Developing a Digital Learning Environment: An Evaluation of Design and Implementation Processes

Leslie Champeny, Christine L. Borgman, Gregory H. Leazer, Anne J. Gilliland-Swetland, Kelli A. Millwood, Leonard D'Avolio, Jason R. Finley, Laura J. Smart
Dept. of Information Studies
GSE&IS Bldg., University of California, Los Angeles
Los Angeles, CA 90095-1520
{lchampen, gleazer, swetland, millwood, ldavolio}@ucla.edu; borgman@gseis.ucla.edu

Patricia D. Mautone, Richard E. Mayer
Dept. of Psychology
University of California, Santa Barbara
Santa Barbara, CA 93106-9660
{mautone, mayer}@psych.ucsb.edu

Richard A. Johnson
Office of Instructional Consultation
University of California, Santa Barbara
Santa Barbara, CA 93106-3200
rick@id.ucsb.edu

ABSTRACT

The Alexandria Digital Earth Prototype (ADEPT) Project (1999-2004) builds upon the Alexandria Digital Library Project (1994-1999) to add functions and services for undergraduate teaching to a digital library of geospatial resources. The "Digital Learning Environment" (DLE) services are being developed and evaluated iteratively over the course of this research project. In the 2002-2003 academic year, the DLE was implemented during the fall and spring terms in undergraduate geography courses at the University of California, Santa Barbara (UCSB). Evaluation of the fall term implementation identified design issues of time and complexity for creating and organizing course domain knowledge. The spring term implementation added new services to integrate course content into class presentation formats. The implementation was evaluated via interviews with the course instructor, development staff, and students, and by observations (in person and videotaped) of the course. Results indicated that usability and functionality for the instructor had increased between the two course offerings. Students found classroom presentations to be useful for understanding concepts, and Web access to the presentations useful for study and review. Assessments of student learning suggest modest improvements over time. Developers are now applying lessons learned during these implementations to improve the system for subsequent implementation in the 2003-2004 academic year.

1. INTRODUCTION

The Alexandria Digital Earth Prototype Project (ADEPT) (http://www.alexandria.ucsb.edu), part of the Digital Libraries Initiative Phase 2 (http://dli2.nsf.gov), adds educational value to a digital library by developing a suite of services for teaching, a digital learning environment (DLE). The DLE offers services for creating, searching, and displaying learning materials such as lectures and laboratory exercises from knowledge databases and personal digital library collections in classroom, laboratory, and self-guided environments [28]. The project staff is organized into two teams. The research and development team includes faculty and graduate students in earth and computer sciences and information technology (IT) staff at UCSB (http://www.alexandria.ucsb.edu/research/index.htm). The education and evaluation team includes faculty and students from educational psychology at UCSB and information studies at the University of California, Los Angeles (UCLA) (http://is.gseis.ucla.edu/adept). The project has adopted the approach of iterative, formative evaluation, a process in which system design is studied in parallel with user needs and requirements [4, 5]. In the 2002-2003 academic year, the research and development team implemented a DLE in the fall and spring quarter versions of an undergraduate introductory physical geography course at UCSB. The course instructor and teaching assistants (TAs) were members of that team. The education and evaluation team observed the development process of designing and implementing the DLE, and reports findings here.

JCDL'04, June 7–11, 2004, Tucson, Arizona, USA.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Information Technologies in Education: system evaluation from user perspectives

The potential of computerized information technologies (IT) to improve learning has long been assumed, but less often confirmed [1, 7, 11]. Evaluators of educational information technology curricula note that the process of designing and implementing such programs is complex, and requires both technological and pedagogical expertise. Technical components (such as hardware infrastructure and software development) must be combined with instructional knowledge (including familiarity with subject content and pedagogical expertise) in order to produce DLEs that achieve the twin standards of success: learning improvement for student users, and cost effectiveness, in terms of time and effort for instructors and funds expended for administrators [26].

Inventing new ways to use new kinds of libraries is a similarly complex process [2, 10, 14]. The ADEPT effort to develop a digital library learning environment to its greatest potential has required the design of both new information management technologies for various kinds of digital learning objects, and new services for collection creation and development, resource description and discovery, and information use. Evaluating the ADEPT DLE requires attention to all of these components as they are used by teachers and students.

The educational IT literature approaches evaluation not as a judgment of success or failure, but rather as a clarification of a project's underlying theory, design plausibility and implementation consistency [26]. Below we clarify how ADEPT pedagogical visions led to a system design that proved difficult to implement at first, and how these difficulties in implementation were addressed by a more practical system redesign.

2.2 Software Development: system evaluation from design perspectives

The ADEPT development process is in some ways similar to software development in any environment. For example, the broader development literature describes "reductionist" [8] and "abstractionist" [21] approaches to system design which encourage the decomposition of complex systems into small, manageable components, and the design of each component for "ideal world" environments, an approach that was evident in ADEPT. Discussion suggests that such design approaches may risk failure [13] if they do not also attend to real world factors, including the human imperfections of users and their social organizations [18, 24, 31]. Differences between designers and users--personalities, world views, functional roles-- are also noted, as well as the resulting management challenges [9, 24].

ADEPT is a research project and thus the development process differs from business approaches. Commercial software development is typically product-based and oriented towards the demands and timelines defined by a paying customer. Most business applications can be evaluated by established metrics of quality assurance, human factors, and economics (i.e., units sold). Product testing is often conducted by a usability team late in the process. In contrast, R&D-based software development in academic environments seeks to test new ideas, rather than to implement known solutions. The "product" of scientific research--new knowledge--is difficult to quantify. Research products evolve over a long term through repeated hypothesis testing. Determining the value to the intended audience (in this case, university faculty and undergraduate students) is itself a research question. The goal of research may be the design of a "proof of concept" demonstration prototype, rather than a finished, marketable product.

