Knowledge Mapper
Authoring System Prototype

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KNOWLEDGE MAPPER AUTHORING SYSTEM PROTOTYPE

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Abstract

We have developed a prototype authoring system for knowledge mapping that provides the capability to (a) specify map tasks (i.e., specify terms and links), (b) launch a knowledge map related to a task, (c) specify criterion or expert maps (for scoring purposes), (d) define groups of users and associate tasks to those groups, and (e) publish tasks for global access. The prototype interface is a simple HTML interface, with any destination function accessible within four mouse clicks. A usability study was conducted with one teacher and 62 fourth- and fifth-grade students. Students were considered beta testers, and the teacher, who had used our existing knowledge mapper, was considered an expert. The teacher reported using the authoring system to create pretest and posttest tasks for students and to access and evaluate student maps. Students used the authoring system to create knowledge maps of their group research projects. The teacher reported that the authoring system was easy to use and thought student authoring promoted ownership of work. Students using the authoring system created more sophisticated knowledge maps, especially in the links specified by students. This anecdotal report is bolstered by analyses of the links used across all student-authored maps. Thirty-eight percent of the links were causal (e.g., *causes*) or functional (e.g., *protects*), and 24% were part-whole (e.g., *part of*). Limited screen real estate, confusing map access, complicated login functionality, and system crashes limited usability. Student performance on a usability task showed that, in general, students were able to independently carry out major authoring and mapping tasks; however, a positive relationship was found between the amount of time a student was at the keyboard and the amount of help that student needed during the usability task, suggesting that practice using the authoring system improves fluency with the authoring system.

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An authoring system is a set of abbreviated procedures that permit a relative novice to create tools, objects, or reports that otherwise would demand more expertise, time, and cost. Authoring systems are typically implemented in computer environments and step the user through a set of key procedures needed to create the product. For example, PowerPoint, created by Microsoft, employs an authoring system that allows users to create presentations that have various structures, individual slides with a range of formats, and different transitions between slides (e.g., fade, fly, dissolve).

Any authoring tool must provide certain clear features that help users. First, it should be easy to use, with a minimum of technical expertise required for success. Second, it should be robust and survive errors made by unskilled users. Third, it should provide assistance on the key component tasks that the authoring system is intended to support. Fourth, it should be economical.

When authoring is applied to the field of testing, additional requirements come into play. With assessment and testing, the key requirement is validity, that is, the extent to which inferences drawn from the result of the test or assessment are warranted (Messick, 1995). Linn, Baker, and Dunbar (1991) have described essential elements of validity applied to open-ended assessment tasks. These validity criteria include cognitive complexity, linguistic appropriateness, transfer and generalizability, content quality, reliability, and instructional sensitivity. Moreover, when conceiving an authoring system (rather than a test, for example) one is interested in the utility of the system for its users (teachers or test developers) in addition to the value of the data yielded by administering tests to students. Our design of an authoring system prototype attempted to address basic functional and usability requirements. Our long-term goal is to implement an authoring system that will address the validity criteria specified by Linn et al.

In testing, it is often the case that teachers who need routinely to use tests and assessments in their classrooms have little time and expertise to create high-quality assessments of student learning. They may use a craft approach, creating each test, one at a time, with a wholly new format, scoring approach, and set of cognitive requirements. This approach generally produces tests of low quality that may lead to suspect inferences. As teachers attempt to bring all children up to high standards, there is a concomitant desire to test performance in a way that stimulates complex cognitive processing. Usually, teachers use essays or other extended written examinations to elicit such performance. These types of tests are difficult to calibrate, take considerable time and expense to evaluate, and frequently cannot be scored with high reliability. Our knowledge maps, on the other hand, provide a straightforward, graphical way for students to demonstrate complex knowledge representations, including declarative, procedural, and systemic knowledge.

Thus, our desire to simplify the creation of knowledge maps grew from a desire to develop tests that were easy to design and that elicited high-quality, reliable information and could be used in a computer-supported environment.

Knowledge Mapping Prototype Components

Our prototype was designed around two major authoring functions (authoring and knowledge mapping), a scoring function (specifying an expert or criterion map), and administrative functions (creating user groups and publishing maps). Each function is briefly described below, and screen shots of the user interface are presented. One user interface goal was to provide a tool with minimal interface complexity and "4-click" access to any destination. Thus, the interface provided a persistent toolbar for random access to the major functions and a list of items with verbal descriptors for access to sub-functions. Briefly, the five functions are:

1. Task specification—provides the capability to create a new knowledge mapping task or edit an existing task. Functionally, this means creating or modifying concepts and links for a particular domain and naming the task.

2. Mapping functionality—for a given task, provides the capability to create a new map or edit an existing map.

3. Expert map assignment—for a given task, provides the capability to specify the criterion map for scoring purposes (e.g., expert, teacher, student).

4. Group functionality—provides the capability to create a "group" and to associate tasks to the group. This administrative function was designed to facilitate the assignment of different tasks to different groups of students.

5. Publish maps—provides the capability to make tasks available for distribution to others. This administrative function was designed into the system to facilitate the dissemination of validated tasks.

Example Flow

In this section we describe a typical user experience for creating a task and then creating a map for that task. A user first logs in with a user name and password. After logging in, the user is directed to the authoring system home page. The home page provides point-and-click access to the major functions described previously (see Figure 1).

Tasks. The first step is to create a task. Clicking on the *Tasks* box directs the user to the task specification page (see Figure 2). This page allows users to create a new task or edit an existing task. The interface for the task specification is a simple HTML form (see Figure 3). There is no limit to the number of concepts or links that can be entered.

Knowledge mapping. The next step is knowledge mapping. Clicking on the *Mapper* box directs the user to the mapping page (see Figure 4) where users can create a new map or retrieve an existing map. The mapping interface is essentially what is shown in Figure 4. The user first selects a task and then clicks on one of the options. A second window opens and prompts the user to provide a name for a new map, launch the current map for the selected task, or select a map from a list of existing maps.

