

Linking Learning Goals and Educational Resources through Interactive Concept Map Visualizations

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Abstract. Concept browsing interfaces can help educators and learners to locate and use learning resources that are aligned with recognized learning goals. The Strand Map Service enables users to navigate interactive visualizations of related learning goals and to request digital library resources aligned with learning goals. These interfaces are created using a programmatic web service interface that dynamically generates interactive visual components. Preliminary findings suggest that these library interfaces appear to help users stay focused on the scientific content of their information discovery task, as opposed to focusing on the mechanics of searching.

1 Introduction

For the past decade there have been a series of reform recommendations in science education calling for more emphasis on inquiry-based pedagogies, and for the development of science curriculum that emphasizes student understanding and making connections between the ideas and skills students develop over time [1, 2]. Educational standards have emerged as a driving force behind these reform efforts. Central to the standards movement is the need for a description of the essential understandings that all students should attain. Within the United States, the *Benchmarks for Science Literacy*, developed by the American Association for the Advancement of Science (AAAS), and the National Science Education Standards (NSES), published by the National Research Council, present a clear description, at the national level, of what all students should know and be able to do across a spectrum of science, mathematics, technology, and engineering disciplines [1, 3].

A primary purpose of the National Science Digital Library (NSDL) is to help educators implement science education reforms [4, 5]. As collections in NSDL grow, a critical challenge will be to provide

library interfaces and services that enable educators, designers of curricular materials, and learners to locate resources that support recognized standards and to integrate these resources into coherent learning activities. Concept browsing interfaces, based on nationally recognized standards, can address this challenge by helping educators and learners to locate, comprehend and use educational resources in NSDL. These interfaces provide navigational and orientational cues that are typically lacking from traditional keyword or fielded search interfaces. Prior research indicates that concept map representations are useful cognitive scaffolds, helping users lacking domain expertise – such as learners, new teachers, or educators teaching out of area – to understand the macro-level structure of an information space [6, 7].

We are creating a web service interface to support the construction of concept browsing interfaces based on the learning goals articulated in *Benchmarks for Science Literacy* [1]. These learning goals, or *benchmarks*, describe what learners should know, or be able to do, at key stages in their education across the natural sciences, mathematics, technology, and social sciences. Strand maps provide a visual representation that emphasizes the coherence intended in the

benchmarks and invite both teachers and learners to make connections between ideas. The *Atlas of Science Literacy* [8], published by AAAS and the National Science Teachers Association, features strand maps on topics important to science literacy (e.g., weather and climate, flow of energy in ecosystems, or conservation of matter). Each map consists of node-link representations illustrating a set of relationships between benchmarks organized around a topic (Figure 1).

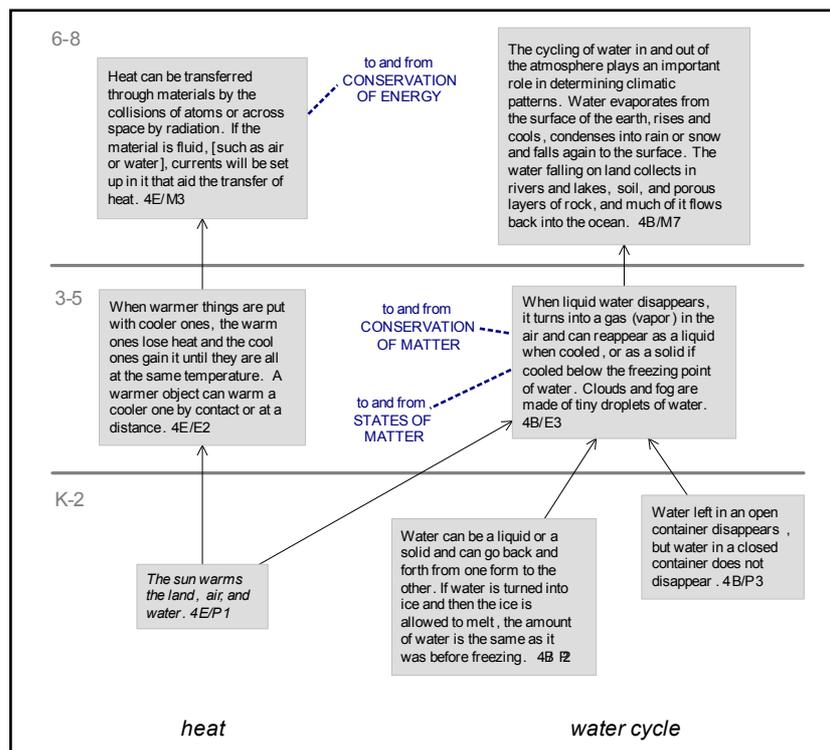


Fig. 1. This is a section of a map called “Weather and Climate.” The full map consists of 22 benchmarks, 7 of which are shown here. The arrows indicate how one benchmark supports the ideas in the next benchmark. Dotted lines show connections to other maps (e.g., Conservation of Matter).