2.3 Case Studies: user and designer collaboration

Previous evaluations of digital libraries [2, 16, 19] and similar information systems [31] have documented many of the peculiarities of the research development process described above. In addition, these studies emphasize the need for shared understandings between designers and users in a successful development process, but describe many obstacles to arriving at such shared understandings. For example, Hill et al [16, p. 257] note that digital library design "requires input from the target user communities, almost always mediated by a *nontrivial process of translation* between the user and engineering domains" (emphasis added). Weedman's [31, p. 9] summary of the literature on requirements analysis elaborates the translation process:

> The literature on requirements analysis has identified the problems; discussions take one of three approaches. The first focuses on users and the difficulties they have in understanding and providing the kinds of information designers need. The second focuses on the designers' responsibilities in structuring the elicitation/analysis process to enable users to provide the needed information. The third focuses on the elusive nature of "requirements" themselves.

Such designer-user communication challenges were encountered in the ADEPT development process, for example in the attempts to define and operationalize the notion of a "concept" (described below).

3. PURPOSE OF STUDY

The purpose of this evaluation is to document progress towards fulfilling the ADEPT project goal of DLE development. The evaluation is conducted as part of the project's commitment to iterative design [4, 5]; many of the findings reported here are already influencing design and implementation during 2003-2004. The larger purpose of such documentation is to inform future digital library work.

4. RESEARCH METHODS

The findings reported here are drawn primarily from ethnographic, qualitative data collected on the design and implementation processes in the 2002-2003 academic year. Some quantitative data was collected on student course evaluations and learning experiences in the fall and spring implementations.

4.1 Participant-observation in Development Team Meetings

Members of the evaluation team had two day-long meetings with the development team during the fall 2002 implementation. Beginning in the winter quarter 2003 and through the spring 2003 implementation, a member of the evaluation team attended development team meetings regularly. Implementation meetings occurred on a fixed weekly schedule; design meetings occurred on an as-needed, sometimes daily basis.

4.2 Interviews with Developers and Users

An evaluation team member conducted one-on-one, open-ended interviews with each member of the development team, as a means to explore each developer's understandings of and contributions to the project. A number of the 10 developers interviewed played multiple project roles, as system designers/ application programmers/content developers/instructional users. The project director/course instructor was interviewed twice, once before the fall 2002 implementation began, and again as the spring 2003 implementation ended. Interviews lasted from 45 to 90 minutes, were recorded and transcribed, and analyzed for thematic content associated with the various developer roles, system components, and design processes.

Students in spring 2003 were also invited to participate in a voluntary interview to discuss the usability of the system. Only one of several volunteers was able to complete an interview with a member of the UCSB evaluation team; the student's comments are consistent with the results obtained from student course evaluations (see User Evaluations, section 4.4 below). (More student interviews are planned during the 2003-2004 implementations.)

4.3 Classroom Observations

An evaluation team member regularly attended the 50-minute, thrice-weekly lectures throughout the 10-week fall and spring implementations, as well as several hour-long weekly lab sections during the spring. Observed lecture attendance averaged 40 to 50 students; lab section attendance between 15 and 20 students. Most of the lectures were also videorecorded for subsequent review.

4.4 User Evaluations

Student course evaluations were designed and collected by the UCSB Office of Instuctional Consultation and a member of the UCSB evaluation team at the end of the fall 2002 implementation and at both mid-term and end of the spring 2003 implementation. Slightly less than half of the approximately 90 students officially enrolled in the course each term completed the evaluation, a response rate similar to comparable courses at UCSB. The anonymized results were made available to the evaluation team. The results included both written answers to open-ended questions (e.g., "What do you like best about the lecture format?"), and aggregated data on answers to Likert-scale questions (e.g., on a scale from 1=very easy to 7=very difficult, "How easy is it to learn from the multi-screen format?")

4.5 Student Learning Outcomes

To assess learning improvement for student users, a final source of data gathered for this study is the psychological assessments of student learning outcomes conducted by the UCSB evaluation team. Students were asked to complete a set of scientific reasoning tests at the beginning, and again at the end of the term, and a difference (i.e., improvement) score was calculated for each student. A statistical analysis (t-test) was then performed to see if the differences scores among groups of students varied significantly. Comparisons were made for students in the fall 2002 implementation, a fall 2002 group of students in an introductory pschology course, and students in the spring 2003 implementation.

5. DESIGNING THE DLE

Design and implementation typically co-occur in significant overlap during the development process; we separate them here for purposes of clarification. Here we describe the visions, principles, goals and objectives which have guided the development process, and how conceptual and pedagogical visions influenced the resulting IT system design.

5.1 Visions

In 2001, the idea of "concept-based learning" began to drive ADEPT system development. As described by the development team in meetings and interviews, *concept-based* learning is based on a vision of scientific knowledge as "strongly structured" concepts, and of scientific activity as the discovery and formal modeling of individual concepts, including their relationships to each other in larger knowledge domains [28, 29]. The ADEPT system would construct "concept knowledge bases" in digital library collections, both for teaching and as a potential basis for collaborative knowledge enviroments [6, 20]. Concept-based *learning* is based on a vision of education as "active learning" [12, 25], and of science education as teaching students how to discover and model scientific concepts [15, 27]. The ADEPT system would provide access to primary data sources such that these sources can be used in hypothesis generation and testing. Thus, design goals evolved during the implementation process.

5.2 Principles

ADEPT developers stress three design principles for the system: flexibility, openness, and ease of use. They want the system to be tailorable to an individual user's preferences regarding technology (e.g., operating systems, browsers), content (e.g., course materials could be built new or migrated from existing personal collections), and presentation (e.g., scrolling or slide lecture views). They are also committed to open source and openly accessible Web-based design. Their design approach considers users to be sharing individuals, eager to publish their personally created or gathered collections of research and course materials in digital libraries, who need easy-to-use services to make such "push-button" publishing possible. In contrast to geographic information systems, for example, which are highly specialized and require significant learning time, the ADEPT system should be widely useful and intuitively learnable in a short time.