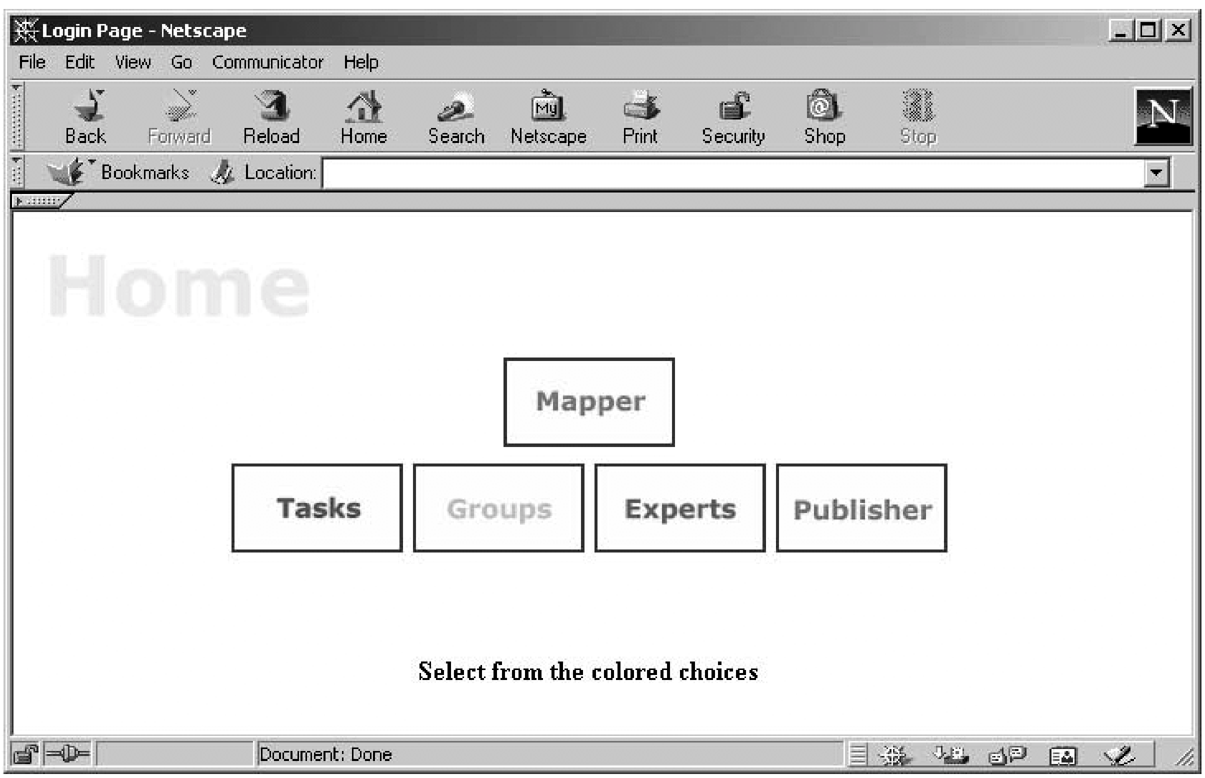

Figure 1. Authoring system prototype home page.

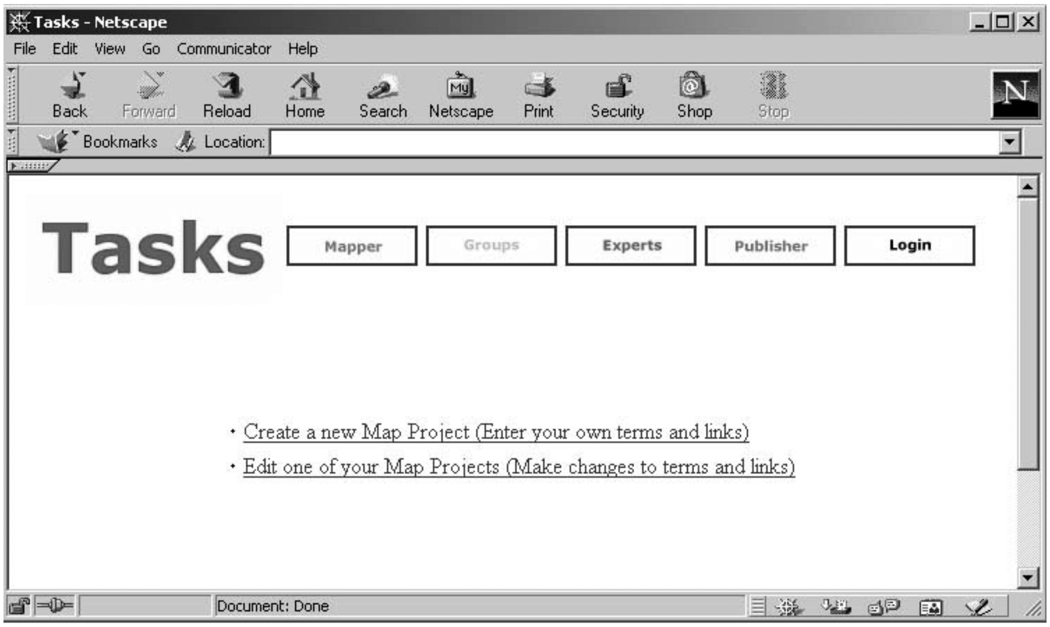

Figure 2. Task specification page.

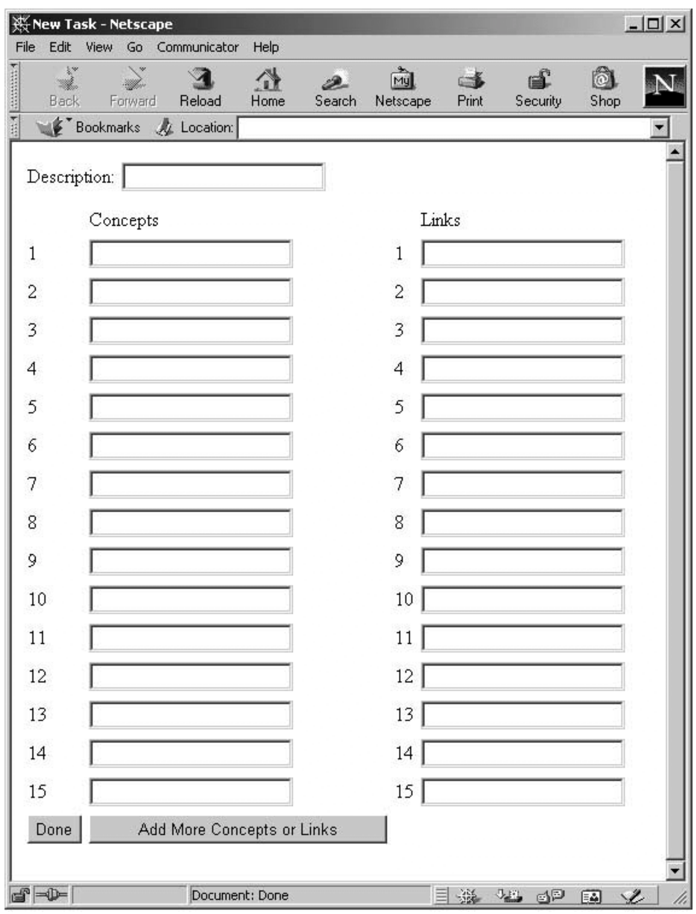

Figure 3. Task specification form.

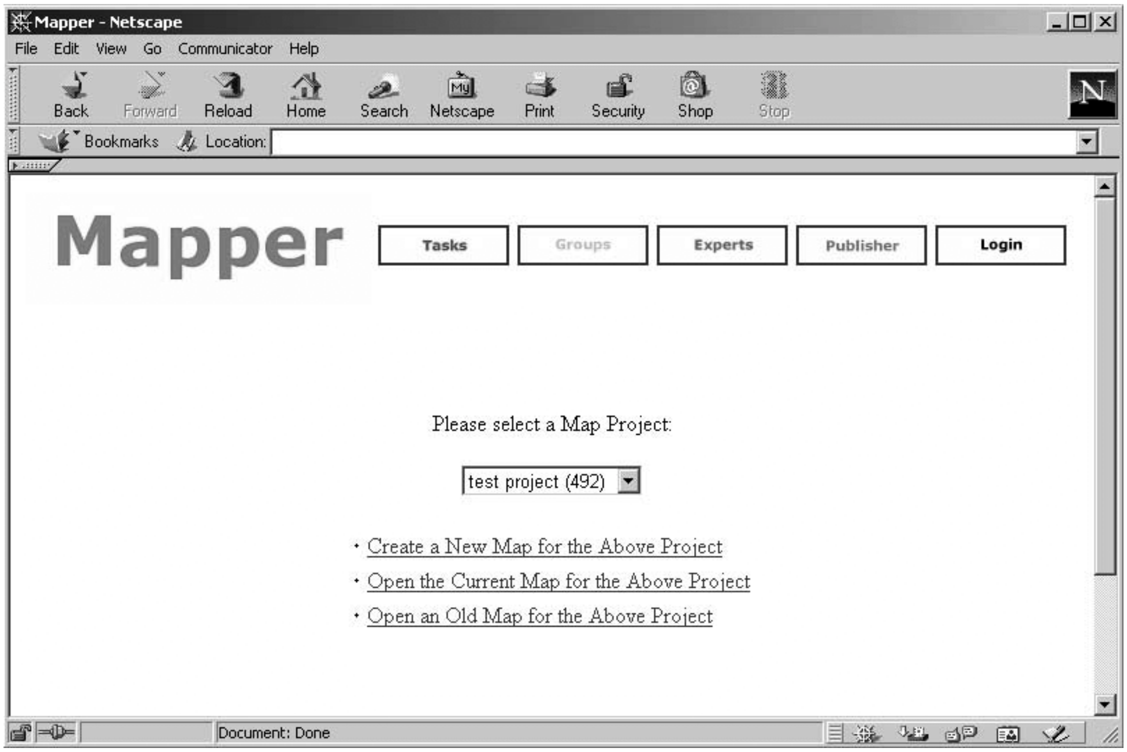

Figure 4. Knowledge mapping page.

