The Digital IdeaKeeper: Extending Digital Library Services to Scaffold Online Inquiry

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ABSTRACT

Online inquiry is an important way of engaging learners in information-rich activities using online sources to explore questions in different fields, such as science. Online inquiry involves a set of interrelated activities, such as planning an investigation; seeking, analyzing, and making sense of online information; and synthesizing information into a final argument. However, learners may encounter several obstacles in trying to tackle an open-ended, complex process like online inquiry. Digital library services support information seeking, but do not necessarily support the full range of online inquiry activities. Therefore, using a learner-centered design approach, we are developing the Digital IdeaKeeper environment to extend digital libraries by integrating different tools and incorporating different scaffolding approaches to help learners effectively engage in online inquiry. IdeaKeeper provides an "online inquiry context" for the full range of online inquiry activities, supporting analysis of the articles found in a digital library, and synthesis of different resources to develop arguments addressing the questions they are investigating.

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1. INTRODUCTION

Major science education standards (e.g., American Association for the Advancement of Science, 1993; National Research Council, 1996) call on students to engage in inquiry-based science learning where they pose driving questions, plan their inquiry, collect and analyze information, and synthesize their findings into an argument. Others note the importance of developing "information literacy" skills, where inquiry serves as a means for people to understand the need for particular information and effectively find and use information to address some issue or decision (Roes, 2001).

We can consider *online inquiry* to be a type of inquiry where learners search for and use information gathered from different online sources to answer questions. Digital libraries can be a key part of online inquiry by providing access to a vast array of information in a wide range of content areas. While many digital libraries have been geared towards expert audiences (e.g., scientists, researchers, etc.), there is a growing focus on developing digital libraries to support learners and inquiry-based activities. There are efforts to develop digital libraries that support search and information management approaches for children (e.g., Druin et al., 2001), and educationally oriented information collections. For example, the National Science, Mathematics, Engineering, and Technology Education Digital Library (NSDL) project (Zia, 2000), an effort by the National Science Foundation to develop wide-ranging digital library software and collections, has an area of focus on the educational objectives of learners from K-12 to graduate students.

But while digital libraries serve a vital purpose, they only address one aspect of online inquiry. Learners with less inquiry experience need additional functionality and support to engage in the full range of online inquiry activities. Open-ended, complex inquiry is difficult for learners. Aside from searching a digital library for information, learners need to plan their inquiry and information needs, analyze and make sense of the information they find, and connect the information they find to address their questions. Rather than simply focusing on search, many feel that digital library services should be extended and augmented to fully support the range of information needs in substantive online inquiry (Marchionini, 1999; Wattenberg, 1998).

Our previous work has involved exploring and articulating a learner-centered design (LCD) approach to design *scaffolding* in software that helps novice learners engage in complex, intellectual activities in a manner conducive to learning (Quintana, Soloway, & Krajcik, 2003). Along these lines, we are currently exploring scaffolded software to support online inquiry with the *Digital IdeaKeeper*, a Java-based scaffolded work environment aimed at supporting middle-school learners through the complexities of online inquiry (Figure 1). IdeaKeeper integrates digital library services with services for inquiry planning, information search, analysis, and synthesis in a single scaffolded environment for learners.

In this paper, we introduce the IdeaKeeper and describe our goals for a single overarching software environment supporting the range of online inquiry activities. We will begin with an overview of our design context and learner-centered design approach. We will then outline a description of the online inquiry process

and some major areas where learners need support to effectively engage in the process. Given this overview of the complexities learners face in online inquiry, we will describe the IdeaKeeper environment, noting how different features of the software serve to address these complexities. Finally, we will conclude with our current plans for IdeaKeeper and some final remarks.