5.3 Goals

Design goals of the developers include good user interfaces, good component integration, and no required plug-in installation. The means to accomplish these goals is influenced by designers' differing experiences and expectations of the educational use environment, particularly the assumptions of underfunded, outdated low-tech vs. cutting edge hi-tech infrastructure.

In 2002, a major project goal became the development of the concept knowledge base that would anchor the system. The knowledge base would comprise a scientific knowledge domain, geography. Geographic knowledge would be organized as strongly structured scientific concepts and the collection of interrelated concepts would eventually become a distributed digital library for teaching and research. The knowledge base would contain all of the information required to teach a course, i.e., concepts and their relationships.

The design metaphor was that a course lecture would be a trajectory through the knowledge base, and ADEPT tools would enable users to create text outlines and graphic representations of the lecture trajectory from the information in the knowledge base. The text outlines and graphic representations could be presented on multiple screens, to satisfy design goals of 1) displaying different levels of course domain knowledge simultaneously, to enable students to see both a single concept and its place in the larger knowledge domain; and 2) presenting information in complementary formats (e.g., text and image), to increase student learning and/or to accommodate differences in student learning styles [22, 23].

5.4 Objectives

When the opportunity arose to implement ADEPT in a general education introductory physical geography course at UCSB, to run for the 10-week quarter in the fall of 2002, additional concrete, specific objectives further shaped the design process. For example, business-style short-term "delivery dates" for specific functions overlaid long-term research goals of collaborative knowledge creation. For the instructor (who was also the development team leader), an important pedagogical objective was to be able to present a large quantity of material in the short 10-week term. Other design goals and objectives were also modified in the course of the implementation process, as described below.

5.5 Original System Design

Figure 1 represents the ADEPT system design as it was proposed prior to implementation:

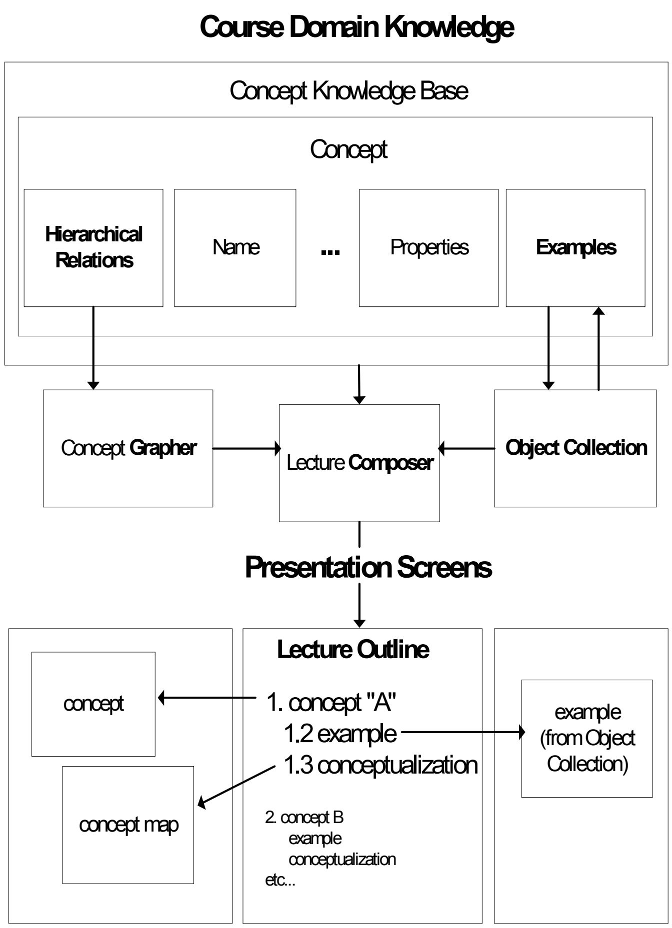

Figure 1: ADEPT System Design, Spring 2002

The system may be divided into subsystems for *producing* knowledge (the "Course Domain Knowledge") and *presenting* knowledge (the "Presentation Screens").

The course domain knowledge would reside in the "Concept Knowledge Base" as a collection of individual "Concepts." The strongly structured format of each Concept would include many fields of definitive and descriptive information, as presented below [28, 29]:

Concept: Mass Movement (Mass Wasting)
Type: Concrete
Facet: Processes
Description: All unit movements of materials propelled by the Force of Gravity, ranging from wet to dry, fast to slow, small to large, and free-falling to gradual or intermittent.
Examples: [items from Object Collection: Rockfall in Yosemite (photo), Slumgullion Earth flow (USGS website link)]
Historical Origins: [not defined for this concept]
Defining Operations:
  Measurement:
    Slope: with a clinometer, DEM, surveying equipment
    Saturation level: piezometer, rainfall measurements, flow rates
    Angle of repose: experimental (grain size and angularity, etc.)
    Movement: Maps, photopoints, surveyed stakes, buried markers (soil creep) lasers, sediment collection, GPS
  Recognition: [not defined for this concept]
Hierarchical Relations: [coded relationships to other concepts]
Classification Representations: by moisture content and speed of motion [Table]; by type of movement and type of material [Table]
Scientific Representations:
  Data: DEM or topographic map time series; time series of survey measurements or GPS points
  Graphical: Slope mechanics diagram
  Symbolic: [not defined for this concept]
  Mathematical: Mohr-Coulomb failure criterion
  Chemical: For every material, there is an angle of repose, beyond which the driving force of gravity overwhelms the resisting force of cohesion and friction, and mass movement occurs.
Properties: Rate of motion; Saturation; Active/inactive; Mass transport rate over time
Causal Relationships: [not defined for this concept]
Co-relations: [not defined for this concept]
Applications: [not defined for this concept]

The most significant fields of the Concept structure for system design are the "Examples" and the "Hierarchical Relations." The Examples field would contain illustrative images of the Concept (e.g., photos, maps, graphs, animations, etc.) from the "Object Collection." The Object Collection itself would be a "personal digital library collection" of items found or created by an instructor-user. The other important field in the structure of a

Concept, the Hierarchical Relations, would describe that Concept's relationships to all of the other Concepts in the larger Knowledge Base. From this information, the "Concept Grapher" would build a "concept map," a visual representation or "conceptualization" of the concept centered within the network of relations to other concepts.

