Contextualizing science education via Earth system science events for meaningful lifelong learning

Sebastian de la Chica
Department of Computer Science, UCB 430
University of Colorado at Boulder
Boulder, CO 80309-0430
sebastian.delachica@colorado.edu

Background
The widespread deployment of ubiquitous communication technologies, including growing Internet access, in the early 21st century has resulted in a growing number of information sources available for educational purposes. These online information sources contribute to an educational landscape increasingly capable of near real-time access to news coverage, scientific data, and critical analyses about earthquakes, volcanic eruptions, tsunamis, and similar Earth system science (ESS) events. By contrast, traditional science textbooks provide sanctioned quality educational content, but require content updating cycles several orders of magnitude longer than online information sources. Lacking meaningful context, scientific information in traditional textbooks often leads to disconnected rote learning and limited understanding of scientific concepts. Lacking the appropriate cognitive skills, learners often fail to recognize and connect the salient scientific concepts and social issues underlying news coverage of significant ESS events with their existing scientific knowledge.

Nationally-recognized science education standards have addressed the importance of learning how to be a scientist through learning goals related to science inquiry and critical thinking skills in authentic settings, including topics derived from current events (National Research Council, 1996; Project 2061, 1993). While real-world ESS events may support authentic integration of science in the classroom with science in the world, learners require appropriate cognitive skills to adequately process and integrate scientific content from diverse sources in the context of their immediate science curriculum learning goals.

The proposed research addresses the following research questions:
- How does the introduction of real-world Earth system science events change learners’ existing scientific understandings and their comprehension of the social relevance of the science curriculum content?
- What are the cognitive skills and strategies required for meaningful learning from multiple sources in an online science research environment?
- How can concept maps be integrated with educational digital libraries to scaffold the development of these cognitive skills and strategies in an online science research environment?
Prior Research

The emergence of the Internet as a primary, albeit largely ad-hoc, source of reference materials in educational settings (L. Graham & Metaxas, 2003) leaves learners to struggle dealing with copious amounts of hyperlinked multimedia content. While traditional text comprehension research often focuses on single text processing (Goldman, 1997), scientific investigations inherently demand reading and comprehending information from multiple sources. The unstructured nature of the Internet complicates these research efforts due to variances in content quality, presentation, and usability across sources. Research on learning from multiple information sources suggests that establishing connections and developing flexible mental models, represent key strategies for effective information integration (Goldman, 1997). Such connection-making activities elicit the notion of intertextuality, related to the reader’s adaptation and transformation of multiple text sources into a mosaic of interconnected ideas (Kristeva, 1969). As a discourse stance, an intertextual approach to reading from multiple sources emphasizes establishing connections with previously processed text content and leads to a richer mosaic of interconnected ideas (Hartman, 1995; Stromso et al., 2003). This approach attends equally to the author’s perspective, the emerging knowledge constructs, and the reader’s own perspective and existing understanding. To use online educational information effectively, learners must aggregate disparate content into an integrated conceptual whole. Unfortunately, most online information sources are designed independently, and not intended to be used as a cohesive educational unit.

Educational digital libraries have emerged as a response to the proliferation of online information sources purportedly providing educational materials. Digital libraries extend online information sources with descriptive metadata for resource cataloguing and discovery, information space navigation, and other learner-appropriate pedagogical activities. Meaningful scaffolding of digital libraries features the characteristics of cognitive tools (Jonassen & Reeves, 1996) if it supports knowledge construction and sense-making activities (Sumner & Marlino, 2004). For instance, the use of concept maps for navigational purposes has shown promise as a cognitive aid for digital library information seeking activities (Sumner et al., 2003). Concept maps as thinking tools to communicate existing understandings (J. D. Novak & Gowin, 1984) appear to help learners better grasp central ideas and promote more effective learning in cooperative situations (O'Donnell et al., 2002). Contextualization of digital library resources around a real-world ESS event provides learners with the opportunity to establish connections between news reports and appropriate science education resources through active processing and representation of the available information via rich knowledge representations.