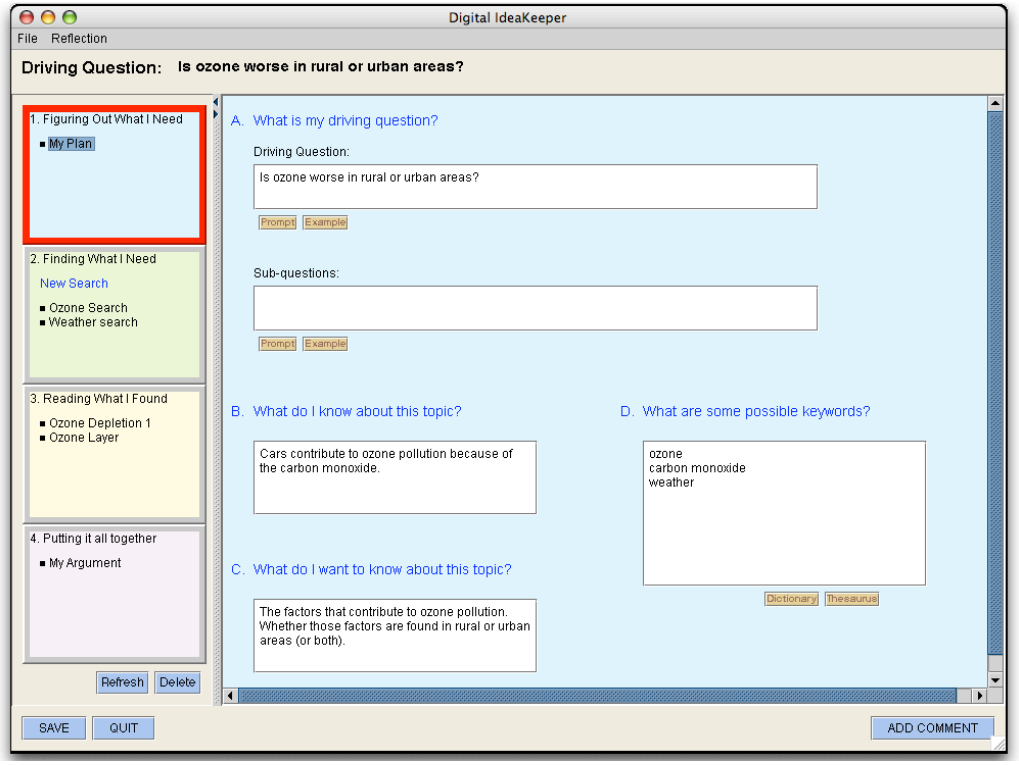

Figure 1
Main screen for the Digital IdeaKeeper

2. A LEARNER-CENTERED DESIGN APPROACH TO SCAFFOLD LEARNERS

Before specifically describing the IdeaKeeper environment in detail, let us briefly discuss more generally how we can approach software design to support the specific needs of learners. We adopt a learner-centered design approach that goes beyond simply addressing software usability to also identify the specific needs learners have as they engage in challenging tasks for which learning is a goal, and then designing software to meet those needs and support that learning (Soloway, Guzdial, & Hay, 1994).

The LCD approach involves designing software that incorporates scaffolding to support learners in their learning tasks. Scaffolding is not inherently technology-based. Rather, the traditional view on scaffolding defines it as the manner in which a teacher or a more knowledgeable peer enables learners to engage in activity that would otherwise be too difficult for them (Wood, Bruner, & Ross, 1976). Furthermore, that assistance should help

learners engage in some activity without making that activity too easy or automatic to perform since too much simplification would be detrimental to learning (Reiser, In press). Similarly, scaffolded software can provide similar assistance to learners. Consider the following example from IdeaKeeper:

- *Context*: Students trying to engage in online inquiry have a range of activities to perform, from planning, to finding and making sense of information, to writing an argument using the information they have read.
- *Learner Obstacle and Support Need*: However, students lack an expert's conceptual understanding of the online inquiry process, thus they do not know what activities make up a complex, open-ended investigation. Therefore, learners need information about their activity options to help them see which inquiry activities are possible.
- *Conceptual Scaffolding Strategy*: One conceptual scaffolding guideline addressing this need is to provide structure for complex tasks and functionality by describing complex tasks with ordered and unordered task decompositions (Quintana et al., In press).
- *Scaffolding Implementation*: One way to implement this scaffolding strategy in software is by visually describing the space of activities in a process. For example, the main IdeaKeeper screen contains an activity sidebar (Figure 2) that visually describes the space of possible online inquiry activities that students should perform.