The instructor would then use the "Lecture Composer" to retrieve information from the Knowledge Base, Object Collection, and Grapher to organize it for presentation on multiple screens during course lectures. The Composer would permit an instructor to develop a customized, hierarchical template for creating textual lecture outlines, and to use the template to create "chunks" of conceptual course content which could be combined (and recombined) into individual lectures easily. The Composer would also create hyperlinks from the lecture text to 1) Concepts stored in the Knowledge Base, 2) concept maps generated by the Grapher, and 3) Example items in the Object Collection. These links would function to display the various images simultaneously with the lecture text, in multiple windows or on multiple screens. For the 2002-2003 implementations, three screens were planned: a central screen with the lecture text outline; a second, side screen with Example images from the Object Collection; and a third screen on the opposite side, presenting either the individual Concept under discussion or the Grapher conceptualization of its relationships. (For additional technical description of the system see [17].)

Not represented in Figure 1 are project plans for the system's connections to external information resources and repositories: ADEPT would be able to draw knowledge base and object collection information from primary sources in digital libraries, electronic databases, or on the Internet; and to place system-generated knowledge collections (i.e., knowledge bases, object collections, course lecture series) into the openly accessible digital library domain.

Each of the system components has a different kind of design history. For example, development of the concept knowledge base was a lengthy group process. There were as many different opinions as there were developers about how to define "concept" and how to operationalize a formal model of a concept. Should the knowledge base focus on comprehensive depth of individual concepts, or on the network of relationships among concepts? A deep concept model was designed intially, as can be seen in the previously presented Concept structure fields.

In contrast, the object collection had a single manager who was charged with the location and/or creation of appropriate geographical content, its organization and its accessibility. The collection manager developed a metadata input process for cataloging objects and was responsible for encouraging other staff to use it. In the original design considerations, the importance of cataloging the objects in order to enable future useful searching of the collection was recognized.

By the summer of 2002, the design of each main component--the knowledge base, the object collection, the grapher, and the composer--had become the responsibility of a different developer, and each developer was encouraged to use his own hardware (e.g., server) and preferred programming tools (e.g., Java, XSLT, XML) to design the necessary software.

6. IMPLEMENTING THE DLE

We identify and describe three phases in the process of implementing the ADEPT system in a college course. Initial *preparation* overlaps to a large extent with the design process, but also includes the use of the system to produce course materials. In *execution*, the system is used to present the course. Finally, system *users evaluate* their experiences with the system. Evaluation of the fall 2002 implementation revealed issues which led to a system redesign during the preparation for the spring 2003 implementation. Additional services also were implemented and evaluated in the spring.

6.1 Fall 2002 Implementation

6.1.1 Preparation

Once the fall 2002 implementation was scheduled, the development team focused on the support of course content and presentation. The biggest challenge was to build an adequate knowledge base. This required the collection and knowledge base developers to add finding content for their components to their design work; two part-time geography graduate students also worked on the knowledge base. An alpha version of the knowledge base, designed as a deep digital library collection, proved to be too complicated and time-consuming for the first system users working on course production, and a shorter, simpler beta version was implemented from August 2002. During the summer the ADEPT project devoted the equivalent of four to five full-time staff to preparing for the first implementation of services in fall; about half of the labor, an estimated 80-90 hours per week, was devoted to knowledge base production. Given the multiple roles of many staff and their multiple goals for the knowledge base, it is difficult to quantify how much of this labor should be attributed to research development, and how much to preparation for teaching a course for the first time.

Lecture outline preparation was also begun by the instructor and TAs in the summer, with help from component designers when needed. The recently designed lecture composer was not yet robust enough to rely upon in a classroom environment, and its implementation was postponed to spring; lecture builders resorted to simple HTML for fall presentation.

All of these preparatory course content production tasks continued throughout the fall execution of the implementation.

6.1.2 Execution

The knowledge base and the object collection had been tested during the summer preparation, and were fully operational during the fall course. The simpler, more stable beta version of the knowledge base was easier to use, but still a bit quirky. For example, it required a plug-in to implement the mathematical scientific representation. Here the designer goal of ease of use was overridden by the instructor's need for equations (although the free plug-in maintained the commitment to open accessibility). Knowledge base construction was also time-consuming. The instructor and three other developers spent much of the summer finding content for the knowledge base. In addition, at an estimated one hour of necessary input labor per concept using the beta version, the approximately 1,000 concepts desired for this course by this instructor would have required 25 weeks of full-time labor (or at least two and a half quarters of full-time course preparation) to build a satisfactory knowledge base. During the fall 2002 implementation, two additional geology graduate students were hired part time to input concept content into the knowledge base, and approximately 400 concepts were eventually entered for the course by the end of the spring implementation. The high labor cost of the knowledge base is in part attributable to the general phenomenon of first-time course preparation, but is also indicative of design tension between the goals of long-term knowledge production and short-term knowledge presentation. The instructor's dissatisfaction with the lean content and slow production speed of the knowledge base contributed to a system redesign for the spring implementation, described below.

