimulate interaction among students. A group presentation frequently consists of a series of small presentations, covering specific parts of a topic. The creation of concept maps in a group is expected to help the group form a common understanding of the material. If the students in a group work together to identify the key concepts and specify important relations, it is expected that a single "big picture" will be adopted by the group. For example, tree structures are frequently described using both family (parent/child/sibling) and plant (root/branch/leaf) metaphors. Reconciling concept maps employing different concept labels requires students to wrestle with differing perspectives. This paradigm is a contrast to many group presentations observed in previous classes.

4.2 The GetSmart System

Figure 1 shows GetSmart's main screen. From there the student can directly access the map and search components or click to the "Class Info" option on the navigation bar to access official class information. Class Info categories are similar to those in WebCT and Blackboard. The searching component is based on a metasearch framework and supports queries and postretrieval analysis. Students can access multiple search portals and view and analyze the results in a combined list. The learning progress component allows users.

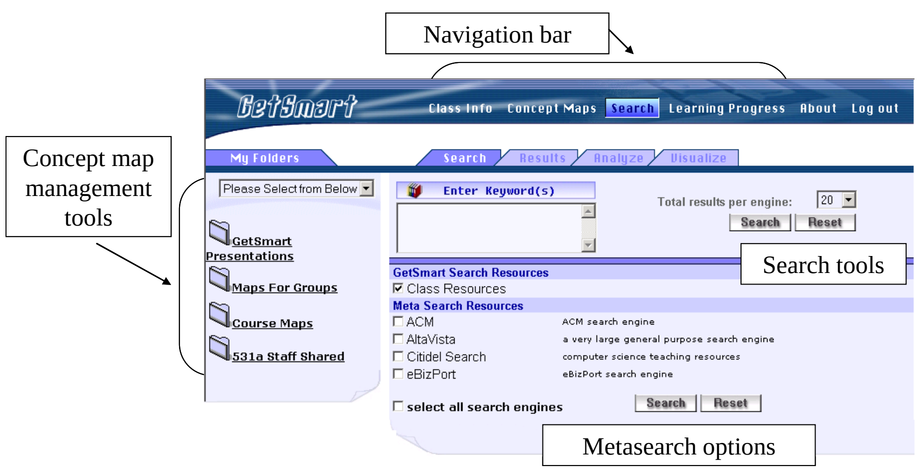

Fig. 1. The main screen from the GetSmart's interface.

to review their previous search and concept-map activities. Search history shows the last 10 searches performed and the results returned. Users can view concept-mapping activities such as the last action performed, when a map was turned in, the number of maps created, and the number of nodes, links, and resources.

The concept-mapping component consists of a set of management functions and a concept-map building applet. The concept-map management panel is displayed on the left-hand side of the interface. Concept maps are organized into folders; users can create different folders to organize the concept maps. Expert and group concept maps, authorized by the system administrator, are displayed in the same folder structure and are identified with special icons. Three types of concept-map operations can be done using the commands in the pull-down menu.

(1) folder operations: create, delete, and rename a folder;
(2) map operations: create, delete, and rename a map; and
(3) advanced map operations:

- *turn in a map* submits maps to the instructor;.
- *print a map* requests generation of a web page showing a map image and a listing of nodes, links, and attached resources;
- *import/export a map* allows XML representations of a concept map to be imported or exported.

After a map has been created and assigned to a folder using the management tools, it is up-dated with the concept map-building applet. Clicking on a folder in the concept map management panel expands the display to list the titles of concept maps stored in the folder. Clicking on the title of a concept map activates a new Java applet window like the one shown in Figure 2. The main window is used for graphical manipulation of the

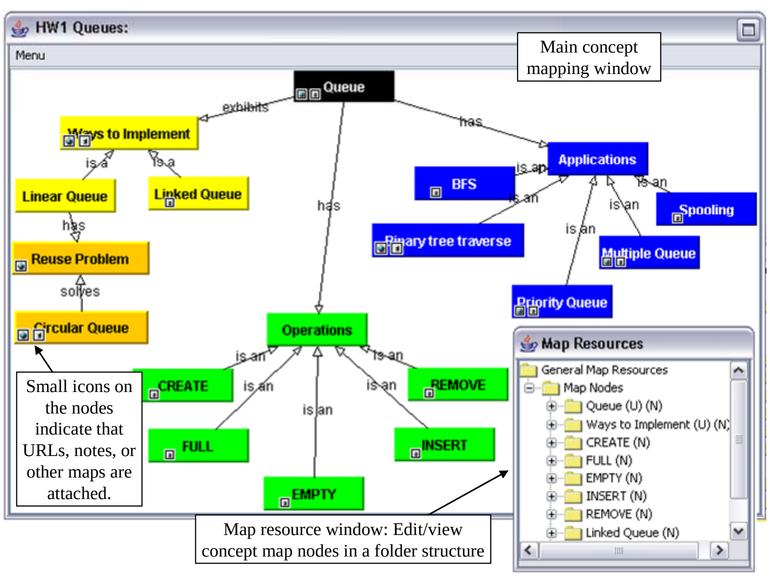

Fig. 2. Concept-map building applet.

concept-map elements. Small icons on the nodes indicate that resources have been associated with the node. These resources include URLs, notes, or other maps. Users can click pull-down menu options to save, print, or turn in a map. The map resource window lists all the map elements in a folder view. When several users are authorized to update a concept map, additional functions are needed. All authorized users can view a map at any time. Users with ownership authority for a map can lock the map for update, but only one user can lock the map at any given time.