Using this example, we can see a scaffolding description has many aspects to it. Given some sort of learning activity, scaffolds should address some learner need, i.e., a cognitive obstacle learners face when they try to engage in new activity. Learner needs can be informed by the literature or from other observations of learners. A conceptual scaffolding strategy defines how a designer might address the learner need. Scaffolding strategies can be informed by research in education, knowledge about the nature of learners, etc. The scaffolding strategy is then implemented in software. There can be different ways that a scaffolding strategy could be implemented (e.g., the activity sidebar could have been a visual map or a list in a menu). The key is that a scaffolding implementation should help learners overcome some stated cognitive obstacle, so scaffolding approaches must be tied back to the difficulties faced by learners.

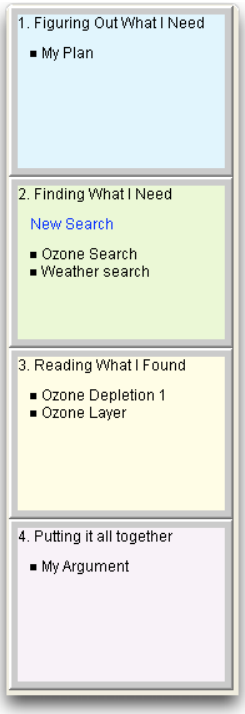

Figure 2
IdeaKeeper activity sidebar

Therefore, our LCD process incorporates different design activities to inform the design of scaffolded software (Quintana et al., 2003). The process involves:

- Understanding the kind of activities learners will engage in (e.g., what are the activities in online inquiry?).
- Identifying the different areas where learners will encounter obstacles in doing those activities.
- Determining the scaffolding strategies to address each obstacle.
- Designing an aspect of the software to implement the scaffolding strategies for the target audience.

This brief overview encapsulates the approach we took as we looked at supporting learners in online inquiry. We will now briefly describe our design approach to prepare for a description of different IdeaKeeper features as we look at online inquiry activities and the broad areas where learners need support in online inquiry.

3. ACTIVITIES AND LEARNER NEEDS FOR ONLINE INQUIRY

Broadly speaking, we can define inquiry as a set of interrelated processes where scientists (and learners) pose questions about the world and perform investigations to explore those questions (National Research

Council, 1996). We consider online inquiry to be an approach where learners gather information primarily from online sources during their investigation. There are similar descriptions of online inquiry (e.g., Grover, Fox, & Lakin, 2001; Harada & Tepe, 1998; Jukes, 2000), but we can generalize online inquiry as consisting of the following interrelated activities:

- *Inquiry planning* involves articulating a driving question to investigate and setting some information goals by thinking about what kind of information might be needed to answer the driving question.
- *Information seeking* involves searching for information given the investigation goals. This is the primary activity traditionally supported by digital library services.
- *Information analysis* involves reading, analyzing, and trying to make sense of the different pieces of information obtained in the information-seeking phase.
- *Information synthesis* involves comparing and connecting the different pieces of information and notes to form an argument addressing the driving question.

There is certainly much work in digital libraries that supports information seeking, especially ways to facilitate searching and information management. There is work that describes what learners do during their information seeking activities (Abbas, Norris, & Soloway, 2002; Wallace, Kupperman, Krajcik, & Soloway, 2000). Additionally, there is work on other individual activities involved in online inquiry, such as support for the various reflective aspects of inquiry (e.g., Davis, 2003), and supporting synthesis and argumentation in an inquiry context (e.g., Sandoval, Bell, Coleman, Enyedy, & Suthers, 2000; Suthers, Weiner, Connelly, & Paolucci, 1995). However, in terms of supporting learners with the broader activities that involve using information, we see that there are still areas where learners need support to effectively engage in online inquiry.