High-level descriptions of the benchmarks are provided in the nodes, while the links depict the interrelationships between benchmarks. Each map contains vertical strands reflecting key ideas in that topic (e.g., heat, water cycle, atmosphere, and climate change are strands within the weather and climate map). Each strand is cross-referenced by grade levels (K-2, 3-5, 6-8, 9-12) to illustrate how student understanding develops over time.

2 The Strand Map Service

The Strand Map Service (the ‘Service’) builds on and extends the significant knowledge base embodied in *Benchmarks* and the *Atlas*.

The Service supports the needs of two audiences through the provision of two public interfaces: (1) graphical concept browsing interfaces for use by K-12 educators and learners and (2) a programmatic web service interface for use by digital library developers.

K-12 Educators and Learners

Strand maps are intended to help teachers and other educators design coherent and comprehensive curricula, plan instruction, develop and evaluate curricular materials, and construct assessment activities [8].

Maps also support teacher preparation and professional development: teachers report that their own content knowledge is improved by studying a map's connections and that maps provide a helpful perspective for reflecting on their own teaching practices (ibid). The Service is being designed to support these traditional uses of the paper-based maps, and to additionally enable educators and learners to locate educational resources that support particular learning goals through integration with digital library collections. Concept browsing interfaces supported by the Service enable K-12 educators and learners to:

- Discover educational resources that support nationally-recognized learning goals (benchmarks)
- Browse learning goals and their interconnections by exploring interactive, concept map visualizations
- Enhance their own content knowledge by examining background information on learning goals, such as prior research on student conceptions, related educational standards, and assessment strategies to check student understanding.

Digital Library Developers

A programmatic web service interface enables digital library developers to easily construct concept browsing interfaces appropriate to the needs of their specific library audiences using dynamically generated visual components provided by the Service. Thus, rather than creating static presentations of strand maps, the Service generates visualizations of maps and map components from information modeled in the Service. Some of these components provide different ways of viewing information specific to the AAAS information space, such as views of individual maps, strands, sub-strands (the intersection between a strand and a specific grade range), and benchmarks. Other components support different ways of navigating through this information space. These components were articulated and refined using a user-centered design process described in [9].

3 An Example – DLESE

Figure 2 shows a demonstrator created using the Service for the Digital Library for Earth System Education (DLESE – www.dlese.org). Users can browse this interface using the pull down menus or by direct manipulation of map elements. For instance, let's assume that a middle

school teacher named Holly is planning a new unit on climate for her 8th grade integrated science class. Holly chooses to view the *Weather and Climate* map by selecting it from the pull down menu. Browsing the map, Holly learns that understanding that the Earth's climate can change is a key concept for learners in this grade range to grasp. She zooms in on the *climate change* strand by selecting the strand name. Benchmarks in this strand indicate that it is important for students to understand that both human activities, such as logging, and natural disasters, such as volcanic eruptions, can cause the climate to change. She sees that it is important for her unit to emphasize that these changes are sometimes abrupt and sometimes gradual in order to lay the groundwork for studies of climate patterns in later grades.

Holly clicks on the benchmark about volcanic eruptions and climate change and elects to retrieve educational resources in DLESE that support this learning goal. As she looks through the search results, she starts to wonder how much her students need to know about volcanoes prior to starting this unit. She presses the related benchmarks button to view all the pre-requisite and subsequent benchmarks, drawn from across all the maps, related to the volcanic eruption and climate change

learning goal. She sees that there are several learning goals related to volcanism and plate tectonics that she will need to address in conjunction with this unit. Holly sees that this library interface really emphasizes the integrated nature of science and is excited about how she can use it to help make those connections in her own teaching.

This scenario illustrated the use of an example graphical user interface that can be created by developers using the Service. The next section describes the architecture of the Strand Map Service and how its programmatic web service interface can be used by library developers.