The map in Figure 2 depicts one student's understanding of the queue data structure. Globe icons attached to the node denote attached URLs and text box icons denote an annotation. The "binary tree traverse" node, for instance, was annotated by a link to the website of a previous course and an annotation was also entered by the student: "*Stacks allow us to implement backtracking; queues allow us to implement ordering. This difference can be seen most clearly in the fact that stacks are used to do a depth-first traversal of a tree, and queues are used to do a breadth-first traversal of a tree.*" By choosing the main ideas related to a topic, organizing them into a coherent structure, and annotating that structure with comments and additional references, a student reinforces learning, creates a resource for future reference, and demonstrates understanding.

Maps in GetSmart are passed between the client and server in XML format. Our goal was to make it possible for a client to handle maps from different sources and to use map information for other processes. While concept maps developed as part of educational processes share many of the characteristics of other node-link knowledge representations (e.g., semantic networks, ontologies, and conceptual graphs) they are different in a few important ways, which are reflected in the XML schema used by the concept-mapping system:

(1) We include display information such as size, color, and position for nodes, links, and the map as a whole.
(2) Each map tends to contain a relatively small set of nodes (10-50).
(3) Map-level information includes:

   a. metadata (author, title, and dates, etc.).
   b. unattached resources (e.g., URLs identified as important for the map as a whole, but not associated with any particular node).

(4) Labeling is informal, with few or no restrictions placed on node and link names.
(5) Nodes can be annotated with notes and pointers to additional information resources.

Figure 3 charts the relationship between GetSmart's functionality and the six-step information search process. *Class info* functions support the initiation and selection phases by providing background information from various course resources such as the syllabus, course assignments, and other materials provided by the instructor. The resources accessed through GetSmart's course management component help students identify and clarify important topics and answer questions such as "What does the instructor want?" and "What do I want to learn?" The search and concept mapping functions can be combined to support exploration, formulation, and collection. Learning progress functions also support exploration and formulation, and allow students to review the query terms and results of previous searches and to check when they last viewed, updated, or handed in existing maps. Groups of users can be authorized to edit and view

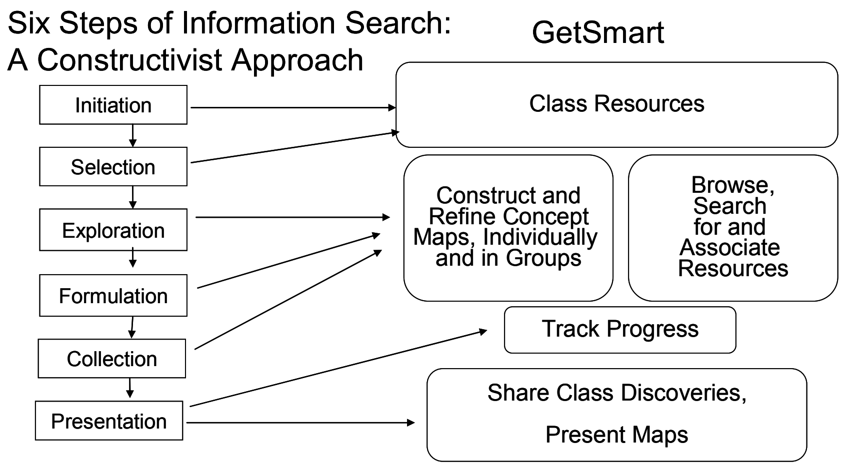

Fig. 3. GetSmart tools and the six-step information search process.