Experts. The most challenging component of open-ended assessment is the development of scoring strategies that are reliable, valid, and economical (Baker & Brown, in press). For example, in the area of essay scoring, the cost of evaluating thousands of essays has led to the selection of testing approaches that can be scored efficiently, such as multiple-choice formats (Hardy, 1995). In our case, the computer provides the power to score student maps directly and efficiently. Our approach has been to include expert representations against which student performance is compared (Herl, Niemi, & Baker, 1996). Because the prototype was tested in an elementary school classroom, the "expert" could have been the teacher; a designated content specialist; an older, high-performing student; or an excellent student in the same class (Baker & Schacter, 1996). The scoring function also permits individual maps to be reviewed for similarity. Therefore, to support ease of scoring, we included in the design the capability to specify a criterion map. Thus, one user (with sufficient privileges) can designate any existing map, for a given task, as the "expert" map (see Figure 5).

Figure 5. Expert specification page.

Administrative functions. Two administrative functions are provided to facilitate access to the maps. The capability to create "groups" and associate particular tasks to a group is accessed under the *Groups* function. The purpose of the group function is to direct users (during login) to appropriate tasks. In this way, authors can create specific tasks for specific groups of users (see Figure 6).

The second administrative function is the task publishing function available via the *Publisher* box (see Figure 7). This capability allows users to "publish," or make accessible, existing tasks. Ideally, tasks released for formal publishing have been validated. However, publishing could be used as a means to obtain additional review and suggestions for improvement.

Knowledge Mapper Prototype Authoring System Usability Study

The purpose of this study was to gather information on the usability of the prototype authoring system. Usability was evaluated from the teacher's perspective via an interview and from the student's perspective via the teacher interview and a usability performance task. Because students were creating their own knowledge maps with our system, we also viewed this as an opportunity to address a separate research question—what are the characteristics of the kinds of relationships used in

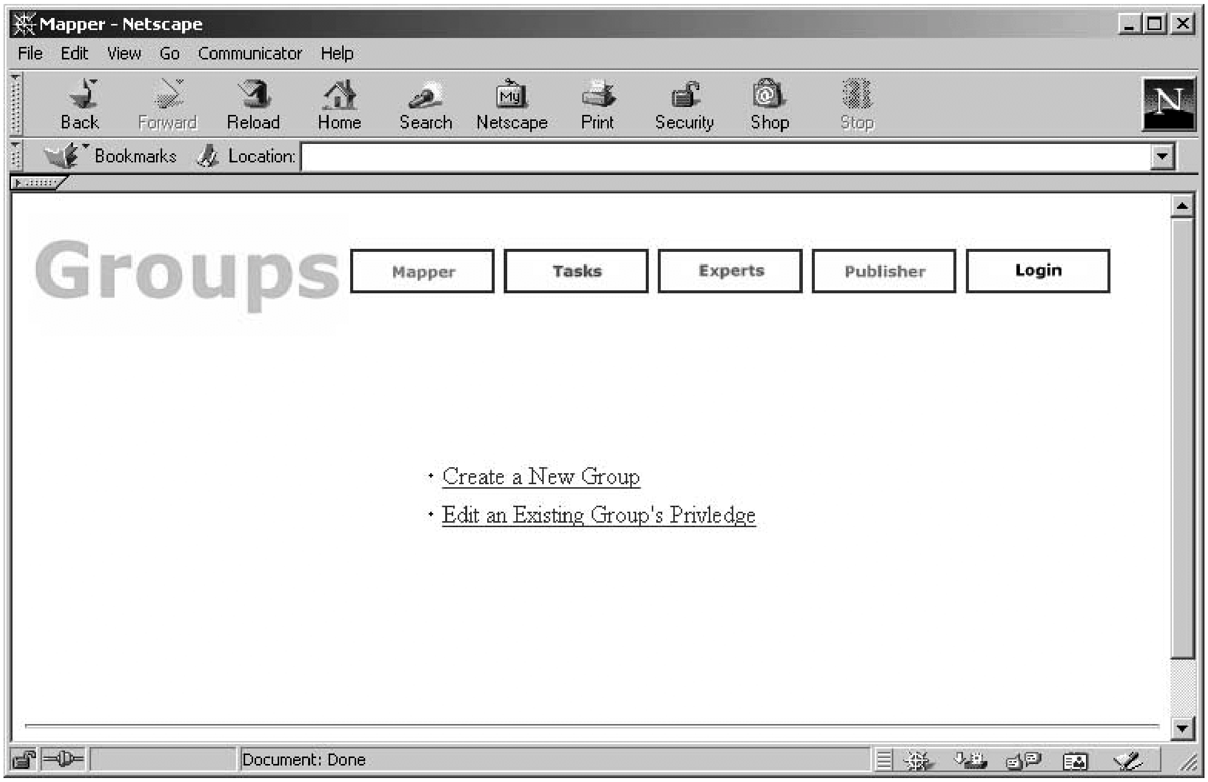

Figure 6. Group specification page.

Figure 7. Map publishing page.

their maps. The latter issue was exploratory and used to gather data on the potential automation of the classification of user-generated link data. Thus, we posed the following four research questions:

1. **What are usability issues for the knowledge mapping authoring system?** Because we expect authoring systems to become increasingly important in education at the classroom level, we wanted to deploy and observe the use of the authoring system in a classroom environment.

2. **How is the authoring system used by students and teachers?** We were interested in how the authoring system would be used by a teacher experienced with knowledge mapping as well as the teacher's observation of how students used the authoring system. Our prior experience with children using the knowledge mapper suggested that they are particularly effective testers of software and adept at pointing out unclear functions (Hanna, Risden, & Alexander, 1997; Osmundson, Chung, Herl, & Klein, 1999).

3. **To what extent can children use the authoring system to create their own tasks and maps?** In addition to the teacher's perception of any difficulty her students had, we wanted a performance measure for a usability test. We assumed our authoring system prototype design was simple and straightforward, and we expected that students who used the authoring system would be able to perform basic tasks independently.

4. **What are the characteristics of relationships (i.e., links) of student-generated knowledge maps?** We intended to explore the extent to which we could systematically characterize or describe the students' linking patterns. If successful, this would offer the possibility to administer open-ended knowledge map assessments with high cognitive demands of students (Ruiz-Primo, Schultz, Li, & Shavelson, 1999).

Method

Design

Data were collected from two intact classes. Each class followed the same science topic and curriculum, which were taught by the same teacher. Data were collapsed across both classrooms; there was no control condition as we were conducting a usability study. It was the teacher's belief that both classrooms comprised students with roughly the same achievement level for academic performance and for interest and performance in science.

At the beginning of Week 1 of the study, all students created an individual knowledge map using the mapping software. Students then brainstormed, as a class, topics of interest related to the human body. During Week 2, students selected their topic and generated four research questions, one of which related to a physiological system. Students used the week to find information on the Web regarding the human body, to use off-line instructional resources (such as newspapers, dictionaries, and books), and to garner feedback from the teachers, teacher's aides, nurses, and even visiting experts. Students were then assigned to groups based on their topics and spent Weeks 3 and 4 of the study sharing information and generating a list of terms and links. The last 2 weeks were allotted to the use of the authoring system. Students used the authoring software as often as they wanted, in the classroom and at home, so long as they had gathered sufficient information to create a list of terms. The teacher's instructions were to have at least five note cards of information before extracting the important concepts and links for an initial list of terms. The list could be modified (e.g., terms could be added or deleted) as the mapping activity took place and gaps in knowledge could be identified. During group work, the teacher circulated among groups, facilitated discussion among group members, and answered group members' questions. At the end of the study (Week 6), students were administered individual knowledge maps, an essay (as homework),[2] and a usability task. Table 1 summarizes the design for the study.