The other fully functioning system component, the object collection, was rich in the estimation of course TAs (adequate in the opinion of the instructor), and it was heavily drawn upon by lecture builders (instructor, TAs, and collection manager) and concept knowledge base content developers. When contributing to (not drawing from) the collection, users other than the collection manager (instructor, TAs, knowledge base builders) often neglected to enter the metadata for contributed items, and hoped for eventual automated metadata extraction directly from contributed objects. This is another example of tension between long-term digital library knowledge production and short-term course knowledge presentation requirements. Where metadata fields were populated correctly, the object collection was searchable through the UCSB Alexandria Digital Library (ADL) search interface (http://webclient.alexandria.ucsb.edu/). (The ADL interface remained disconnected from the collection due to ADL development issues outside the scope of the ADEPT project.)

As noted in *Preparation* (section 6.1.1) above, the lecture composer was still in software development and not implemented in the fall. The concept grapher also was not implemented in fall, largely because the data on which it was designed to operate--knowledge base concepts and their hierarchical relations--were incomplete. So that students in the course could experience the system as it was designed to function in classroom presentations, static graphics of concept relationship maps and HTML lecture outlines were produced. These served as adequate substitutes to project onto the three screens during lectures.

6.1.3 User Evaluations

The ADEPT system serves two kinds of users: those making the course (instructor, TAs, knowledge base and object collection builders), and those taking the course--i.e., the students. Course producers work with edit-enabled versions of the components, i.e., they are able to create and change content. Because of design and implementation overlap, some of their user evaluations have already been mentioned in *Preparation* (section 6.1.1) and *Execution* (section 6.1.2) above, for example, their difficulties in using the alpha version knowledge base, and in entering object collection metadata.

Student users of ADEPT had view-only access to the created course materials. The student website was a fortuitous result of instructor-centered design: Web-based utilities for the instructor yielded Web-based access for the students.

All fall 2002 users (producers and students) experienced significant unreliability of access. Access problems were typically due to the overlapping design process: e.g., offline component updating, or failed attempts at component integration due to incompatibilities between designers' hardware or software.

Course producers also experienced instability in component functioning due to changing design. Some producers were stimulated by the challenges of using a developing system, and enjoyed contributing to research. Others found it frustrating, particularly when it required repetition of teaching preparation tasks, on last-minute deadline schedules. The majority of producers expressed both opinions.

From a student user perspective, the more significant fall system shortcomings were pedagogical. Based on classroom observations and comments from students, TAs and the instructor, some students seemed a bit overwhelmed in lecture by the amount of material presented on the three screens--unsure of what to focus on, or of how to combine all the information presented on the three screens in order to form a coherent understanding of presented topics. Suggested modifications for the next implementation were captions for the example images, more explanation of organizational cues such as color coded text in the lecture outlines, and simplifying the knowledge base presentation screen. During the fall, at students' request, a concept ranking system was instituted in the lecture outline, to indicate the degree of importance of each concept.

Overall, student course evaluations indicated that the majority of students appreciated the ADEPT presentation--e.g. 30 of 42 students who completed the fall course evaluation found the use of the three-screen format in class to be "always" or "frequently" effective.

Student learning outcomes for the fall implementation showed an increase in scientific reasoning abilities from the beginning to the end of the course, but the increase was not significantly greater than that demonstrated by students in a comparison group of introductory psychology students. It was premature to claim any effects for ADEPT.

6.2 Spring 2003 Implementation

6.2.1 Preparation: system redesign

The fall implementation highlighted the tension between long and short term aims in concept knowledge base design. In response to the pressures of execution, system development priorities and resources shifted during the winter quarter 2003 from knowledge creation in the knowledge base to knowledge presentation through the lecture composer. Research towards the long-term vision of a distributed, collaborative, authoritative digital library collection--for example, on automated harvesting of concepts from digital resources such as online textbook glossaries and course syllabi--moved outside the scope of the project and into the hands of graduate students who were not members of the ADEPT development team.

In order to maintain instructor flexibility in course content organization, the development team decided that the hierarchical relationships among concepts could not be entered in a single fixed form. Different knowledge base users, particularly different instructors might disagree on how to represent the relationships among concepts in a knowledge domain. Each instructor should be able to define a personal set of concept relationships best suited to his or her instructional goals. This desire for flexibility, coupled with the fall implementation experience of slow and costly knowledge base production, led to a system redesign during winter 2003 (represented in Figure 2):