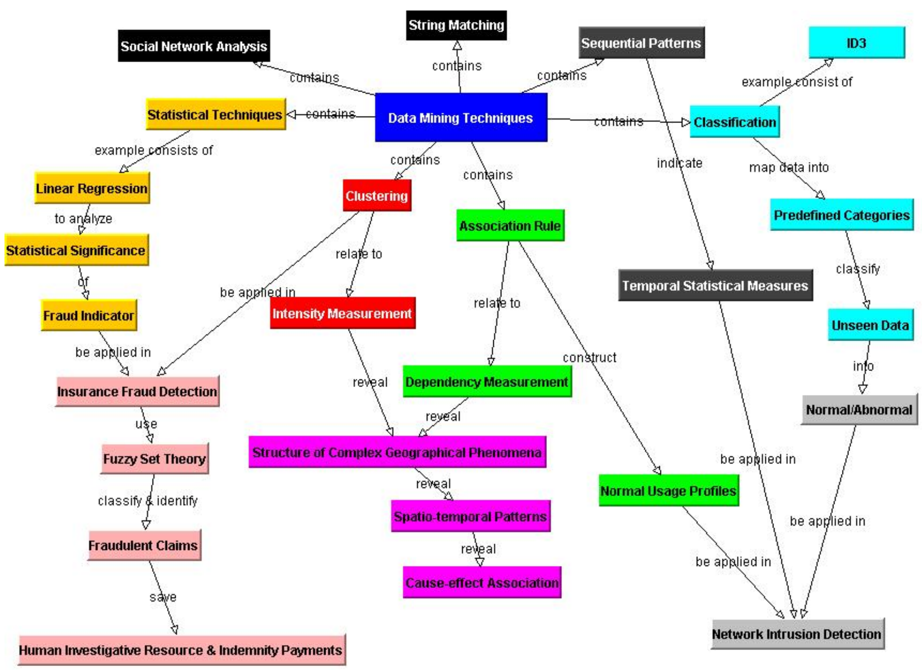

Fig. 4. A group concept map for law enforcement data mining.

shared maps. Personal maps and shared maps are used to prepare individual assignments and class presentations.

The GetSmart system was used at the University of Arizona and at Virginia Tech in graduate-level computing courses in the fall of 2002. A course called "Information Storage and Retrieval" (CS5604) was taught at Virginia Tech, the class had 60 students

Table I. Overall Usage: MIS531A and CS5604

114	Student Users
4,000 +	User Sessions
1,400 +	Homework and Presentation Maps
600 +	Searches Performed
50 +	Group Maps
40,000 +	Relationships Mapped

engaged in creating and accessing concept maps. At the University of Arizona, a "Data Structures and Algorithms" course (MIS531A) had 54 management information students enrolled. Students at both universities prepared a series of concept maps. The MIS531A students each created three sets of maps as homework assignments and worked in groups to map the main points of their group presentations. Figure 4 is a concept map created in one of these group projects. It was used to present data mining techniques for law enforcement applications. The CS5604 students, singly and in groups, created concept maps of the material in each chapter covered in the course. These maps were presented and reviewed during class meetings. When homework assignments were due the system was accessed 24-hours a day by students as they completed their assignments. Table I lists some overall usage statistics. Although this article focuses on usage in the fall of 2002, the system has been used in two courses per year through the end of 2004. Due to space constraints, analysis of the logs after the 2002 academic year is deferred to the future.

5. RESULTS

To address our three research questions, our results are presented in three parts:

- Section 5.1 relates to the integrated usage of various technological components in support of the information search process.
- Section 5.2 reports on quiz scores when GetSmart was employed.
- Section 5.3 presents evidence of collaboration related to the concept maps.

We also include related user preference information which was gathered and organized with the help of L. Cassel as part of the GetSmart project. The survey sample includes 44 Virginia Tech students (74% from computer science and the balance from other IT-related fields) and gives some general insights into user perceptions of the system. A second survey was conducted in 2003 with 20 respondents, focusing on the usefulness of the concept-mapping tools in the course. The activities at the University of Arizona are the focus of this analysis because the GetSmart system was used in a more integrated fashion in Arizona, while at Virginia Tech only parts of the system were deployed, since the browse and search features were largely ignored in favor of other Web search tools. The assignments were also somewhat different. The Arizona students were asked to create maps representing their personal understanding of the topic drawn from lecture notes and other resources while the Virginia Tech students were asked to create maps of each chapter in the text in preparation for the online quiz.

Because the version of GetSmart used here is primarily for research rather than fully developed, as in a commercial product, many features can be improved. Even so, in the 2002 survey, which covered the students who completed the prequiz maps, 27% (12/44) of the respondents reported that the GetSmart Concept mapping tools were "well designed, helpful," while 54% (24/44) chose "somewhat helpful." In the latter survey the results were not as positive, although it should be noted that the word "very" was added to the top response in the second survey. Only 10% of the respondents reported that the mapping tools were "well designed and very helpful" and 60% reported them as "somewhat helpful but having some limitations." Clearly, there is room for improvement in the concept-mapping tools. We expect that a more fully developed system would be used more, resulting in improvement in many of the results we present.

5.1 Integrated Usage

The GetSmart system combines course management, searching, and knowledge representation tools in an integrated package. If the students perceived this as valuable, we would expect to see cases where they used the tools in an integrated fashion. We checked three measurable indicators of integrated activity:

(1) activities indicating use of the system to gather basic course information (this relates to the initiation and selection phases);
(2) records of students turning in their homework using the system (which would indicate presentation-phase activity); and
(3) integrated use of concept-mapping and search tools.