3.1 Learners lack a full "inquiry context" in their tools.

We see that online inquiry can demand that learners use a range of cognitive and metacognitive skills. Learners have to make and readjust plans; find, make sense of, and assess information according to those plans; and connect different pieces of information together. Without supporting all the activities in online inquiry, and the connections that lie between this interrelated set of activities, learners can be hampered with the complexity of the overall inquiry process. In order to address this complexity, learners may oversimplify their tasks and

translate online inquiry into an exercise of simply scanning to find text that might suffice as a "right answer" (Wallace et al., 2000).

Traditionally, digital libraries are standalone services that, while being crucial for information seeking, tend to be divorced from the rest of the online inquiry process. As a result, learners may have difficulty monitoring their online inquiry given the different activities and pieces of information they are dealing with while they are using digital library services. For example, as learners use a digital library, they have to also constantly keep track of the inquiry goals during their investigation, plus manage different pieces of information (e.g., bookmarks, notes, etc.) as they move towards answering their questions.

For successful online inquiry, learners essentially need to engage in and connect between a range of different activities, which is not something that digital library services necessarily support. Since learners need to access and connect information from different inquiry activities, they need tools that provide a more overarching "inquiry context", giving them a single place where they can monitor their questions, goals, activities, and the information they find and analyze to develop substantive answers to their driving questions.

3.2 Learners need support for information analysis.

Digital libraries support information seeking by giving learners access to a range of resources. However, digital libraries are not designed to help learners read, analyze and make sense of the information they retrieve from those libraries. Finding extensive information is only half the battle; if learners cannot understand the information they find and tie it to their driving question, their inquiry will be unsuccessful.

Learners can encounter several problems when trying to read texts. One problem is that they may not have a sense of how to purposefully scan and read the information they find. Learners can have trouble understanding the structure of complex documents, and thus read without any clear purpose or direction (Chapman, 1993). Learners also do not know what cues or content to look for in the document structure, or how to judge a document for relevance (Readence, Bean, & Baldwin, 2000). Furthermore, if we consider electronic texts, such as the web-based articles returned by most digital libraries, we see that learners may find it difficult to direct their reading in productive directions due to the distractions arising from hyperlinks to other webpages, enticing images and animations, and dramatic differences in complexity, length, and readability (Wallace et al., 2000).

Therefore, learners need more than the information seeking functionality found in digital libraries. Learners also need support to help them make sense of the information they find with respect to the driving question they are trying to investigate.

3.3 Learners need support for information synthesis.

Similarly, if the aim of online inquiry is to address some overriding driving question, learners need to also deal with the information synthesis activity to develop an argument answering their question. Again, while some digital libraries do support saving certain potentially useful documents for later review, they are not designed to help people connect different pieces of information to develop an argument.

As with information analysis, learners also need support for information synthesis. Often, learners can encounter significant difficulty integrating multiple resources into a coherent argument. Because of the complexity arising when developing a rich argument, students may instead try to rely on a single resource from which they copy information for their argument rather than synthesizing information from different resources and writing their argument in their own words (Oliver & Hannafin, 2000).

Therefore, learners need synthesis support to develop a sound argument. Learners need help to look at different sources of information, make comparisons, and other connections between the sources that they have found and analyzed.

4. IDEAKEEPER: EXTENDING DIGITAL LIBRARIES FOR ONLINE INQUIRY

Having detailed different areas where learners need support for online inquiry, we began exploring some scaffolding approaches for the IdeaKeeper project. The goal of the IdeaKeeper is to combine the increasing number of learner-oriented digital library collections with services and scaffolding in an overarching online inquiry environment. The IdeaKeeper aims to support middle-school learners through more open-ended inquiry activity so they can find *and use* information in digital libraries to pursue substantive driving questions. Here we describe different aspects of the IdeaKeeper and show how they address the broad learner needs that we outlined.