Table 1

Design of Knowledge Mapping Usability Study

Week	Tasks
1	a. Individual pretest knowledge map assessment administered. b. Students brainstormed questions and ideas related to the body as a class.
2	Students independently researched chosen topic.
3-4	Teacher assigned students to groups based on topic. Students collaborated in small groups on their research.
5-6	a. Authoring sessions. Students created, reviewed, and revised tasks and maps using the authoring system. b. At the end of Week 6, assessments administered: individual posttest knowledge map, usability task, and essay.

[2] We dropped the essay as a measure because of problems with the administration. There was too much variation in the time spent on the essay and in the help students received in completing their essays.

Setting

Students. Sixty-two 9- to 11-year-old (mean age = 10.33 years) students from a university laboratory elementary school participated in this study. In this sample of 29 boys and 33 girls, ethnicity and socioeconomic status were mixed. Student ethnicity was identified as White (33 students), Latino (8 students), Asian (4 students), and Black (3 students). The remaining 14 students belonged to other ethnic groups or were of mixed descent. Family income ranged from $12,500 per year to greater than $250,000 per year, with a median annual family income range of less than $60,000. Fifty-eight students spoke English as their first language.

Classroom setting. The teacher was a veteran instructor, with more than 30 years of teaching experience, 20 of which were spent teaching physiology. She volunteered two classes for this study (morning and afternoon science classes). Science instruction occurred daily for approximately 45 minutes.

Science instruction was administered using an information management curriculum that was developed at the school. The focus was to have students actively engage in discussion and the research process, synthesize information from a variety of sources, and arrive at a conclusion; lectures were kept to a minimum. The teacher used videos, expert speakers, and classroom discussions to get students interested in the human body. Students brainstormed questions and investigated topics on the body that were of interest to them. Students were asked to generate four questions, one of which had to be a general question relating to one of the six physiological systems. These questions served as the framework for guiding their research. After a week and a half of independent research, the teacher assigned the students into groups by topic. In these groups, students engaged in discussion, shared information they had collected, and worked together to create a list of concepts and links for use during the authoring sessions. The authoring sessions served as a forum for students to organize the information they had collected and, having mapped their own concepts and links, to identify gaps in knowledge that could then be addressed by further research.

The teacher had prior experience with computers and was familiar with the knowledge mapping software, having participated in a computerized mapping study 2 years earlier (Klein, Chung, Osmundson, Herl, & O’Neil, 2001; Osmundson et al., 1999). The teacher had 3 years of experience using computers for school activities such as grading or making handouts and 2.5 years of experience using the

Web. Students in her class used computers weekly and had been exposed to paper-based concept mapping the previous year.

Instrumentation

Authoring system prototype. The authoring system prototype had two components: (a) the authoring component, and (b) the knowledge mapping component. The authoring component allowed students to create new tasks or modify existing tasks. It was through the authoring component that students had the capability to modify their knowledge maps (i.e., students could not modify their maps directly with the knowledge mapper).

Knowledge mapping system. The online knowledge mapping system was designed to provide anytime, anywhere access capability for students and teachers. Thus, we created a Web site that integrated the use of a relational database into the knowledge mapper. The main requirement for this site was to support the creation and maintenance of knowledge maps by students, teachers, and experts. Figure 8 shows the main user interface of the knowledge mapper. The knowledge mapper was written in Java and was accessible from Netscape browsers running on either a Macintosh or a Windows platform. The knowledge mapper in the current study was adopted from earlier work (Klein et al., 2001; Osmundson et al., 1999).

The user interface required only the use of a mouse. Concepts were added to the map via menu selections. Links were created by connecting two concepts and then selecting the desired link from a pop-up menu to form a proposition. The set of concepts and links was defined a priori. Our previous studies and in-house usability testing showed that participants of various ages (fifth graders to graduate students) could be trained to use the knowledge mapper in approximately 10 minutes (e.g., Chung, Baker, Harmon, & Burks, 2000; Herl, O'Neil, Chung, & Schacter, 1999; Herl, O'Neil, Schacter, & Chung, 1998; Klein et al., 2001; Osmundson et al., 1999). Changes to the concepts or links were made in the authoring system; no changes could be made directly in the knowledge mapper.

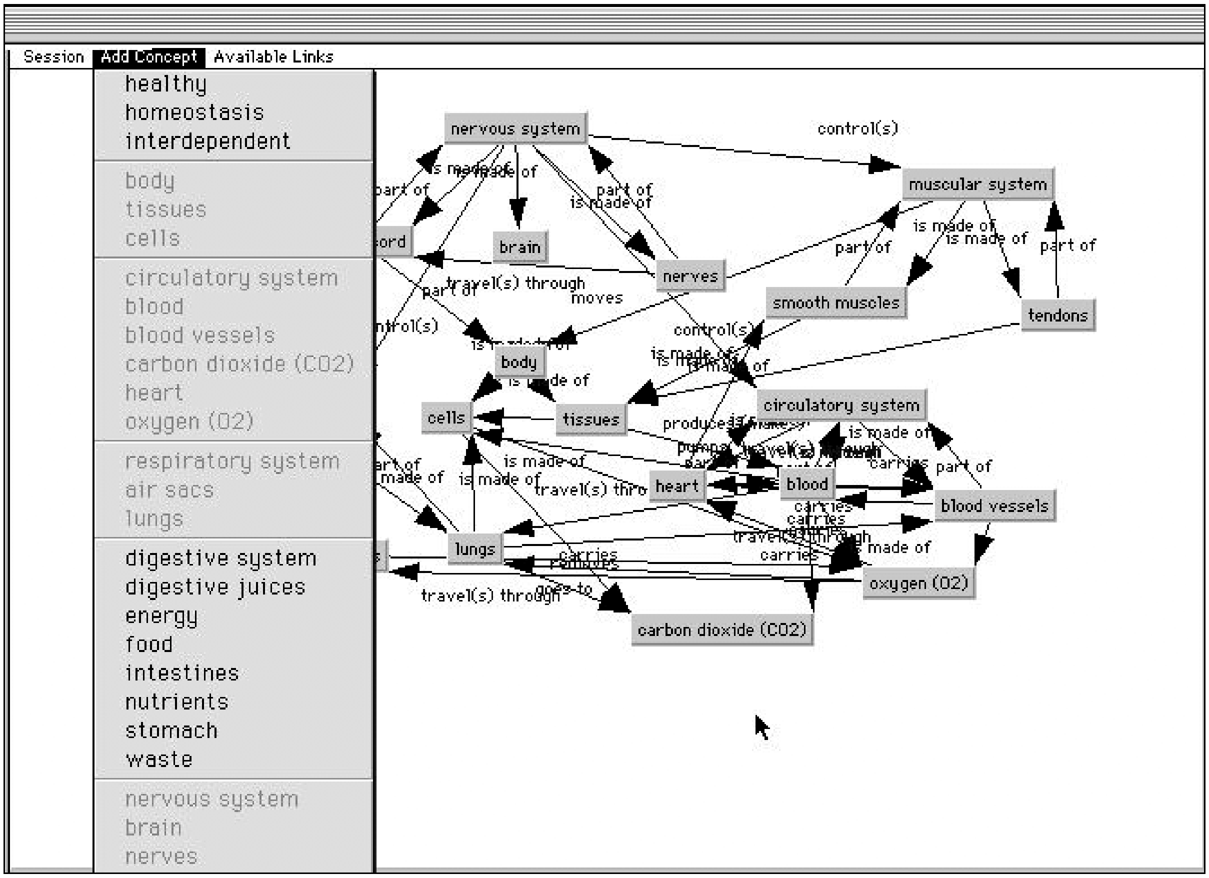

Figure 8. Example of a knowledge map (pretest).