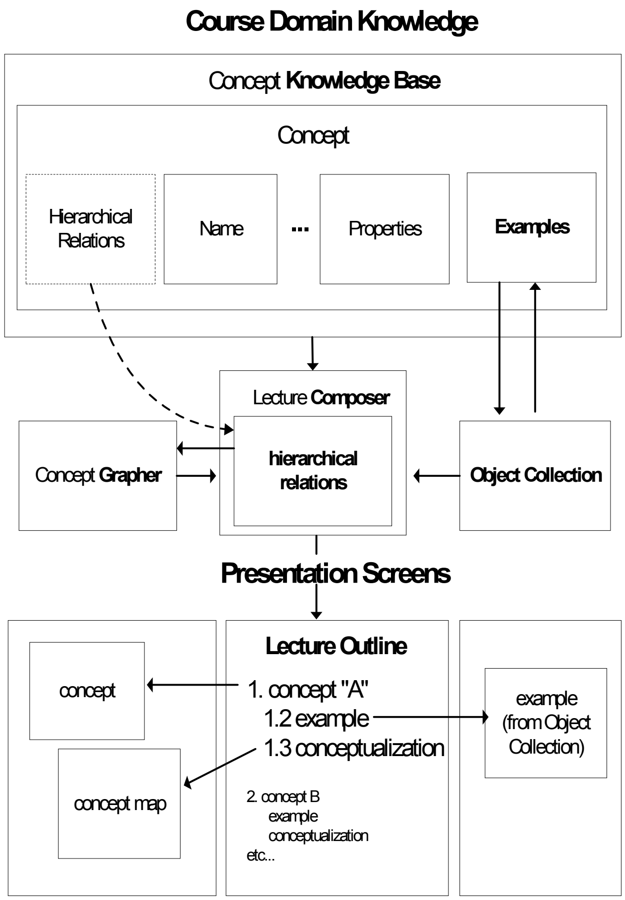

Figure 2: ADEPT System Redesign, Winter 2003

As indicated by the dotted line, the Hierarchical Relations moved from the Knowledge Base to the Lecture Composer. The instructor now enters the hierarchical relations into the Composer in outline form during lecture creation. This move takes advantage of the Composer's original design for creating hierarchical chunks (section 5.5). It also requires the Concept Grapher to interact with the lecture products of the Composer instead of with the Knowledge Base. In implementation this process gives control over defining relationships to the user who is creating the lectures--the instructor--rather than to the user building the knowledge base--here, various research and teaching assistants. (The question of how knowledge base developers--designers and producers--should implement the relationship fields in the Knowledge Base remains open.)

6.2.2 Execution

During the spring, the lecture composer and the concept grapher were implemented and system integration improved. Rebuilding the course lectures in the composer, in order to relocate the concept relationships, required more work from the instructor (reportedly up to a day and a half per lecture), but the effort paid off: integration of the composer and grapher was achieved with dynamically generated, interactive concept maps. The grapher required a newer version of Java which was not yet universally implemented, and which caused widespread but temporary difficulties in accessing the concept maps.

The integration of the composer editing mode with the knowledge base and object collection was somewhat incomplete: for example, some functions for automated linking of components were indicated, but not implemented in the interface. Viewing the system components through the composer was sometimes confusing. Issues included how many windows should open, in what temporal and spatial order, and how they should be identified. The lecture composer had a variety of presentation capabilities which the instructor did not use in the spring implementation.

Display of and access to collection objects from the lecture text was simplified by using thumbnails of the illustrative images. The thumbnails were generated with freeware and pasted manually into the lecture text through the composer. System-internal thumbnail functionality is recommended for future development; thumbnails are a desirable means of browsing the object collection, and should be drop-and-draggable into the lecture composer.

Knowledge base and object collection content development continued to lag behind the instructor's course requirements. Because of the unclear intellectual property status of many items, the collections are not publicly available. For example, a publisher provided digital images of a course text but did not approve access for users outside of that course. Such digital rights management issues also discourage the work towards the development of ingest capabilities for these collections.

A noteworthy addition to the spring implementation was the TA use of ADEPT for weekly lab section presentation and discussion. In the labs, only one presentation screen was available, forcing the TA to select and the students to focus on a single item of information most relevant to the discussion at any given moment. Chalkboards on either side of the presentation screen were heavily used to elaborate the onscreen presentation.

6.2.3 User Evaluations

User satisfaction increased overall during the spring implementation, as did overall reliability of access. For producers, using the newly implemented lecture composer and grapher presented the most challenges (as described in *Execution*, section 6.2.2 above), but also a sense of reward. Student users also faced the Java upgrade and composer windows issues, and complained accordingly. For this implementation, the design assumption of a hi-tech educational environment seems to be appropriate--all students who completed the mid-term course evaluation reported high-speed, not dial-up, Web access.

The spring 2003 ADEPT implementation was still difficult for students to learn. For example, interpretation of the grapher-generated concept maps was somewhat mysterious for many students--it was "cool" to watch the grapher generate the maps, and "fun" to be able to rearrange the concepts in the maps via drop-and-drag, but the significance of the distance, direction, and color of the mapped relationships was not always clear. In spring students attributed the experience of "information overload" more clearly to the overall quantity of course information, instead of the ADEPT technologies of presentation, and some students felt more comfortable during lectures, knowing that the presentation was available to review afterwards on the Web.

Learning outcomes in spring 2003 showed some significant improvement in student scientific reasoning ability when compared to fall 2002 results, specifically on tests of graph comprehension and hypothesis generation. It is difficult to say the extent to which these improvements might be attributable directly to ADEPT-enhanced student cognition; the teachers' (both instructor and TAs) growing experience with an improved ADEPT system also contributed to a better student learning experience. In either case, the results are encouraging for DLE designers and users.

7. DISCUSSION

This analysis of the ADEPT development process notes a functional dichotomy between design and implementation along the lines of the designer-user differences and difficulties described in the literature review. ADEPT designers view ongoing system change as a positive sign of improvement, of system flexibility and ease of use. Some ADEPT users, on the other hand, experience continuing change as time-consuming and frustrating. From a user perspective, flexibility and ease of use can be inversely related--the more changes made (or choices possible), the more there is to be learned and the longer it takes to learn, and thus the harder the system is to use. Like their colleagues elsewhere, ADEPT designers prefer the intellectual challenge of creating new software to the drudgery of debugging components already developed, while ADEPT users, both producers and students, prefer that "known issues" be repaired, particularly if the issue requires a clumsy workaround. ADEPT designers expect users to discover system functionality for themselves, believing in the inherent transparency and ease of use in their designs; but when ADEPT users need to accomplish specific tasks, they seek explanatory documentation or tutorials, especially if they have been uninvolved in the design process. The development gap between designers' and users' understanding of a finished product is embodied by the paucity of end-user guides at the end of the spring 2003 implementation.

We found a similar dichotomy between production and learning. For example, productive users--e.g., the instructor or the TAs--were generally tolerant of system flaws, and sometimes in a design role to work around them. Many of these tolerable flaws resurfaced for student users, who were uncomfortable with their lack of understanding and control of the system. In 2002-2003 the ADEPT development focus was on the producer-user; in future implementations, it will be worthwhile to factor student-user experiences more prominently into the iterative design process, particularly if a development goal for the system is to serve knowledge creation and dissemination equally well.