4.1 Providing an integrated online inquiry environment.

We have described IdeaKeeper as a scaffolded work environment, an integrated software environment that incorporates a range of scaffolding approaches and software tools to support a multi-faceted process like online inquiry (Quintana, Wells, & Soloway, 2002). IdeaKeeper follows this model by providing workspaces for inquiry planning, digital library searching, information analysis, and information synthesis. Each activity workspace integrates the necessary tools and support needed to help learners engage in the given activity.

The planning workspace provides an area for learners to set up the driving question and questions that they will investigate. Additionally, the planning workspace implements different features to help learners stop and think about their question and information needs before they begin doing any searches. For example, the planning workspace implements aspects of the KWL strategy (Ogle, 1992) used by teachers to help students trigger their prior knowledge about a topic and describe what they want to learn about that topic. Once learners have taken some time to think about their problem and information goals, the planning workspace also provides them with an area to brainstorm some potential search terms before they begin their searching activities.

The information seeking workspace is where learners use a digital library to search for information. The workspace allows learners to review and refine the search term list they brainstormed earlier and then use those terms as queries for searching a digital library. In its initial version, IdeaKeeper integrates the Digital Library for Earth System Education (DLESE) (Digital Library for Earth System Education), a NSDL-affiliated digital library for earth science. (Note that the IdeaKeeper architecture has been designed in a way that allows other digital libraries to be integrated in the future.)

The final two IdeaKeeper workspaces support information analysis and synthesis. Those workspaces will be described more fully in the following sections.

Creating a single environment can help learners reflect on, view, and share important information about their inquiry throughout all the stages of their work. Inquiry is an interrelated set of activities, so by supporting all learner activities in one environment, learners can see and share related information throughout the inquiry process (e.g., articulating the information goals in the search workspace to direct subsequent search activities). Digital libraries can be situated within the specific area where learners need to search for information, but can be augmented by tools and other support in an organized manner to support the full inquiry process.

Certainly, learners could use separate tools for the same purpose. However, a single integrated environment allows learners to avoid other complexities that would result from trying to use separate tools in a fragmented process:

- Using individual activity workspaces is one way to implement a scaffolding strategy about constraining an activity space by using functional modes (Quintana et al., In press). Such a model can help learners focus on their given activity without being overwhelmed by the full set of tools and activities.
- Working in one environment lets learners keep all the artifacts they use during inquiry (e.g., plans, search hits, notes, arguments, etc.) together in one place. Having software facilitate the organization of work products is one scaffolding strategy addressing a management "chore" for learners so they can focus on the more important aspects of their inquiry (Quintana et al., In press). IdeaKeeper maintains all the artifacts that learners save throughout their inquiry in the activity sidebar (e.g., the two website articles and two sets of search results shown in figure 2) so that learners can easily access those artifacts.
- Also, with a single integrated environment, learners can easily see the different activities involved in the overall process, making the process more manageable. This was illustrated in our initial scaffolding example of the sidebar presented earlier in section 2.

Other related projects take an integrated approach to develop wide-ranging software environments. Examples include the Knowledge Integration Environment (Linn, Bell, & Hsi, 1998) and its successor, the Web-based Inquiry Science Environment (Linn & Slotta, 2000); BGuILE (Reiser et al., 2001); and Symphony (Quintana, Eng, Carra, Wu, & Soloway, 1999). These projects address different aspects of science inquiry, and the IdeaKeeper project follows along these lines to extend digital libraries for online inquiry.

4.2 Supporting Information Analysis

After learners have searched a digital library and received a list of resources to review (e.g., web-based articles), they must read the articles to look for information that will bear on their investigation and help them arrive at some answer to their question. The information analysis workspace in IdeaKeeper supports learners with information analysis to help them make sense of the different information resources.

When learners open a new article to read from the article list returned by the digital library, IdeaKeeper displays the article in a browser window that is framed by a *scaffolded notepad* (Figure 3). The primary focus of the notepad is to support learner reflection on the articles they are reading, and learner articulation of different notes and other information about the article. The notepad has two major areas that implements these different scaffolding approaches.