Development of knowledge mapping terms and links. To create a mapping task that broadly covered the topic (human physiology), researchers reviewed the instructional materials used by the teacher and generated a list of terms and links. The classroom teacher was also asked to list important concepts relating to the circulatory, digestive, excretory, muscular, nervous, respiratory, and skeletal systems. Emphasis was placed on including concepts that were general and comprehensible to fourth- and fifth-grade students and on providing for the formation of reasonable propositions (term-link-term sets). Link terms were also selected that would allow the physiological systems to be interconnected on the maps. The full set of concepts and links generated from all sources underwent review and modifications by the teacher and researchers. The final knowledge mapping task contained 40 terms and 19 links and spanned seven physiological systems. The teacher and a medical student then created a knowledge map using the final list of terms and links. Table 2 summarizes the process of creating the lists of concepts and links. Table 3 and Table 4 present the final list of concepts and links, respectively. Table 5 shows the concepts grouped by system category.

Tasks and Measures

Pretest and posttest student knowledge map measures. An individual mapping task with predefined concepts was given to all students prior to the start of the physiology curriculum (as a pretest measure), and at the end of the curriculum (as a posttest measure). Students were given 25 minutes to complete their maps on both occasions.

Table 2

Procedure Used to Generate Final Concepts and Links for Knowledge Mapping Task

Step	Procedure
1	Reviewed relevant instructional materials.
2	Teacher generated a list of all possible terms relevant to the circulatory, digestive, excretory, muscular, nervous, respiratory, and skeletal systems.
3	Preliminary set of terms and links reviewed and modified.
4	Final list of terms and links created.
5	Classroom teacher and medical student created a knowledge map using the final list of concepts and links.

Table 3

Physiology Knowledge Map Concepts

Air sacs	Digestive juices	Kidney	Respiratory system
Bladder	Digestive system	Ligaments	Skeletal system
Blood	Energy	Lungs	Smooth muscles
Blood vessels	Excretory system	Muscular system	Spinal cord
Body	Food	Nerves	Stomach
Bones	Healthy	Nervous system	Teeth
Brain	Heart	Nutrients	Tendons
Carbon dioxide (CO_2)	Homeostasis	Oxygen (O_2)	Tissues
Cells	Interdependent	Perspiration	Waste
Circulatory system	Intestines	Red blood cells	Water (H_2O)

Table 4

Physiology Knowledge Map Links

Absorb(s)	Eliminates	Maintains	Pumps
Carries	Excrete(s)	Moves	Reduces
Connect	Filters	Part of	Removes
Control(s)	Goes to	Produces (makes)	Travel(s) through
Digests (breaks down)	Is made of	Protects	

Table 5

System Categorization for Mapping Concepts

System	Concepts
Circulatory	Blood vessels, blood, heart, body, circulatory system
Digestive	Energy, intestines, digestive juices, digestive system, food, nutrients, stomach, waste
Excretory	Kidneys, bladder, water (H_2O), perspiration, excretory system
Muscular	Smooth muscles, tendons, muscular system
Nervous	Brain, nerves, spinal cord, nervous system
Respiratory	Carbon dioxide (CO_2), oxygen (O_2), air sacs, cells, lungs, respiratory system, tissues
Skeletal	Bones, teeth, red blood cells, ligaments, skeletal system
Other	Homeostasis, interdependent, healthy

Student authoring and knowledge mapping tasks. Over a period of 2 weeks, students underwent a series of authoring sessions in their assigned groups. Students had the opportunity to work together to organize the information they had collected and to map their understanding of their topic area. Groups were allowed to use the authoring system after they had completed their research and compiled a list of terms. Thus, some groups had more opportunities to work on the authoring system than others. The amount of time groups received to create, review, and revise their collaborative maps was progressively increased to 45 minutes, the approximate length of the class period. Figure 9 shows an example of a knowledge map created by a group. Student-authored knowledge maps were not scored.

Teacher pretest and posttest interviews. The teacher was interviewed before and after the use of the authoring system. The interview covered the teacher's use of knowledge mapping the year before this study (i.e., use of paper-and-pencil mapping), how she used the authoring system, and comparisons between the use of the authoring system and the use of the paper-and-pencil method, for both students and teachers. Appendix A contains the pretest interview questions; Appendix B, the posttest interview questions; and Appendix C, the teacher background survey.

Student posttest usability task and measure. A usability task was administered at the end of the study to measure students' proficiency with the authoring system. Students received written instructions asking them to log in to the authoring system and create a knowledge mapping task using a set of predefined terms and links. Researchers recorded the type of assistance given to students (if

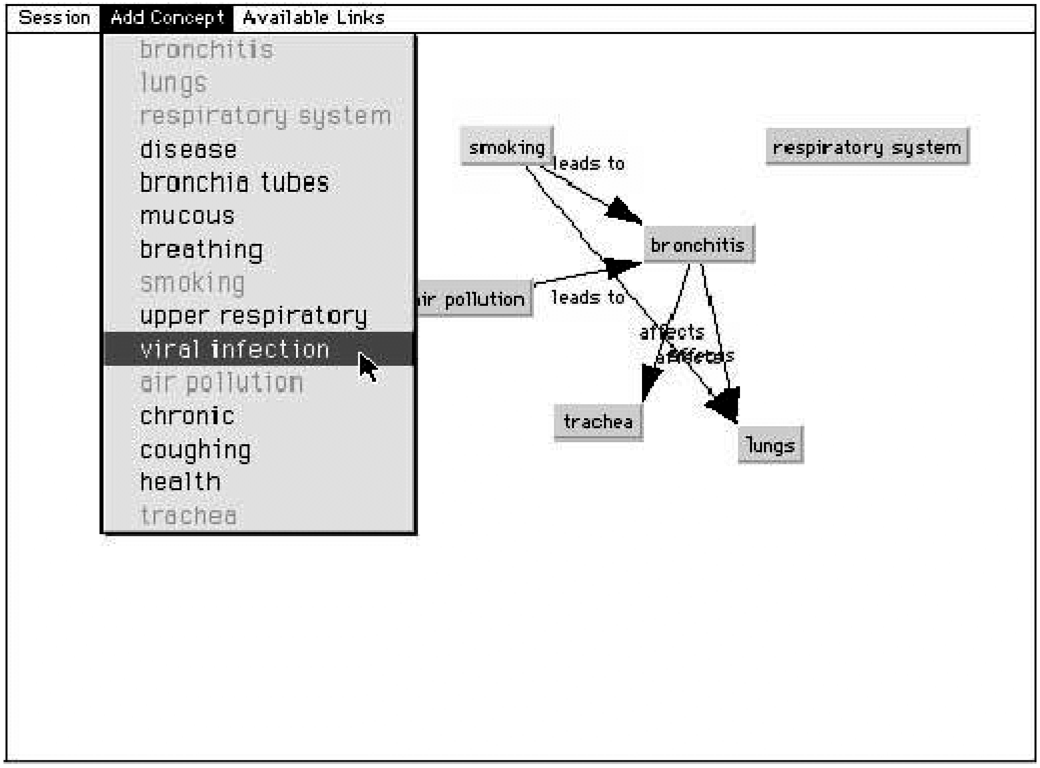

Figure 9. Authoring system user interface: mapping student-generated concepts and links.

any) as they completed the task. The areas include selecting major options and sub-options, entering data, updating the database, and naming the map; type of assistance was classified as *remind*, *teach or explain*, and *do*. Appendix D contains a copy of the directions for the usability activity.