The logs suggest that students did log into the system to get course information. We anticipated that students would move through the early steps of the information search process by logging into the system and looking at the course materials. Our usage log shows that of the 1,659 Arizona user sessions with activity spread over more than two minutes, there were 301 sessions involving 51 of the 55 students in which no mapping activities were logged (see Table II). We identified 153 (18%) additional sessions in which there was at least a 5 minute delay between completion of a successful login and the beginning of mapping activity. These sessions were somewhat evenly distributed over the course of the semester. We conclude that many of these logins were made as students prepared to work on concept maps and other class assignments.

Students did use the concept-mapping tool to complete homework assignments. This is not surprising, since both in Virginia and in Arizona the maps were assigned by the

Table II. University of Arizona GetSmart Sessions with Searching and Mapping

	University of Arizona	
	Users	Sessions
All Sessions	55	1,659
No Mapping Activity	51	301 (18%)
5+ Minute Delay Before Mapping	49	153 (9%)
GetSmart Search Activity	51	234 (14%)
Search and Mapping	43	145 (9%)
Search Before Mapping	38	107 (6%)
Search but No Mapping	38	89 (5%)
Resources Added	54	540 (33%)
URLs Added	49	252 (15%)

User counts reflect the number of distinct users who had a session of the listed type. Only sessions with activity spanning 2 or more minutes were included.

instructor. However, only a small portion of the course grade depended on concept mapping. In Arizona, all students completed maps for each of the three homework sets; in Virginia there were both individual and group maps for each of 11 textbook chapters.

Table II also highlights the integrated use of search and map tools. GetSmart search activity was observed in 14% of the Arizona user sessions. Most of these sessions involved both search and mapping activities (145/234). We also observed that in most sessions that involved both search and mapping activities (107/145), one or more searches preceded the first mapping activity. This suggests that the students frequently used the search tool to help them find resources that were then used in the formulation process. Resources (URLs or annotations) were attached to nodes in one-third of the sessions and URLs in particular were added in 15% of the sessions. These statistics suggest that the process of creating concept maps included a variety of information search activities. The numbers reported here reflect only document search activities done using the GetSmart tools. Many additional searches were certainly performed by students, so the degree of integrated search and map activity is understated in our results.

Students using the system did include some external resources in their final concept maps, even though this was not required by the assignments. The system log for both sites shows 169 sessions involving 66 distinct users, including both mapping and searching activities. Table III charts the inclusion of URLs in turned-in maps. The numbers here represent the URLs associated with nodes of turned-in maps for the University of Arizona's MIS531A course. Because the students at Virginia Tech were assigned to make concept maps that covered a particular chapter from the assigned text, they did very little searching for additional information. The students at the University of Arizona were given a more open-ended assignment, to "depict your understanding of the topic." The mapping instructions and feedback given these students mentioned that it was beneficial to search for related materials and attach URLs to the maps. Nearly all the Arizona students included some additional resources (49 out of 55), attaching 1,310 URLs to 256 maps.

The initial map training and the online tutorial showed students how to search using GetSmart and how to associate resources with nodes on their maps. However, no feedback was given to students about their use of the searching component after the

Table III. URLs Attached to Maps at the University of Arizona

MIS531A: 55 users turned in 616 Maps			
	Total URLs	Users	Maps
URLs attached to turned-in maps	1,310	49	256
Attached URLs were found in a GetSmart search	428	40	127
Attached URLs were found in a search run by the same user	263	17	46
Attached URLs were returned to the same user in a query containing at least one keyword found in the same map's node names	159	11	34

initial training. In the 2002 user survey, half of the respondents (22 of 44) reported that they preferred other search tools. This is not an unexpected result, since the students had extensive experience searching with other tools. Thus it is quite likely that some of the information search activities were executed using external search tools. As shown in Table III, 428 URLs were both returned in searches run on the GetSmart system and attached to a student map. The same student ran a search and later included a returned link in 263 of those 428 cases. In the other 165 cases (428 to 263), a search run on the GetSmart system returned a URL to one user which was attached to a concept map by another user. This suggests that even though some students preferred other search systems, the GetSmart system queries did return a number of relevant resources.

One important demonstration of the integration of the mapping and searching tools is shown in the last row of Table III. The system tools are designed to support students as they move through the information search process:

(1) *initiation and selection*: course assignments are presented in the syllabus and course outline to help students select a topic of inquiry;
(2) *exploration*: the student identifies key concepts;
(3) *formulation*: concepts are included in a concept map and used as search terms;
(4) *collection*: some URLs returned in response to the query are then incorporated into the concept map; and
(5) *presentation*: the map is turned in or presented in class.