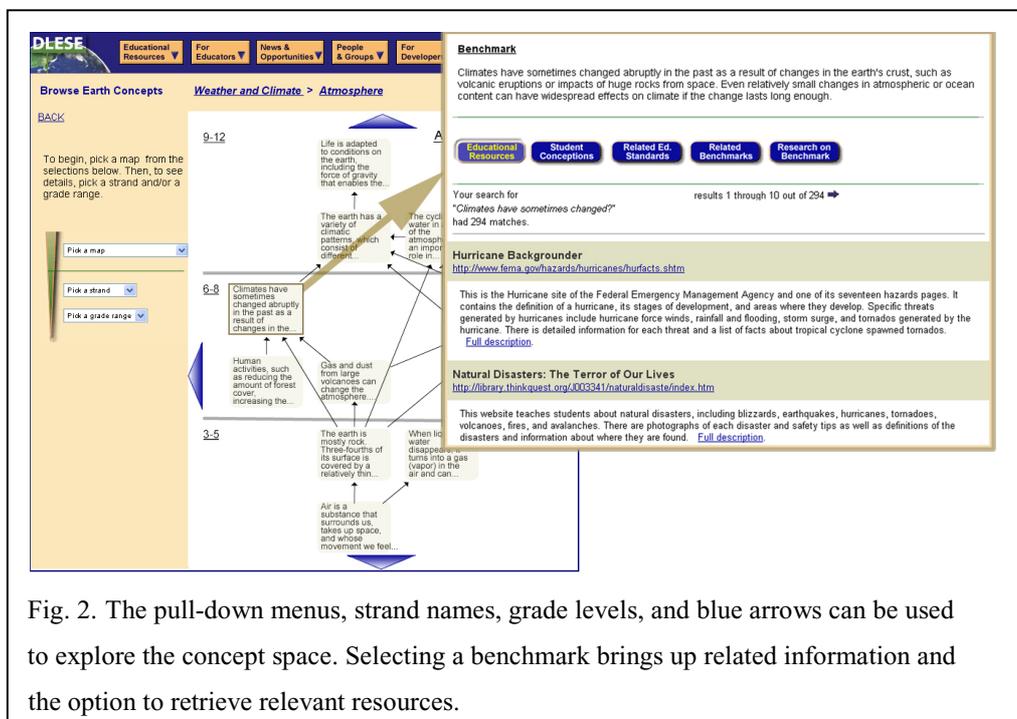


Fig. 2. The pull-down menus, strand names, grade levels, and blue arrows can be used to explore the concept space. Selecting a benchmark brings up related information and the option to retrieve relevant resources.

4 Service Architecture and Protocol

Our approach builds on recent advances in visualization components [10] and programmatic interfaces to knowledge organization systems [11]. Figure 3 illustrates the overall Service architecture. The Benchmarks Repository is a database housing the benchmarks, strand maps, and related information. Library developers create concept browsing interfaces by requesting information using the web service interface: the Concept Space Interchange Protocol (CSIP). When the user performs an action in a client interface, the interface makes an information request to the Strand Map Service, such as “retrieve all the benchmarks associated with a particular strand.”

The Service returns the requested information as XML or as Scalable Vector Graphics (SVG) [12], as specified by the developer at implementation time. Returning the information as XML provides flexibility, developers can use or display the information in any way they see fit. For instance, the pull down menus in the DLESE demonstrator interface used the XML option supported by CSIP; this DLESE-specific interface element was created by the developers to mimic menus in the rest of the library. Developers can request that this