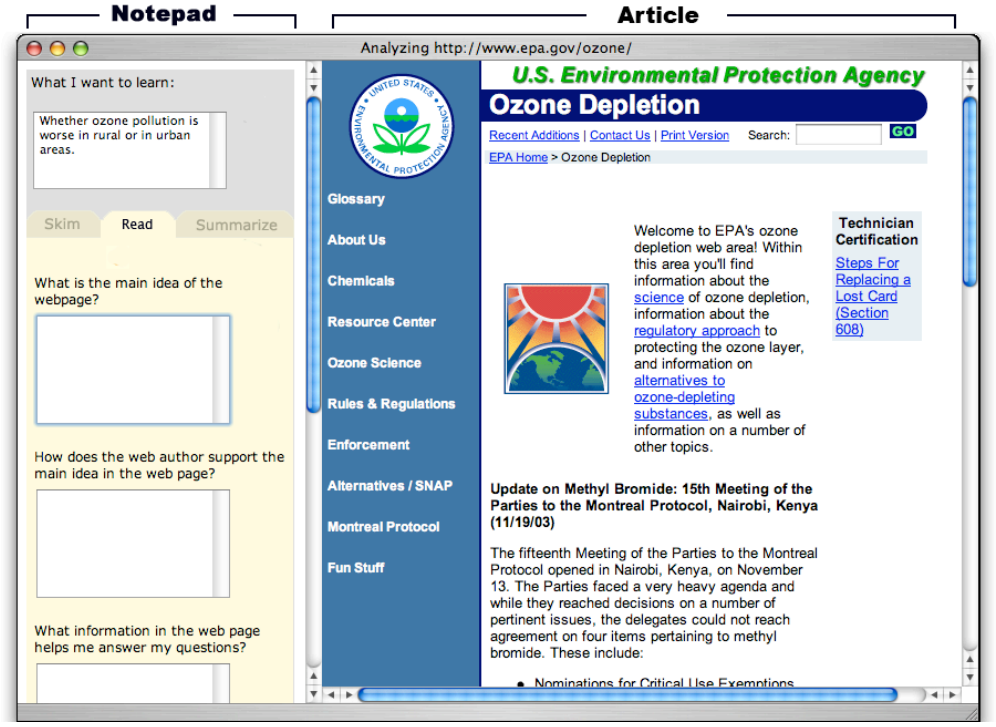

Figure 3
Browser window with scaffolded notepad and the article being read

The top of the notepad displays the "What do I want to learn?" information that the learners entered earlier in the planning workspace (i.e., the KWL information stating the information goals, or what the learners want to know). Since learners may read without any specific direction, the intent of this field is to remind them of their information goals so they keep in mind what kind of information they are looking for as they read.

The "Skim-Read-Summarize" portion of the notepad is a structured area that contains prompts and notetaking areas for analysis. Here, the notepad implements the "process visualization" scaffolding strategy we noted earlier to display an unordered decomposition of analysis tasks (i.e., the tabs correspond to the tasks). Learners are first directed to the "Skim" tab, where they see different criteria to consider whether the article is worth reading by looking at how credible the article is or how relevant it is to the information goals. Learners can

then move to the "Read" tab where they have different questions to answer about the article (Figure 4). Finally, after reading the article, learners move to the "Summarize" tab where they summarize what they learned from their reading. Reflection and articulation are important cognitive activities for learning. The notepad text prompts and text areas implement different scaffolding strategies to facilitate productive articulation and highlight epistemic features of scientific practices (e.g., describing the important things experts might think about as they analyze information) (Quintana et al., In press). The content of the text prompts is informed by techniques from research on general reading strategies and comprehension (e.g., Brozo & Simpson, 2002; Farstrup & Samuels, 2002; Pressley & Woloshyn, 1995).