The logs of the system show that at least 20 % of the users at the University of Arizona used the integrated tools all the way through the search process for a single map. On 159 occasions (involving 11 users and 34 maps), a student used a term in both a map and a GetSmart query and attached a URL from the query's result set to a node in that map. Of the 159 attached URLs, 111 are distinct URLs, and of those, 88 are attached to only one map, and no single URL is attached more than 9 times. Thus, the inclusion of resources in GetSmart is not simply attributable to a few interesting documents. Obviously, the 882 (1,310 to 428) URLs not found in GetSmart searches were located using other means. For example, a student may have used a map's node names as search terms in Google to locate useful resources that were later associated with nodes in the map. These inclusions suggest that electronic search and mapping tools were used in an integrated fashion even more often than is reflected by looking only at GetSmart searches.

A careful analysis of the order in which nodes and attachments were added also provides some evidence of student collection and presentation activities. The collection and presentation phases of the information search process follow the formulation stage, in which the user forms a personal model or understanding of the topic. In a concept-mapping context, we say that the addition of new nodes represents formulation, while the addition of URLs and annotations are collection or presentation activities. Table IV shows the average number of distinct sessions in which maps were updated. It appears that maps with resources were updated in more sessions (4.15 vs. 4.03 in Arizona) and that the resources were added to the nodes in only a few of those sessions (1.57). After the nodes were created, presumably the users went back and recorded information to expand on or polish their maps for presentation. Unfortunately, our logging methodology only records the contents of a map when the user saves it. Thus, we have no indication of the order in which various actions were taken between map saves. Still, we were able to compare the status of each map as it was saved, finding evidence that students frequently created the nodes first and then added URLs to the maps later. Table V reports on 797

Table IV. Adding Resources to Existing Maps

	University of Arizona		Virginia Tech	
	Users	Average Sessions per Map	Users	Average Sessions per Map
All Maps	55	4.03	57	2.57
Maps with Resources	54	4.15	25	3.27
Only Sessions with Resource Adds		1.57		1.11

Table V. University of Arizona Node URL Resources

256 of 616 Turned-in Maps With URLs Attached			
	Nodes	% of Nodes with URL Resources	Creating Users
Nodes with URLs (out of 38,624 nodes)	797		49 of 56
URLs Added 5+ Minutes Later	427	54%	43
URLs Added 1+ Hours Later	237	30%	40
URLs Added 1+ Days Later	135	17%	29

nodes on turned-in MIS531A homework maps that had URLs attached. Most of the time (54% of all cases) resources were saved at least 5 minutes after the corresponding node was saved, and in many cases (17%) the URLs were added to the nodes one or more days after creation of the node. This kind of behavior suggests that while searching frequently preceded mapping (indicating selection or exploration), URLs were also added to nodes after the student's ideas had been captured in the map (indicating collection and presentation activity).

5.2 Academic Performance

During the semester each student in CS5604 was required to pass (with a score of 80% or higher) an automatically graded online quiz on each chapter in the textbook. If the first attempt was unsuccessful, the student was encouraged to study more and then to take a second version of the quiz. Since mastery was the objective, a third attempt was also allowed. More than 90% of the students preferred to prepare a concept map using GetSmart before taking a quiz. The average number of times that students took to pass a quiz in fall 2002 was 1. In the same class a year earlier, before GetSmart was developed, the average number of times that students took to pass a quiz was 1.55. That is, without the GetSmart assignments, students took more quizzes before they were able to master a chapter. The quiz scores of students in fall 2001 compared to those in fall 2002 are shown in Figure 5.

Our survey results indicate that the students found concept mapping to be educationally useful. In the 2002 survey, students were asked to rate the value of group concept-map creation and group concept-map discussions. Groups of students were asked to collectively create concept maps of the text and present them in class for discussion. In the survey, 86% of the respondents reported positively on the creation of group concept

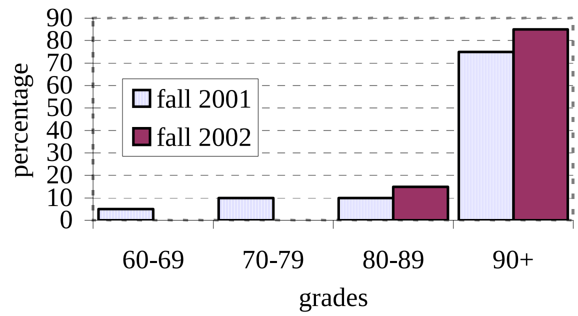

Fig. 5. CS5604 quiz scores: fall 2001 compared to fall 2002.

Table VI. How Has Concept Mapping Contributed to Your Understanding?

	Assignment (A)	Assignment (B)
a very valuable part of the learning activity	20%	45%
somewhat helpful	40%	35%
not particularly useful	25%	5%
inconvenient	5%	5%
bad use of time	10%	5%
no answer	0	5%

maps ("very valuable" or "somewhat helpful") and 77% reported positively on the group discussions. In the 2003 survey, students were asked how the concept-mapping assignments contributed to their understanding of the material. Two types of concept-mapping assignments were considered: in assignment (A) students were asked to prepare extended concept maps of the chapters of the textbook; in assignment (B) students were asked to summarize additional readings in a concept map. The first is a somewhat closed-ended assignment focusing on a single well-covered source, while the second is more open, calling on the students to process more new information; their responses are shown in Table VI. While both assignments were considered helpful, the more open-ended assignment (B) elicited a more positive response.