Coding of student-generated links. Though there were no direct measures of the quality of student-authored knowledge maps, we did examine the links of student-authored maps. Five hundred thirty-nine propositions were generated across all student group-authored maps. Two raters coded the links in two steps: (a) simplifying the original, student-typed text into a nominal representation, and (b) coding the nominal representation into functional categories. We followed this procedure because these steps would be necessary in any automated coding procedure (which is a long-term interest).

The process of simplifying the text into its nominal representation required examining each link and then transforming it into a standard representation. We defined nominal as the most parsimonious representation of the text. For example, the relation *are in the* was simplified to *is in*. Likewise, *is a part of* was transformed to *part of*. Of the original 539 links, 75 were discarded because they were judged to be invalid relations (i.e., not a verb, for example, *the*), resulting in 464 links that were simplified to 92 nominal link representations.

Ten categories of link types were defined, based on work on semantic and language structure (Evens, Litowitz, Markowitz, Smith, & Werner, 1980; Sowa, 1984; Wilkins, 1976). The categories are given in Table 6.

Nominal representations (links) were coded into one of the 10 categories in two ways. Using the first method, links were coded without considering the concepts connected by the links. Using the second method, links were coded with consideration of the concepts. The purpose of coding the links without concepts was to mimic the way automated analyses would be done. The purpose of coding with the concepts was to get an estimate of how much information was lost (as reflected in disagreements in coding). Agreement statistics are given in Table 7 for each coding step.

Results

What Are Usability Issues for the Knowledge Mapping Authoring System?

To answer this question, we relied on two types of analyses: teacher interviews and pre- and post-authoring system use.

Table 6

Relationships Categories for Student-Generated Knowledge Maps

Relationship category	Definition[a]
causal	*X* involving or constituting a change or effect Y, or on Y, or vice versa
characteristic	*Y* is an abstraction belonging to or is characteristic of an entity X or vice versa
classification	X is a class, category or type of Y, or vice versa
comparison	involves a comparison in order to show a similarity or difference in some respect
conditional	X is a state of being contingent on something Y; a possible event
duration	involves a time relation
function	X designed for or capable of a particular function or use (i.e., what something is used for)
is-link	general link (i.e., varies with context)
location	involving spatial relations static or something that changes location or vice versa
part-whole	any concrete entity which is contained in an object, substance or a group or any concrete entity consisting of multiple discrete objects

[a]General form: *X* type-of-relationship *Y*, where type-of-relationship is the relationship category.

Table 7

Agreement Statistics for Each Link Coding Step

Coding step	Agreement level
Analysis 1: Given original student-generated links, simplify the link to its nominal form.	
Coding original student links into their nominal form.	85%. Disagreement was mostly in the coding of "meaningless" links.
Analysis 2: Given nominal form of link (agreed to by Rater1 and Rater2), Rater1 and Rater2 classify each link into relationship categories.	
Concept information unavailable.	88%. Disagreement was mostly on the causal and function categories.
Concept information available.	91%

Teacher interview: Challenges. Most of the negative issues were technical in nature. The teacher noted three, in particular, that took time away from the task. All three could easily be addressed. These issues were small screen size, system access and knowledge map tracking, and loss of maps.

a. Small screen size. The teacher reported that students could not place all their terms and links into the given screen space and have all the terms visible or legible. The result was often a messy representation with concepts and links overlapping each other.

b. Accessing the system and keeping track of different versions. The teacher reported that one of the biggest problems was the number of passwords needed to access the authoring system. Although students had little difficulty with creating a task and the mapper, the process of getting into the system and finding the desired map was confusing and frustrating. Students tended not to distinguish one authoring attempt from another. As such, over the course of the 2 weeks, many groups accumulated several versions of the same map. Much time was spent locating the most recent map.

c. Loss of maps. According to the teacher, the biggest drawback was the loss of maps. Students, in the midst of a mapping activity, often lost their maps when the system crashed if they did not periodically save their work. At other times, students might have saved their maps but were unable to retrieve them later. On these occasions, whether or not the maps were actually lost was unable to be determined, as identification problems made them difficult to track down. The teacher recommended that automatic screen shots of the maps be made before students exit the system.

Other nontechnical issues to address involved teacher familiarity with the authoring system and the need to better match curriculum goals to authoring capabilities. Although the process of authoring maps was simple, the teacher, owing to technical problems inherent in the program and her lack of experience with the system, required technical support during system crashes and retrieval of missing maps.

There was a problem with time and organization. Because of a lack of time, the teacher did not have a chance to provide an overview of the human physiological system or to provide the background information on all the subsystems. The authoring system was a valuable tool that students could use to organize, consolidate, and evaluate information they had gathered for their own research topic.

Teacher interview: Opportunities. Technical issues aside, the teacher was highly supportive of the authoring system and believed it was a more individualized way of teaching and assessing students. Compared to previous knowledge mapping activities without the authoring option (i.e., mapping on large pieces of paper with Post-it Notes the prior year), the authoring system facilitated the mapping of ideas, increased understanding, instilled a sense of ownership, and provided students an opportunity to represent their ideas at a much higher level than anticipated. The teacher also thought student-authored maps provided a literal picture of knowledge representation and offered a more individualized means of evaluating student learning.

a. Ease and flexibility of use. The teacher reported that students had an easier time entering terms and creating maps on the authoring system compared to the knowledge mapping activity 2 years previous (students struggled with using the predefined terms and links). With the authoring system, students generated terms that were meaningful to them, and they had the freedom to revise the list of terms when needed. The teacher noticed that with regard to group dynamics, students with prior mapping experience tended to dominate the authoring activity, with younger, less experienced, or less assertive students watching or engaged in other activities such as making a list on paper.

b. Ownership. The teacher reported an increase in the sense of ownership students had for their maps. The teacher noticed that within groups, most students were engaged in the activity, and she marveled at "how the students would sit around [the computer] even though one person was typing." Additionally, for students who worked independently on the map, there was an extra sense of ownership, whereby the student "owned not just the map, but the ideas."

c. Sophistication of terms and increased understanding. According to the teacher, students used links at a much higher level through the authoring system and had definite ideas about how their concepts were related. Compared to the year before, the maps created this year, with the authoring system, made more sense. The teacher also noted that students who had prior experience with knowledge mapping created more sophisticated maps than those for whom knowledge mapping was a novel activity. This suggests that when students gain greater familiarity with the program, their attention will shift from technological aspects of the program to the task at hand (i.e., knowledge mapping).

How Is the Authoring System Used by Students and Teachers?

To answer this question, we relied on the teacher interview. The classroom teacher believed the authoring system complemented and enhanced the curriculum. The system allowed students to pursue their own interests and to revise their understanding over time. It also gave the teacher a more authentic picture of student knowledge.

Students. Students used the authoring sessions to organize and consolidate research information on a particular topic related to human physiological systems, and having defined and mapped their own concepts and links, to identify gaps in knowledge and guide future research. Authoring provided students with the flexibility to chart their own knowledge and to revise and refine their understanding as they saw their ideas mapped out before them. Rather than working from a predetermined list of terms and links, students used the authoring system to accommodate the evolving nature of learning and knowledge construction.

Teacher. The teacher reported using the authoring system to create the pre- and posttest mapping activities to assess student understanding of general principles associated with human physiological systems. Although each subsystem in the body was researched and studied individually, emphasis was placed, through the course of the curriculum, on recurring themes such as health, interdependence, and homeostasis, and the interconnections that exist between related systems such as digestion, circulation, and respiration. The teacher reviewed final student-authored maps to see how knowledge was structured and to determine the quality of understanding. In comparing different versions of the maps, the teacher was able to see how knowledge changes and develops over time.