The academic environment of the ADEPT project both decreased and increased the distance between design and use. In the early stages of ADEPT development, the common gap between designers and users was bridged by ADEPT developers occupying both designer and user roles. Perhaps because of this unique situation, designers of specific ADEPT components were on the whole freer to experiment with design possibilities than their commercial counterparts. This freedom has prolonged the path to stable implementation, typically by generating new or altered design goals. An anonymous reviewer of this paper asks what it would take to make implementation (beyond a "proof of concept" protoype) into a research question equally attractive as design--or in Weedman's [31] terms, what is the incentive to apply academic research? One answer, of course, would be targeted economic support--funding earmarked for the infrastructure and the labor necessary to convert prototypes into tools. Another answer might be to improve classroom infrastructure in ways that would bring teaching activities closer to research [3].

Overall, the successful development of a functioning system appears to rely on the integration of the design and implementation processes through effective communication between designers and users. Communication was achieved in the ADEPT 2002-2003 development process most markedly by the dual designer and user roles of many of the development team, which enabled responsive implementation of ongoing design change. As ADEPT moves into the hands of more users who do not occupy a design role, system functionality must move from the heads of the designers--i.e., their availability to make quick fixes on demand--into the stable operation and integration of the computerized system components [30].

The classroom implementation of ADEPT returns us to some of the longer term development issues for DLE services in digital libraries. For example, what is a personal digital library collection? The ADEPT project has developed two approaches to the collection creation function. One scenario is for ADEPT services to enhance information seeking for educational resources already in digital libraries, electronic databases, and other distributed sources. Enthusiam for this scenario has been dampened by digital rights management issues. For example, many ADEPT concept records and object collection items contain digitized content from the required textbook for the course. This approach does not scale beyond the research environment if a textbook publisher grants use of their digitized materials only to instructors and students in the course that requires the text, and only during the term the course is offered.

A complementary scenario for collection creation is for ADEPT services to enhance information use, by providing ingest capabilities for instructor-created materials (e.g., knowledge bases, object collections, lecture series) to become digital library collections. This scenario also raises the issue of where DLE services belong. During the ADEPT spring implementation, a fair amount of discussion was devoted to whether and how to incorporate the geography course digital objects--the completed lectures, the object collection, the knowledge base, and the grapher with its dynamically generated concept maps--into a digital library such as ADL. Design proposals are being tested in 2003-2004 implementations.

Another issue is the best development path(s) for the concept knowledge base. Both long-term, research-oriented visions and shorter-term, teaching-oriented goals are being pursued in 2003-2004. The team continues to assess the long-term challenge of designing a truly collaborative knowledge base, which would both possess cumulative authority and preserve individual flexibility. The usefulness of the current knowledge base design is being assessed by new instructor and student users in different geography courses during 2003-2004, and will be reported in the next evaluation.

8. CONCLUSIONS

The successes of the 2002-2003 implementations of the ADEPT DLE have moved the project a significant distance towards the original vision and achieved a number of goals. Many of the lessons learned are being applied to the implementation of the system with new instructors in other geography courses in 2003-2004. We hope to report a stable and transferable implementation of DLE services at the end of the coming academic year.

9. ACKNOWLEDGMENTS

The research reported here is funded by National Science Foundation grant no. IIS-9817432, Terence R. Smith, University of California, Santa Barbara, Principal Investigator (http://www.alexandria.ucsb.edu/) and a subcontract to UCLA, Christine L. Borgman, Principal Investigator (http://is.gseis.ucla.edu/adept/).

Special thanks to all the members of the ADEPT research and development team for the time and effort they gave to this evaluation.

10. REFERENCES

[1] Apple, M. Teaching and technology: The hidden effects of computers on teaching and students. In Beyer, M. A. L., ed., *The Curriculum: Problems, Politics, and Possibilities*. New York: State University of New York Press, 1998, 314-336.

[2] Bishop, A. P., Buttenfield, B. P., and Van House, N., eds. *Digital Library Use: Social Practice in Design and Evaluation*. Cambridge, MA.: MIT Press, 2003.

[3] Borgman, C. L., Smart, L. J., Millwood, K. A., Finley, J. R., Champeny, L., Gilliland-Swetland, A. J., and Leazer, G. L. Comparing Faculty Information Seeking in Teaching and Research: Implications for the Design of Digital Libraries. *Journal of the American Society for Information Science & Technology*, in press.

[4] Borgman, C. L., Leazer, G. H., Gilliland-Swetland, A. J., and Gazan, R. Iterative design and evaluation of a geographic digital library. In Constantopoulos, P. and Sølvberg, I.T., eds, *Research and Advanced Technology for Digital Libraries, 5th European Conference (ECDL 2001)* (Darmstadt, Germany, September 4-9, 2001). LNCS 2163. Berlin: Springer, 2001, 390-401.

[5] Borgman, C. L., Gilliland-Swetland, A. J., Leazer, G. H., Mayer, R., Gwynn, D., Gazan, R., and Mautone, P. Evaluating digital libraries for teaching and learning in undergraduate education: a case study of the Alexandria Digital Earth Prototype (ADEPT). *Library Trends* 49(2) (2000), 228-250.

[6] Bowker, G. C. and Star, S. L. Social theoretical issues in the design of collaboratories: customized software for community support versus large-scale infrastructure. In Olsen, G. M., Malone, T. W., and Smith, J. B., eds., *Coordination Theory and Collaboration Technology*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc., 2001, 713-738.

[7] Burbules, N.C. and Callister Jr., T.A. *Watch IT: The Risks and Promises of Information Technology for Education.* Boulder, CO: Westview Press, 2000.