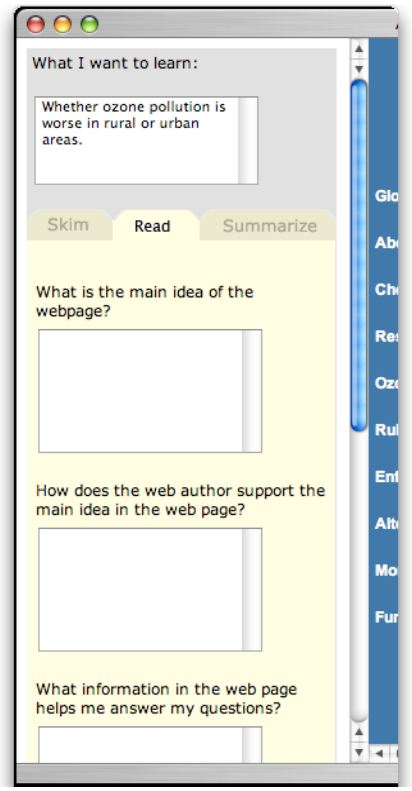

Figure 4: Detailed view of notepad (in "Read" view)

Finally, the notepad mechanism also helps learners manage the different articles they read and notes they write. IdeaKeeper automatically saves the article/notepad pairs as a single unit—a "digital notecard". When learners save a workspace, both the article and the accompanying notepad contents are saved together under a single name displayed in the sidebar. When learners reopen an article, the analysis workspace displays the article

with the specific notes learners wrote about that article in the notepad. Again, this implements a scaffolding strategy about organizing work products so that learners will have easy access to these products.

Other tools have similar structures that allow learners to keep notes on articles they read, although they are implemented in a less structured way. The Artemis Digital Library (Wallace et al., 2000) gives students some note areas in the library interface. However, the note areas are not structured nor directly connected to the websites that students view. Thus it can become an unwieldy for students to simultaneously review both their notes and the website.

4.3 Supporting Information Synthesis

While an information analysis workspace supports learners in taking a detailed look at an individual article, learners also need to synthesize and connect information over several articles to make headway in their investigation. IdeaKeeper also incorporates an information synthesis workspace where learners can compare information, make a claim about their question, and develop an argument.

The synthesis workspace has different views that allow learners to compare notes and begin developing their argument. The top portion of the workspace (Figure 5) is an area where learners can display and compare the notes from different notepads (i.e., compare from different articles that learners read). Learners can simultaneously display multiple notes from up to four notepads, and compare the notes from the "Read" or "Summarize" areas of those notepads.

The bottom area of the workspace contains a tabbed area. The first tab takes learners to the "Claim" area where they review their driving question and sub-question, and propose a claim, or a proposed answer to the question (Figure 5). The combination of the comparison area and the claim area implement a scaffolding strategy to facilitate articulation as learners are trying to make sense of previous work and articulate their current understanding in the form of a possible answer to their question (Quintana et al., In press).

The second tabbed area in the synthesis workspace allows learners to use a concept mapping tool similar to argumentation tools like Belvedere (Suthers et al., 1995) to create a visual concept map outlining their argument (Figure 6). The concept map allows learners to describe how different information resources connect to their claim about the driving question. Learners can represent the articles that support or contradict their claim by

linking in digital notecards from their analysis activity. Then as learners develop their concept map, they can move to the third tabbed area, which allows them to write out their argument textually.