To What Extent Can Children Use the Authoring System to Create Their Own Maps?

Prior to analyzing the usability information, we verified that students learned content across the 6-week period by examining the change in knowledge mapping scores from pretest to posttest. A paired *t* test was conducted on the pre- and posttest knowledge map scores. As expected, the mean posttest mapping scores (M = 4.59, SD = 4.58) were significantly higher than the mean pretest scores (M = 2.43, SD = 2.82), $t(50) = 5.1$, $p < .001$. Descriptive statistics and intercorrelations among the knowledge mapping measures are given in Table 8.

Analyses of usability performance. To examine usability, we analyzed the extent to which students were fluent with the use of the authoring system. We analyzed the type of help required to complete the usability task. Table 9 shows the number of students needing different types of assistance.

As Table 9 shows, in general most students did not need assistance across the different task components. More students had difficulty with the authoring part of the usability test, as indicated by the larger number of students who needed to be reminded about how to use the system, or taught or given explanations about how to use the authoring system. To gain further insight into the kind of help required, an analysis was done of the type of help given. In general, help was needed more with the authoring system than the knowledge mapping task. Given a student who

Table 8

Descriptive Statistics and Intercorrelations (Spearman) for Mapping Measures

Measure	*N*	Min.	Max.	*M*	*SD*	Pretest map score	Posttest map score
Pretest map score	56	0	12	2.29	2.73	—	
Posttest map score	55	0	18	4.69	4.52	.73*	—
Map gain score	51	-3	14	2.16	3.02	.24	.77*

*$p < .05$ (two-tailed).

Table 9

Number of Students (and Percent) Requiring Assistance During the Usability Task

Usability task component	No. of students that did not help	No. of students requiring assistance at least once during the task: Remind	Teach or explain
Authoring task			
Given help with major option	43 (69.4)	11 (17.7)	8 (12.9)
Given help with sub-option	46 (74.2)	9 (14.5)	7 (11.3)
Given help with entering data	61 (98.4)	1 (1.6)	0
Given help with updating database	59 (95.2)	2 (3.2)	1 (1.6)
Knowledge mapping task			
Given help with major option	52 (83.9)	5 (8.1)	5 (8.1)
Given help with sub-option	54 (87.1)	5 (8.1)	3 (4.8)
Given help with naming map	57 (91.9)	4 (6.5)	1 (1.6)
Given help with using mapper	62 (100.0)	0	0

needed help with the authoring task, there was an equal chance that the student would or would not need help with the knowledge map task. If a student did not need help on the authoring task, then they were not likely to need help on the mapping task. As Table 10 shows, 23 students needed some type of help with the authoring component (vs. 16 students for the mapping), but in general, a little over half of the students required no help ($\chi^2 = 13.28$, $df = 1$, $p < .01$).

We also examined how students spent their time during the group mapping activity at the computer. Each week we recorded whether a student was at the keyboard, or at the computer but not at the keyboard. Interestingly, 26 students were not observed to ever be at the keyboard, and 10 were never observed to be with their groups at the computer (see Table 11).

Table 10

Type of Help Given During Usability Task

Help with authoring task	Help with knowledge mapping task: No help	Helped at least once
No help	35	4
Helped at least once	11	12

Finally, we examined the relationships between opportunity to use the computer and assistance (help given, help not given) during the usability task. We expected that students who were on the computer would perform higher on the usability task. As Table 12 shows, there was a significant relationship between those who were at the keyboard and whether help was needed ($\chi^2 = 3.64$, $df = 1$, $p < .05$). This finding is consistent with our initial expectations and common-sense notions about technological fluency—competence with computer-based tasks requires practice on those tasks. This finding also provides evidence for the utility of our usability task—the need for help reflects less competency or experience on the authoring system.

What Are the Characteristics of Relationships (i.e., Links) of Student-Generated Knowledge Maps?

Our final set of analyses addressed the type of links used by students in their authored maps. Eleven student groups used the authoring system to create their knowledge maps. Each group had a different topic related to the human body: circulation, digestion, the eye, immune system, infancy, nervous system, respiration, sight, skeletal system, skin, and sleep. Our analyses of student-generated links yielded two interesting findings. Table 13 shows the 10 most commonly used links.

Table 11

Number of Students (and Percent) at the Keyboard and Computer (*N* = 62)

	No. of students at the keyboard or computer				
Location	0 times	1 time	2 times	3 times	4 times
Keyboard	26 (41.9)	28 (45.2)	6 (9.7)	2 (3.2)	0
Computer	10 (16.1)	34 (54.8)	10 (16.1)	4 (6.5)	4 (6.5)

Table 12

Relationship Between Help Given and Keyboard

	Help with usability task (authoring or mapping)	
At keyboard	No help	Helped at least once
Never	11	15
At least once	24	12

In general, about 17% of the links are causal (*causes*, *protects*, *controls*, *caused by*), whereas most of the links are descriptive (*part of*, *is*, *has*, *is in*, *made of*, *type of*).

Table 14 shows the distribution of all links into functional categories. In general, when examined by category, 38% of the links were substantive in terms of science (function, causal).

Table 13

Ten Most Common Link Types Used in Student Maps (Nominal Form) (N = 11)

Nominal form	Frequency	%
part of	81	19.9
is	23	5.7
causes	22	5.4
has	22	5.4
protects	20	4.9
is in	18	4.4
made of	16	3.9
type of	14	3.4
controls	14	3.4
caused by	13	3.2

Note. These data represent 60% of the links.

Table 14

Type of Links Used in Student-Generated Maps

Category	Frequency	%
function	98	24.1
part-whole	97	23.8
causal	56	13.8
location	52	12.8
characteristic	35	8.6
is-link	23	5.7
classification	16	3.9
comparison	12	2.9
conditional	12	2.9
duration	4	1.0
no relation	2	0.5

Discussion

We have developed a prototype authoring system for knowledge mapping that provides the capability to (a) specify map tasks (i.e., specify terms and links), (b) launch a knowledge map related to a task, (c) specify criterion or expert maps (for scoring purposes), (d) define groups of users and associate tasks to those groups, and (e) publish tasks for global access. The prototype interface is a simple HTML interface, with any destination function accessible within four mouse clicks. In this study students were considered beta testers, and the teacher was consulted for expert opinion.

With respect to usability issues, data from the teacher interview and our own on-site observations suggest that work remains to be done to further simplify the user interface. One issue is designing a better method of providing access to maps. The current system is structured hierarchically—users need to log on to their group, and within their group they can create any number of tasks and maps within tasks. There are no naming conventions to tasks or maps and no supplementary information to help users remember which task or map is the latest. Further, the map-task relationship is hidden. That is, there is no option to explicitly show all the tasks and maps associated with those tasks. Instead, users select a task first, and only then are the associated maps displayed. Other usability issues were limited screen real estate, confusing map access, complicated login functionality, and system crashes.

However, despite these shortcomings, most students were able to use the system. This interpretation is supported by our on-site observations, the teacher, and our usability test. A performance usability test administered to students at the end of the study showed that, in general, students were able to independently carry out major task and mapping functions; however, a positive relationship was found between the amount of time a student was at the keyboard and the amount of help needed during the usability task, suggesting that fluency with the authoring system is associated with practice using it.

The target user for our authoring system is the teacher or other end user who is interested in creating assessments. As expected, the teacher reported using the authoring system to specify tasks for testing purposes. However, unexpectedly, students also benefited from using the authoring system. We originally viewed students as beta testers who were using the authoring system to complete their group research project. The teacher reported that student authoring promoted ownership of work. Compared to the prior year when students used paper-and-pencil mapping, the teacher believed students using the authoring system this year created more sophisticated knowledge maps, especially in the sophistication of the links specified by students. This anecdotal report is bolstered by the analyses of the types of links used in the student-authored maps, which showed that 38% of the links across all student-authored maps were causal or functional.