5.3 Collaboration

As discussed in the literature review, a computerized, graphical knowledge representation tool has interesting possibilities for collaborative class activities. Various collaborative undertakings have been pursued by the GetSmart group at the University of Arizona and Virginia Tech. At Virginia Tech students worked in teams to create concept maps. Maps were created using pencil and paper, GetSmart, or IHMC's CMap tool. These maps were then presented in class to promote discussion of key topics. Group maps were created in H. Chen's data structures and algorithms course at the University of Arizona (MIS531A) as integral parts of group presentations. These maps were all created using the GetSmart system by groups of 5 to 7 students (although, if they preferred, they were allowed to use pencil and paper or another tool). Interestingly, in the 2002 survey, while only 34% of the students reported that "work in teams" was *important, valuable*, 49% reported that their

Table VII. Shared Maps Saved and Opened by MIS531A Students

Project Topic	Maps Created	Average Number of Students Who		Average Times Opened Per Student
		Saved Each Map	Opened Each Map	
Financial Data Mining	5	2.6	4.8	7.2
E-Voting	4	1.8	6.0	5.8
Criminal Data Mining	8	1.0	6.1	4.2
CRM Data Mining	6	2.7	6.2	5.1
OnLine Auctioning	7	1.9	6.1	2.7
Average Per Map		2.0	5.8	5.0
Range		1-5	5-7	2-11

Table IIX. Summary of Information Search Activities in GetSmart

Information Search Stage	**Indicative GetSmart Usage** Table 3 highlights the use of the search and map tools together in an integrated information search process.
Initiation and Selection: identify an area to explore	**Students prepared to work on concept maps and class assignments**. Many user sessions include time to review posted course materials as shown in Table 2.
Exploration: form a focus	**Students frequently searched for information before mapping began.** Table 2 notes 107 sessions in which search preceded mapping activity and many searches were run on more familiar search portals.
Formulation: develop a personal sense of meaning	**Students combined search and representation activities in the same session.** Many users' sessions included both search and map activities as highlighted in Table 2. Table 6 and Figure 5 demonstrate that concept mapping facilitated student understanding.
Collection: gather information	**Students frequently searched for information and added annotation information after creating nodes.** Search events often followed map updates in user sessions (Table 2).
Presentation: organize for sharing	**Students refined their maps.** Maps were turned in. Maps were saved multiple times (Table 4). URLs were often added to previously saved concept nodes (Table 5). In the case of collaborative maps, multiple students viewed and saved maps (Table 7).

experiences with group concept maps were *very valuable*. This suggests that students preferred group concept-mapping efforts over group work in general.

Table VII highlights the degree of map-sharing in the GetSmart activity logs for the MIS531A group project maps. The maps were opened repeatedly by group members. Each group was instructed to provide one or more concept maps related to their class projects. However, the assignment parameters did not say that the maps had to be shared and project grades did not depend specifically on the maps or on map usage. On average, every map was viewed by 5.8 students, and since groups ranged from 5 to 7 members, almost every map was opened by almost every group member. On average, each map was opened 5 times per student. Map updating was also a shared process, with as many as 5 students updating each map in the system and, on average, two students saving each map (although one group partitioned the work such that each map was updated by only one student). Additional collaborative editing is likely to have taken place as students met together to discuss their projects; but this activity would show only one user actually updating the map.

6. DISCUSSION

We believe our results support the value of integrating course management, concept mapping, and digital library technology. While it is true that the students who used GetSmart were taking computing-related courses, we expect that encouraging results would also be observed in other educational environments. The evidence we have presented is summarized in Table IIX. Integration of course management, concept mapping, and digital library tools seems like a promising educational strategy. Further, we have made available a stand-alone GetSmart tool that allows a user to create concept maps, attach URLs and other annotations to map elements, and execute queries to existing search portals using the terms stored in concept maps. The tool is available at http://feathers.dlib.vt.edu/ConceptMap/GetSmart.html.

7. FUTURE DIRECTIONS

Concept maps created as part of educational processes have a number of potential uses. Well-constructed concept maps with links to external resources created in one class are potentially useful to other instructors and students. These resources represent a kind of visual index to a topic, connecting external resources and key terms from a particular instructional perspective. Concept maps stored in an XML format can be provided as information resources and also leveraged in other processes to establish context for user queries. The XML structure used by the GetSmart system captures semantic relations between concepts and allows for annotation of that information with external resource links and positional information. Creating a repository of student maps on a particular topic or relevant to a particular course could potentially give instructors insight into student perspectives, support retrieval processes, facilitate online learning, and support semi-automatic student map evaluation. To pursue this line of work, we plan to expand on and test the search-from-map capability built into our stand-alone concept mapping tool.