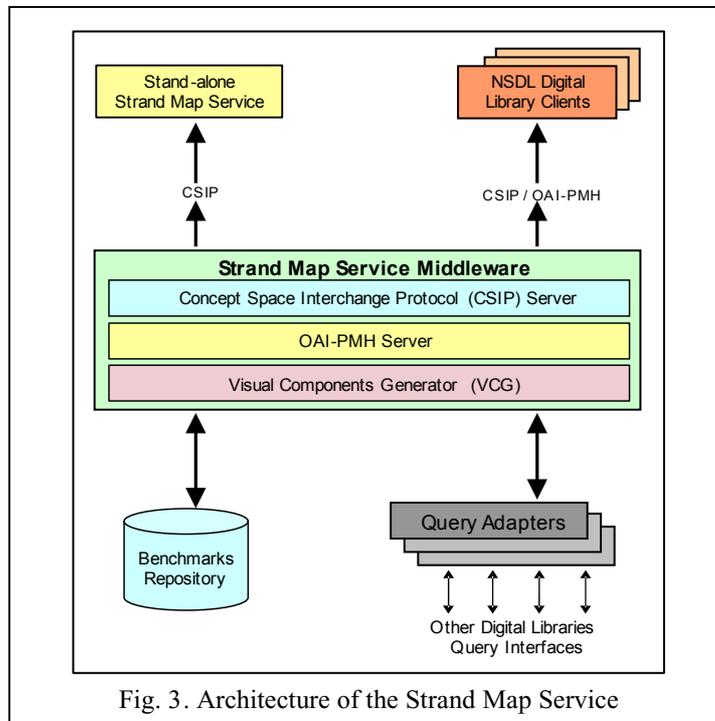


Fig. 3. Architecture of the Strand Map Service

XML information be returned in a specified metadata format: either the Service's native Concept Space Metadata Framework (CSMF) or Qualified Dublin Core. The SVG option enables developers to easily construct concept browsing interfaces from interactive visual components that are dynamically generated by the Service. Using this option, the same information is returned to the interface as in the XML option, but it is already embedded in a visual component that can be directly displayed and interacted with in the client interface. This option is used to create the views of the Weather and Climate map and the climate change strand used in the DLESE demonstration interface.

The Service middleware uses query adapters, designed to search over different collections within NSDL, in order to locate resources that support specific learning goals. The Service can retrieve resources in several ways. First, resources can be retrieved that are indexed as being aligned with a particular benchmark or benchmarks. Second, resources can be retrieved that are indexed as being aligned with one or more National Science Education Standards (NSES), using the mapping between the benchmarks and the NSES captured in the Benchmarks Repository. Third, resources can be retrieved using keywords and audience information corresponding to a particular benchmark or standard; this information is also modeled in the Benchmarks Repository. These methods can be used individually or in combination. For instance, the DLESE demonstrator uses a combination of the second and third methods to increase the precision of the returned results when searching over their collections.

The Concept Space Interchange Protocol

The CSIP design is based on the REpresentational State Transfer (REST) style of web architecture [13]. This architectural style reflects the stateless, document-centric view of the web. Each service request is

represented by a unique URL, and each request response is seen as a transfer of representation in the form of a document. CSIP supports three types of requests: (1) service description (which returns information about the capabilities and version of this instance of the Service), (2) submit resource (which is used to submit additional benchmark information to the Service), and (3) query (which is used to request AAAS information and visual components useful for creating concept browsing interfaces). Libraries developers initiate requests using either HTTP Get (for service description and submit resource requests) or HTTP Post (for query requests) with a unique URL associated with each of the three request types.

The protocol is divided into two parts: core and extension. CSIP-core supports a limited set of queries called content queries. A content query is similar to conventional queries where search is performed over textual data without assuming any semantics. CSIP-extension supports complex combinations of content queries using logical operators, and a specialized navigational query type. A navigational query makes use of the relations that are part of the AAAS concept maps; e.g., is-part-of or contributes-to-achieving. The navigational query starts from one

benchmark and finds all objects that are related to the benchmark through a specific relation. An example of a navigational query is to find the ‘nearest neighbors’, i.e., the prerequisite and subsequent learning goals for a particular benchmark, using the contributes-to-achieving relation. This type of query is used to retrieve *Related Benchmarks* in the DLESE demonstration interface. This query illustrates how the Service can be used to generate new visualizations, inherent in the Benchmarks Repository data model, that were never published in the AAAS books.

To illustrate how developers create concept browsing interfaces using CSIP, let’s consider three of the queries used to create the DLESE demonstration interface. In this interface (Figure 2), the left hand pull down menu displays all of the strand maps modeled in the Benchmarks Repository. The right hand frame displays requested map components dynamically generated by the visualization system in SVG. The generation of these left and right hand components is performed when the client interface initiates a CSIP query. In the DLESE example, the CSIP query used to generate the list of all strand maps shown in the pull down menu is:

```
<Query DetailLevel="Skeleton" Scope="Map" Format="SMS">
  <Content-Query></Content-Query>
</Query>
```

This query response returns all the maps in the Benchmarks Repository in the Service's native metadata format and this information is used to construct the list of the maps shown. When Holly selects the *Weather and Climate* map, the following CSIP query request is used to generate the graphical representation of the map rendered in SVG:

```
<Query DetailLevel="Detailed" Format="SVG" Scope="MAP">
<Content-Query>
  <Name MatchType="Equal">Weather and Climate</Name>
</Content-Query>
</Query>
```

As previously discussed, CSIP queries can also be used to generate new visual components that were never published in AAAS books. In the DLESE example, Holly's final action is to request a visualization of all the prerequisite and subsequent benchmarks, drawn from across all the maps, related to the volcanic eruption and climate change benchmark.