Our initial prototype authoring system was, in general, a success. We have identified several issues that need to be addressed in future versions of the authoring system. This study addressed the basic issues of usability and functionality. Our long-term interest is to integrate validity functionality into the authoring system itself; that is, to aid end users in ensuring that validity criteria are addressed—cognitive complexity, linguistic appropriateness, transfer and generalizability, content quality, reliability, and instructional sensitivity. In doing so, we expect end users to develop high-quality assessments appropriate for the intended purpose.

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APPENDIX A
PRETEST TEACHER INTERVIEW MEASURE

Usability Study
[Name, date]

Pretest Interview Questions

#	Question	Construct
1	Why did you use concept mapping in your classroom last year? What do you see as the main advantages and disadvantages, both for you and for students? - Interconnection among subject areas? - Collaboration? - What skills were developed or improved? - What attitudes were changed? - How did student learning improve due to use of concept maps? - Were the concept maps an effective teaching or assessment tool?	General questions to get info. on why teacher is using concept mapping.
2	Describe how you used concept mapping in your classroom last year (manual, paper-pencil version). - Which topics? - Group vs. individuals? - Actual process of creating terms, links, assigning questions to groups, group presentations, etc. -- describe in detail we need to paint a picture of paper-pencil so we can contrast w/computer authoring system. - How easy was it to create the concept maps last year?	**Provide point of contrast for post-interview.** Provide pre-authoring system description of use. Last year the teacher used concept mapping with paper and pencil. We want to see how things remain the same, how they differ.
3	Describe any difficulties or challenges in the instructional process, materials, or instruction. - How long did it take to prepare materials (teachers and students)? - How many days did students engage in the concept mapping activity?	**Point of contrast w/use of authoring system.** Specifics about implementation.

#	Question	Construct
	- Was the revision process cumbersome so as to take away from instructional time? - Give examples of successful use. - Give examples of unsuccessful use.	Identify strengths and weakness of manual process. Need to identify advantages of authoring system.
4	How do you plan to use the authoring system this year?	Anticipated use. Point of contrast for actual use. May yield interesting findings in terms of "surprises."
5	What advantages and disadvantages of the authoring system do you anticipate: - For students? - For teachers?	Anticipated use. Point of contrast for actual use. May yield interesting findings in terms of "surprises."
6	Can you provide samples of instructional materials related to the concept mapping activity? - Time to generate materials (if relevant).	Sample materials related to manual concept mapping activity. Again, point of contrast for authoring system.

APPENDIX B
POSTTEST TEACHER INTERVIEW MEASURE

Usability Study
[Name]
Pretest: [Date]
Posttest: [Date]

Posttest Interview Questions

#	Question	Construct
1	Please comment on how you used the authoring system and concept mapping in your classroom this year with the computer. - Actual process of creating terms, links, research, creation of groups, group presentations, etc. -- describe in detail we need to paint a picture of computer use so we can contrast w/paper-pencil method used last year.	Current use of system. We want to compare the use of the authoring system with the manual method.
2	Please compare this year with last year (i.e., use of the computer authoring system and concept map vs. the paper-pencil/manual) on the following: - Difference in the amount or quality of students' concept maps compared to last year. a) more efficient? b) more abstract? c) more conceptual maps? d) more meaningful? e) more understanding? - Difference in the amount or quality of student learning compared to last year. a) more efficient learning? b) more conceptual learning? c) more conceptual maps? - Group processes compared to last year. a) was there something special about the computer that made kids work more/less or better/worse? b) nature of kids interacting w/each other—how different?	These questions deal with the instructional impact of the authoring system.

#	Question	Construct
	c) extent of learning—how different? - Difference in student attitudes toward the activity compared to last year. - Teaching effectiveness compared to last year. - Ease of creating concept maps compared to last year.	
3	Please comment on your experience and your students' experience with the authoring system: - Did you receive CRESST help? If so, please describe the type of help, the amount of help, and the quality of the help. - Was it enough? How could it be improved? - How easy was it for you to use? Do you think you could use it effectively? - How easy was it for your students to use? Did they like it? - How could the authoring system be improved?	
4	Overall, please describe the 3 most important advantages and 3 most important disadvantages to the use of the authoring system.	Take-away message.

APPENDIX C

TEACHER BACKGROUND SURVEY

UCLA Center for the Study of Evaluation (CSE)
Graduate School of Education & Information Studies

Knowledge Map Authoring System
Pretest Teacher Interview

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1. **Gender:** [ ] Male [ ] Female

2. **Ethnicity:**

[ ] African American	[ ] White, non-Hispanic
[ ] Asian American	[ ] Biracial/multiethnic
[ ] Latino	[ ] Other ___________
[ ] Native American	

3. **What grade level(s) do you teach this year? Check all that apply.**
   [ ] 3 [ ] 4 [ ] 5 [ ] 6

4. **What is the highest degree you have received?**

[ ] Bachelor's + Teaching Credential	[ ] Master's + units beyond
[ ] Bachelor's + units beyond	[ ] Doctorate
[ ] Master's	[ ] Other (specify)

5. **Your teaching experience, counting this year:**
   Years of teaching: _____ yrs
   Years at this school: _____ yrs

6. Please list the subject area(s) you plan to use the authoring system for and the number of years you have taught the subject.

Subject	**No. of years taught**
______________________________	__________
______________________________	__________
______________________________	__________

How many years have you used technology in each of the following ways?

7. Assigned computer tasks to students in your classes. ______ yrs

8. Used computers for your own school work (grading, making handouts, etc.). ______ yrs

9. Used the Web to gather information or do research for school-related activities. ______ yrs

10. Used computers for your personal use (not school-related activities). ______ yrs

11. About how many computers do you have in your classroom?
Number of Macintoshes: _____

Please mark the extent to which you agree or disagree with each of the following statements.

		Strongly Agree	**Agree**	**Disagree**	**Strongly Disagree**
12.	Computers and appropriate software are readily available for teacher use.	[ ]	[ ]	[ ]	[ ]
13.	Computers and appropriate software are readily available for student use.	[ ]	[ ]	[ ]	[ ]
14.	I have someone to turn to if I need help with computer hardware or software.	[ ]	[ ]	[ ]	[ ]
15.	I have the skills needed to help others with computers.	[ ]	[ ]	[ ]	[ ]

16. On average, about how often do you have your students use computers?
[ ] 2-3 times a week [ ] Weekly [ ] Monthly [ ] 2-3 times a school year [ ] Yearly

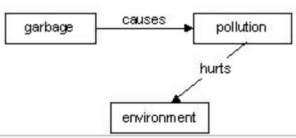
APPENDIX D
USABILITY TASK

Name:______________________

Group:______________________

Class: Morning or Afternoon (circle one) Posttest Usability Study

Please create a concept map using the terms and links given below. The purpose of this activity is to see how familiar you are with the Authoring System. This information will help us improve the Authoring System for next year. Thank you for your help.

DIRECTIONS	FOR UCLA USE ONLY				
1. **Log into the Authoring System** http://cdi.cse.ucla.edu/author/login.html		Re-mind	Teach or Explain	Do	Other
2. **Use the Authoring System to create a Map Project with the following terms and links:** Description: *XXXX* (*XXXX* = your name) Terms: *garbage, pollution, environment* Links: *causes, hurts*	Selecting major option	☐	☐	☐	
	Selecting sub-option	☐	☐	☐	
	Entering data	☐	☐	☐	
	Updating DB Other	☐	☐	☐	
3. **Use the Authoring System to create this concept map:** Description: *XXXX* (*XXXX* = your name) 	Selecting major option	☐	☐	☐	
	Selecting sub-option	☐	☐	☐	
	Naming map	☐	☐	☐	
	Use mapper Other	☐	☐	☐	