Student concept maps reveal a student's overall grasp of a topic while specific essay questions, multiple choice questions, and other evaluation questions generally focus on testing for a particular concept. However, evaluating concept maps is time-consuming and somewhat subjective. Scores should reflect both content evaluation, to see if the student can recall important concepts and relationships, and structural evaluation that measures cognitive notions such as progressive differentiation, integrative reconciliation, and subsumption. Algorithms that match student and instructor maps, count levels of hierarchy, categorize link labels, and identify cross-links would allow for more efficient educational processes and support real-time feedback systems to aid student learning during a mapping process. Some initial work has been done on the problem of matching elements between these maps, as reported [Marshall et al. 2006]. In addition, we plan to do more analysis of actual student-drawn concept maps to better understand how they make maps, so we can support their cognitive learning processes better. We expect to find, for example, that allowing students to classify their links (e.g., is-a, part-of, causes), in addition to providing free-form link labels, will allow us to recognize hierarchical structures better. This work should help in the development of semi-automatic scoring techniques, support better learning by helping students explore mapped relationships at a deeper level, and capture more useful semantic information for other concept-map-based knowledge management processes.

ACKNOWLEDGMENT

We thank the GetSmart team and other members of the University of Arizona's AI Lab who built GetSmart components, especially Benjamin Smith, Chun Q. Yin, and Steven Trush. Many thanks to Lillian Cassel for her work collecting and organizing the user satisfaction information. Finally, we thank the University of Arizona and Virginia Tech students who used and commented on the GetSmart system.

BIBLIOGRAPHY

AUSUBEL, D. P. 1968. *Educational Psychology: A Ccognitive View*. Rinehart and Winston, New York.

CANAS, A. J., LEAKE, D. B., AND WILSON, D. C.1999. Managing, mapping and manipulating conceptual knowledge: exploring the synergies of knowledge management & case-based reasoning. In *Proceedings of the AAAI Workshop on Exploring Synergies of Knowledge Management and Case-based Reasoning* (Menlo Park, CA), 10-14.

CHEN, S.-W., LIN, S. C., AND CHANG, K. E. 2001. Attributed concept maps: Fuzzy integration and fuzzy matching. *IEEE Trans. Systems, Man, and Cybernetics 31*, 842-852.

CHMIELEWSKI, T. L.AND DANSEREAU, D. F.1998. Enhancing the recall of text: knowledge mapping training promotes implicit transfer. *J. Educational Psychology 90*, 407-413.

DALGARNO, B. 2001. Interpretations of constructivism and consequences for computer assisted learning. *British J. Educational Technology 32*, 183-194.

GAINES, B. R.1995. Class library implementation of an open architecture knowledge support system. *Int. J. Human-Computer Studies 41*, 59-107.

GAINES, B. R. AND SHAW, M. L. G. 1995. Concept maps as hypermedia components. *Int. J. Human-Computer Studies* 43, 323-361.

HAMILTON, S. 2001. Thinking outside the box at the IHMC. *IEEE Computer 34*, 61-71.

HERL, H. E., O'NEIL,J., CHUNG, G., AND SCHACTER, J. 1999. Reliability and validity of a computer-based knowledge mapping system to measure content understanding. *Computers in Human Behavior 15*, 315-333.

HONEY, M., MCMILLAN CULP, K., AND CARRIGG, F.1999. Perspectives on technology and education research: Lessons from the past and present. Presented at the *National Conference on Educational Technology* (Washington DC). http://www.ed.gov/rschstat/eval/tech/techconf99/whitepapers/paper1.html.

HUNG, D. 2001. Design principles for web-based learning: Implications from Vygotskian thought. *.Educational Technology 41*, 33-41.

HUNG, D. AND NICHANI, M. 2001. Constructivism and e-learning: balancing between the individual and social levels of cognition. *Educational Technology 41*, 40-44.

KINCHIN, I. M. 2001. If concept mapping is so helpful to learning biology, why aren't we all doing it? *Int. J. Science Education 23*, 1257-1269.

KOMIS, V., AVOURIS, N., AND FIDAS, C. 2002. Computer-supported collaborative concept mapping: study of synchronous peer interaction. *Education and Information Technology* 7, 169-188.

KREMER, R.1994. Concept mapping: informal to formal. In *Proceedings of the International Conference on Conceptual Structures* (University of Maryland) http://pages.cpsc.ucalgary.ca/~kremer/papers/ICCS94.html

KREMER, R. AND GAINES, B. R.1994. Groupware concept mapping techniques. In *Proceedings of the 12th Annual Iinternational Conference on Systems Documentation* (Banff, Alberta).