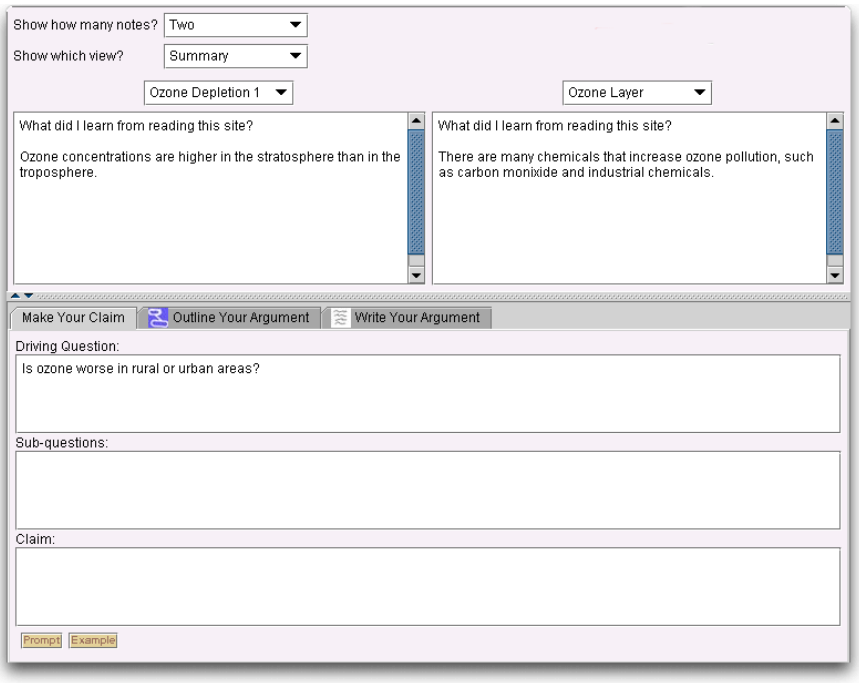

Figure 5
Information synthesis workspace with "Compare" area on top and "Claim" area on the bottom

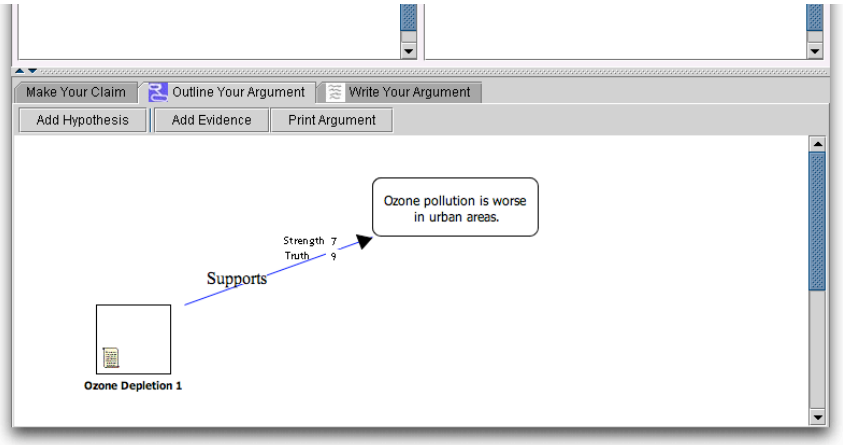

Figure 6
Concept map area of the synthesis workspace

5. FUTURE PLANS AND CONCLUDING REMARKS

After gathering teacher feedback and design suggestions for IdeaKeeper, we are currently pilot testing it with small groups of 8th grade students to look at mainly at usability issues. We also want to see how students use IdeaKeeper for their inquiry, and gather their opinions on the software.

Following the pilot testing, we will revise the software for larger-scale tests in middle-school science classrooms, where students will use IdeaKeeper for longer-term inquiry projects. Here, testing will be more in-depth, as we consider the "effect of" and "effects with" the software (Salomon, Perkins, & Globerson, 1991), taking a close look at how students work with the different scaffolded features to do their online inquiry and what they are learning both about the content area and online inquiry. Some items we will be looking for include how learners plan their inquiry and whether they use this information throughout their investigation, how they read articles given the presence of the notepad to look for improvements over learners that may not use a notepad, whether learners take more notes (and better notes) with the notepad, how learners use their notes and information to develop an argument, and what learners learned about the online inquiry process after using IdeaKeeper.

Given the feedback we receive in the different testing phases, we will continue to refine and expand IdeaKeeper functionality and scaffolding, and eventually we hope to integrate IdeaKeeper with other NSDL libraries to support inquiry in different content areas. In the end, our aim is to not only develop an effective inquiry tool for learners, but also to show how digital libraries can be extended and enhanced, coming closer to the "sharium" concept (Marchionini, 1999) that can help learners engage in inquiry activities and truly use information effectively to answer substantive questions in a range of disciplines.

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