[8] Chen, Q, and Sharma, V. Human factors in interface design: an analytical survey and perspective. In Szewczak, E. J. and Snodgrass, C. R., eds., *Human Factors in Information Systems*. Hershey, PA: IRM Press, 2002, 45-54.

[9] Constantine, L. *Beyond Chaos: the Expert Edge in Managing Software Development*. Boston: Addison Wesley, 2001.

[10] Crane, G. R., Chavez, R. F., Mahoney, A., Milbank, T., Rydberg-Cox, J. A., Smith, D. A., et al. Drudgery and deep thought: Designing a digital library for the humanities. *Communications of the Association for Computing Machinery* 44(5) (2001), 35-40.

[11] Cuban, L. *Teachers and Machines*. Cambridge, MA: MIT University Press, 1986.

[12] Dewald, N. H., and St. Clair, G. S. Active and collaborative learning in online courses. In Snyder, C. A. and Fox, J. W., eds., *Libraries and other Academic Support Services for Distance Learning*. Greenwich, Conn: JAI Press, 1997.

[13] Ewusi-Mensah, Kweku. *Software Development Failures: Anatomy of Abandoned Projects.* Cambridge, MA: MIT Press, 2003.

[14] Gilliland-Swetland, A. J. Evaluation design for large-scale, collaborative online archives: Interim report of the Online Archive of California Evaluation Project. *Arch. Museum Informatics* 12 (1998), 177-203.

[15] Hay, K and Barab, S. Constructivism in practice. *The Journal of the Learning Sciences* 10(3) (2001), 281-322.

[16] Hill, L. L., Carver, L., Larsgaard, M., Dolin, R., Smith, T. R., Frew, J., and Rae, M.-A. Alexandria Digital Library: User evaluation studies and system design. *Journal of the American Society for Information Science* 51(3) (2000), 246-259.

[17] Janee, G., and Frew, J. The ADEPT Digital Library Architecture. *ACM/IEEE-CS Joint Conference on Digital Libraries (JCDL 2002)* (Portland, OR, July 14-18, 2002). New York, N. Y.: ACM Press, 2002, 342-350.

[18] Kling, Rob. What is social informatics and why does it matter? *D-Lib Magazine* 5(1) (1999). [Retrieved October 17, 2003 from http://www.dlib.org/dlib/january99/kling/01kling.html]

[19] Marchionini, G. Evaluating digital libraries: A longitudinal and multifaceted view. Library Trends 49(2) (2001), 302-333.

[20] Marshall, B., Zhang, Y., Chen, H., Lally, A., Shen, R., Fox, E., and Cassel, L.N.. Convergence of knowledge

management and e-learning: the GetSmart experience. *ACM/IEEE Joint Conference on Digital Libraries (JCDL 2003)* (Houston, TX, May 27-31, 2003). Los Alamitos, CA: IEEE Computer Society, 2003, 135-146

[21] Martin, F. G. Ideal and real systems: a study of notions of control in undergraduates who design robots. in Kafai, Y. and Resnik, M., eds., *Constructionism in Practice: Designing, Thinking and Learning in a Digital World.* Mahwah, NJ: Lawrence Earlbaum Associates, 1996, 297-322.

[22] Mayer, R. E. *Multimedia Learning*. New York: Cambridge University Press, 2001.

[23] Mayer, R. E. and Mautone, P., and Prothero, W. Pictorial aids for learning by doing in a multimedia geology simulation game. *Journal of Educational Psychology* 94(1) (2002), 171-185.

[24] McConnell, S. *Professional Software Development: Shorter Schedules, Better Projects, Superior Products, Enhanced Careers.* Boston: Addison Wesley, 2003.

[25] Modell, H. I. and Michael, J. A., eds. *Promoting Active Learning in the Lfe Science Classroom*. New York, N.Y.: New York Academy of Sciences, 1993.

[26] Owen, J. M., Calnin, G. T. and Lambert. F. C. Evaluation of information technology (Chapter 6). In Altschuld, J. W. and Kumar, D. D., eds., *Evaluation of Science and Technology Education at the Dawn of a New Millenium.* New York: Kluwer Academic/Plenum Publishers, 2002, 133-164.

[27] Sandoval, W.A. and Reiser, B. J. Explanation-driven inquiry: integrating conceptual and epistemic supports for science inquiry. *Science Education* 87 (2003), 1-29.

[28] Smith, T. R., Ancona, D., Buchel, O., Freeston, M., Heller, W., Nottrott, R., Tierney, T., and Ushakov, A. The ADEPT concept-based digital learning environment. In Koch, T., and Solvberg, I. T., eds., *Research and Advanced Technology for Digital Libraries, 7th European Conference (ECDL 2003)* (Trondheim, Norway, August 17-22, 2003). Berlin: Springer, 2003, 300-312.

[29] Smith, T.R., Zeng, M.L.and the ADEPT Knowledge Team. Structured models of scientific concepts for organizing, accessing, and using learning materials. In López-Huertas, M. J., ed., *Challenges in Knowledge Representation and Organization for the 21st century: Integration of Knowledge Across Boundaries, Seventh International ISKO Conference* (Granada, Spain, July 10-13, 2002). Advances in Knowledge Organization 8. Würzburg: Ergon, 2002, 232-239.

[30] Soergel, D. An information science manifesto (remarks at the acceptance of the Award of Merit, American Society of Information Science,Washington, DC, November 5, 1997). *Bulletin of the American Society for Information Science* 24(2) (December 1997/January 1998), 10-12.

[31] Weedman, J. The structure of incentive: design and client roles in application-oriented research. *Science, Technology & Human Values* 23(3) (1998), 315-345 [1-20]. [Retrieved March 6, 2004 from http://infotrac.galegroup.com/]