KUHLTHAU, C.1997. Learning in digital libraries: An information search process approach. *Library Trends 45*, 708-724.

KUHLTHAU, C. 1991. Inside the search process:Information seeking from the user's perspective. *J. American Society for Information Science 42*, 361-371.

LAGOZE, C., ARMS, W., GAN, S., HILLMANN, D., INGRAM, C., KRAFFT, D., MARISA, R., PHIPPS, J., SAYLOR, J., TERRIZZI, C., HOEHN, W., MILLMAN, D., ALLAN, J., GUZMAN-LARA, S., AND KALT, T. 2002. Core services in the architecture of the national science digital library (NSDL). In *Proceedings of the 2nd ACM/IEEE-CS Joint Conference on Digital Libraries* (Portland, OR). ACM, New York,. 201-209.

LAMBIOTTE, J. G., SKAGGS, L. P., AND DANSEREAU, D. F.1993. Learning from lectures - Effects of knowledge maps and cooperative review strategies. *Applied Cognitive Psychology 7*, 483-497.

LAMBIOTTE, J.G., DANSEREAU, D.F., CROSS, D.R., AND REYNOLDS, S.B.1989. Multirelational semantic maps. *Educational Psychology Rev. 1*, 331-367.

MARSHALL, B., ZHANG, Y., CHEN, H., LALLY, SHEN, A.R., FOX, E., AND CASSEL, L. 2003. Convergence of knowledge management and e-learning: the GetSmart experience. In *Proceedings of the Joint Conference on Digital Libraries* (Houston, TX). 135 - 146.

MARSHALL, B., CHEN, H., AND MADHUSUDAN, T. 2006. Matching knowledge elements in concept maps using a similarity flooding algorithm. *Decision Support Systems 42*, 1290-1306.

MCCAGG, E.C. AND DANSEREAU, D.F. 1991. A convergent paradigm for examining knowledge mapping as a learning-strategy. *J. Educational Research 84*, 317-324.

MCCLURE, J. R., SONAK, B., AND SUEN, H. K.1999. Concept map assessment of classroom learning: reliability, validity and logistical practicality. *J. Research in Science Teaching 36*, 475-492.

MISHRA, S. 2002. A design framework for online learning environments. *British J. Educational Technology 33*, 493-496.

NOVAK, J. 1998. *Learning, Creating, and Using Knowledge: Concept Maps as Facilitative Tools in Schools and Corporations.* Lawrence Erlbaum, Mahwah, NJ.

NOVAK, J. AND GOWIN, D. B.1984. *Learning How to Learn*. Cambridge University Press, Cambridge, UK.1984.

NSF 2005. NSDL Funded Projects, 2005. Accessed 9/7/05. http://nsdl.org/about/projects.php

NSF 2004. NSDL Annual Report, 2004. Accessed 9/7/05. http://nsdl.org/about/annual_report.php

O'DONNELL, A. M., DANSEREAU, D. F., AND HALL, R. H. 2002. Knowledge maps as scaffolds for cognitive processing. *Educational Psychology Rev. 14*, 71-86.

OLIVER, R. 1999. Exploring strategies for online teaching and learning. *Distance Education 20*, 240-254.

OUGHTON, J. M. AND REED, W. M.1999. The influence of learner differences on the construction of hypermedia concepts: a case study.*Computers in Human Behavior 15*, 11-15.

PERUGINI, S., MCDEVITT, K., RICHARDSON, R., PEREZ-QUINONES,M., SHEN, R., RAMAKRISHNAN, N., WILLIAMS, C., AND FOX, E.A.2004. Enhancing usability in CITIDEL: Multimodal, multilingual, and interactive visualization interfaces. In *Proceedings of the 4th ACM/IEEE-CS Joint Conference on Digital Libraries*. (Tucson, AZ). ACM, New York, 315-324.

REGEV, G. 2000. Knoware, a concept map based collaborative virtual environment. *SIGGROUP Bull. 21*, 14-15.

SAAD, A. AND ZAGHLOUL, A.-R. M. 2002. A knowledge visualization tool for teaching and learning computer engineering knowledge, concepts, and skills. In *Proceedings of the 32nd ASEE/IEEE Frontiers in Education Conference* (Boston, MA), T2F-7 - T2F-10.

SOLOWAY, E., NORRIS, C., BLUMFIELD, P., FISHMAN, B., KRAJCIK, J., AND MARX, R. 2000. K-12 and the Internet. *Commun. ACM 43*, 19-23.

SOWA, J.F.1984. *Information Processing in Mind and Machine*. Addison-Wesley, Reading, MA.

SUMNER, T. AND MARLINO, M. 2004. Digital libraries and educational practice:A case for new models. In *Proceedings of the 4th ACM/IEEE-CS Joint Conference on Digital Libraries* (Tucson, AZ). ACM, New York, 170-178.

Received November 2004; revised October 2005; accepted April 2006