The following CSIP query request is generated when Holly presses the *Related Benchmarks* button:

```
<Query DetailLevel="Detailed" Format="SVG" Scope="Benchmark">
<Navigational-Query>
  <ObjectID>SMS-BMK-9023</ObjectID>
<Relation>
  <Prerequisite />
</Relation>
</Navigational-Query>
</Query>
```

In this navigational query, the “prerequisite” element in the “relation” field is used to retrieve all the benchmarks that have this kind of relation to the benchmark with the object ID of “SMS-BMK-9023”. All the benchmarks that meet this requirement are retrieved from the Benchmarks Repository and rendered in SVG.

5 Visualization System

An overview of the major components of the visualization system is provided in Table 1. We use the sample navigational query from the previous section to illustrate the functions of the visualization system components and how these components work together. The

Table 1. Overview of visualization system components.

User Request Analyzer Component:

- Receives CSIP query from the client
- Analyzes and transfer CSIP to graphical query

Data Resource Component:

- Parses graphical query to SQL Executes SQL Query
- Gets the result set from the database
- Converts the SQL result set to system defined data structure

Graph Layout Component:

- Embodies the visualization algorithm
- Refine the requested conceptual browsing interface
- Renders the result in SVG
- Wrap the result in CSIP response format

Rules and Aesthetics Component:

- Contains map drawing rules
- Represents the semantic constraints and the aesthetic heuristics
- Define the priorities guiding rule application

navigational query is first processed by the User Request Analyzer Component. The Analyzer parses this query, and initiates a request to the Data Resource Component to generate a visual representation using the target benchmark and other benchmarks related to it. The Data Resource Component uses an SQL query to retrieve the related benchmarks and the inter-relationships between these benchmarks from the Benchmarks Repository. The Data Resource Component then converts the SQL result set to a tree based data structure that sets the target benchmark to be the tree's root and other related benchmarks as its descendents. The Graph Layout Component uses the visualization algorithm described below to generate a 'draft' visualization. The Rules and Aesthetics Component refines this draft representation and the final result is rendered in SVG and wrapped as a CSIP response.

The core of the visualization system is the visualization algorithm used by the Graph Layout Component. The design goals for this algorithm were three-fold. First, the algorithm needed to generate all the visual components identified in earlier user-centered requirements studies as being desirable to support in CSIP v1.0 [9]. Second, the algorithm

needed to preserve both the semantics underpinning the strand maps and the aesthetic standards of the AAAS human experts who made the original maps. Third, the algorithm needed to extend the maps modeled in the *Atlas*, by representing interdisciplinary relationships between benchmarks and strands that cross map boundaries imposed in the two-dimensional paper-based publications. Prior research in graph drawing techniques informed the development of this algorithm since strand maps are a form of directed acyclic graphs (DAGS) [14]. Strand maps have unique features and aesthetics compared to other type of DAGS: they have a relatively small number of nodes, the node size is significantly larger in order to contain descriptions of the benchmarks, and the vertical and horizontal alignment of groups of nodes is an important semantic distinction that needs to be represented.

Our methodology for designing the visualization algorithm intertwined expert knowledge acquisition activities, to inform algorithm design and evaluation, with rapid prototyping. Our knowledge acquisition activities involved analyzing the published maps and interviewing professional strand map developers in order to articulate the semantic constraints that needed to be preserved and the desirable aesthetic

heuristics used by human experts who created the published maps. The resulting visualization algorithm uses tree-based processing, where a strand map is viewed as consisting of a tree with multiple roots.

Breadth First Search is used to compute the vertical depth level of each node relative to its nearest root. Depth First Search is used to compute the horizontal relationships, across strands and within a strand, between nodes at the same vertical depth. The results of these two searches are combined to quantitatively identify internal relations between nodes.

These quantitative relations are then used to allocate nodes to placements within a predefined grid that represents the available drawing space. Where pairs of nodes conflict; e.g., the link between two nodes may cross a third node and violate an aesthetic heuristic, local placement adjustments are then made by moving the conflicting node to the next available placement in the grid.

6 Evaluation

A small pilot study was conducted in order to begin to study the effect of the Service's concept browsing interfaces on the cognitive strategies of users browsing a digital library like DLESE. Twelve undergraduate psychology students participated in the study. Six were male, and six

were female. Half the participants performed the study using the existing DLESE search engine (the nonStrandMaps group) available at <http://www.dlese.org>, while the other half (the StrandMaps group) performed the study using a Strand Maps interface to DLESE.

Participants in both groups were given the same set of 4 pre-determined tasks to perform with the system. Each task required them to imagine themselves as a teacher in a secondary school. They were asked to find specific kinds of resources that they could use to teach certain specified concepts. In order to study their cognitive strategies, participants were asked to do a self-explanation while performing the tasks. A self-explanation protocol aims to capture the representation of knowledge that the user has [15]. Participants doing self-explanations have been shown to make comments about the conditions under which specific actions are advisable, the relationships between actions and goals, and the consequences of actions [16]. During the self-explanation, participants were asked to talk aloud about their choices while using the system, and to verbalize the reasoning behind their actions. The audio of this self-explanation was recorded for each participant. On average, participants took 45-60 minutes to complete the study.

Findings

The self-explanation for all participants performing all the tasks produced 110 pages of verbal transcripts. As a preliminary analysis, two researchers performed multiple readings of these transcripts, from which emerged patterns of comments that differ across the two groups. It can be postulated that participants in the StrandMaps group used the concept browsing interface as a tool rather than as a learning device, but it was an effective tool. They read the benchmark text displayed in nodes of the maps and compared it to the text of the tasks, thus using the Strand Map interface to figure out which benchmark was appropriate for their task. They also used the displayed benchmarks to facilitate their decision process by analyzing and comparing the text in different benchmark boxes. For example, one participant tasked with finding a classroom activity related to the cause of earthquakes, said:

“...since he wants to talk about earthquakes, we'll just go to [the] earthquakes and volcanoes section..and he wants to find out the cause of earthquakes, so.. I'm reading the different little boxes to find out which one sounds more related to why earthquakes occur...Let's see, this one talks about .. how the core of the earth is hot and that's what makes earthquakes and volcanic eruptions but .. this one says that they also occur along boundaries with colliding plates, so I'm going to try this one...”

The comments made by the nonStrandMaps group on the other hand, suggest that they spent a significant amount of time thinking about the mechanics of searching, and what sorts of queries would return sufficient numbers of results yet still be relevant to their assigned task. They spent time talking about issues like the search options they needed to select before they hit the ‘Search’ button. For example, a participant doing the task related to the cause of earthquakes talked about the ‘Resource Type’ and the ‘Grade Level’ options he chose:

“..says it wants a classroom activity, so for resource type I’m going to click classroom activity, and then grade level it says they’re seventh graders so .. middle, sixth through eighth grade .. then search for volcanoes; wait, no, earthquakes..”.

Based on these emergent patterns of comments, it is possible to say that the participants in the StrandMaps group made effective use of the information provided in the concept browsing interface (the text in the benchmark boxes, the grade levels assigned to each benchmark, etc) to complete their tasks. The nonStrandMaps group, who did not have the support offered by the Strand Map, picked keywords from the text of the tasks, and used those to create search terms, often with limited success. They spent a significant amount of time talking and thinking

about how to translate their information seeking needs into suitable search engine queries.

As future work, a propositional analysis of the verbal data will be conducted, which entails separating the verbal data into complex propositions, analyzing the types of processes present in the data, and developing a formal method for identifying and scoring these processes across participants [17]. This type of analysis would enable a finer-grained identification and analysis of participants' cognitive strategies.

7 Conclusions

Given the small number of study participants, the results presented here should be viewed as descriptive in nature. However, these preliminary findings underscore the potential value of this visualization approach to digital libraries with an educational mission: these interfaces appear to help users stay focused on the scientific content of their information discovery task, as opposed to focusing on the mechanics of searching. We attribute these results to the navigational and orientational cues afforded by the strand maps. The merit of our approach lies in its

innovative use of web services technology to provide an educationally-relevant visualization service across distributed library sites, as opposed to creating a visualization interface for a single library. We hope that concept browsing interfaces created with the Service will help teachers and students to understand that science is not a list of facts to memorize, but instead a rich network of ideas to explore.

Acknowledgements

This research is funded in part by the National Science Foundation under NSF Award #0226286. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF.

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