Experimental studies have shown the positive impacts of scaffolds on learners generating scientific explanations (McNeill et al., 2004). Furthermore, inquiry science educational technologies feature a variety of scaffolding artifacts to assist learners in the learning process (Edelson, 2001; Linn et al., 2003; Quintana & Zhang, 2004b; Reiser et al., 2001). Educational technology research efforts have also provided complementary design theory contributions, such as the Create-a-World project and the Learning-for-Use design framework (Edelson, 2001) or the Digital IdeaKeeper (Quintana & Zhang, 2004a) and the
Learner-Centered Design approach (Soloway et al., 1996). Such theoretical contributions have converged into a scaffolding design framework for software to support scientific inquiry activities inspired by theories of inquiry practices and examples of scaffolding in existing educational software environments (Quintana et al., 2004). While this framework addresses important educational software design issues, it provides limited guidance related to supporting learners’ integration of multiple information sources into coherent mental representations. The proposed research addresses issues of scaffolding design anchored in the realities of real-world ESS events and the Internet as primary reference source, particularly focused on supporting coherent mental model construction from a multiplicity of heterogeneous information sources.

**Conceptual Approach**

**Scope**
While the pedagogical principles investigated as part of this effort are applicable across curriculum topics, this work focuses on on NSES content standards for middle and high school learners of science related to earthquakes and volcanic eruptions (National Research Council, 1996). Table 1 illustrates the content areas of interest.

<table>
<thead>
<tr>
<th>Grades</th>
<th>NSES Content Standard D - Earth and Space Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-8</td>
<td>Structure of the earth system</td>
</tr>
<tr>
<td></td>
<td>Lithosphere</td>
</tr>
<tr>
<td></td>
<td>Plate motions</td>
</tr>
<tr>
<td></td>
<td>Land form causes</td>
</tr>
<tr>
<td></td>
<td>Rock cycle</td>
</tr>
<tr>
<td></td>
<td>Earth’s history</td>
</tr>
<tr>
<td></td>
<td>Common processes, occasional catastrophes</td>
</tr>
<tr>
<td>9-12</td>
<td>Energy in the earth system</td>
</tr>
<tr>
<td></td>
<td>Convection in the mantle</td>
</tr>
<tr>
<td></td>
<td>Origin and evolution of the Earth System</td>
</tr>
<tr>
<td></td>
<td>Evolutions of the Earth system</td>
</tr>
</tbody>
</table>

**Table 1 – NSES Content Areas**

**SciNews Online**
The proposed research extends SciNews Online (SNO), a configurable collaborative research tool co-designed with teachers for middle and high school students of science (de la Chica et al., 2005). SNO provides scaffolds to promote the development of collaborative science inquiry and information literacy skills. SNO introduces the following innovative approaches: structured educational blogs, configurable scaffolding, and rich digital library integration. Figure 1 depicts the high-level components in SNO.
Teachers use SNO to create assignments based on online ESS news articles for learners to collaboratively develop web reports using structured educational blogs, a modified blog technology supporting structured web content publishing and teacher/peer reviews. Figure 2 shows a sample SNO report built around Mt. St. Helens’ heightened volcanic activity in 2004. Each assignment consists of editable report sections, including introduction, vocabulary, science research, social impacts, conclusions and references. Teachers configure the level of available scaffolds including textual prompts and tools, such as online dictionary, educational digital libraries and Internet search, reference management and web content editing. Learners use SNO to construct an online web report around a real-world ESS event collaboratively, and complete the different sections of the report through transparent interaction with the underlying structured educational blog.
SNO illustrates design alternatives to increase student collaboration, de-emphasize rote learning, minimize technology training time, support task structuring, and ease teachers’ time demands (de la Chica et al., 2005). Initial usability evaluation provides encouraging signs that the design principles explored in SNO effectively address the needs of teachers using science news in the classroom.

**Intertextual Learning Process**

Reading from multiple texts for learning requires a variety of cognitive skills and strategies (Goldman, 1997) that serve as the basis for an intertextual learning process model that supports knowledge integration from multiple sources. The proposed model includes four components: location, selection, organization and critical integration. provides a depiction of this process. Figure 3 shows the process components contributing to knowledge integration as cohorts not inherently bound by a pre-defined sequence of activities.
The location component focuses on the discovery of relevant information sources and encompasses traditional issues in information retrieval. The selection component concentrates on the strategies used to decide which sources appear most appropriate for the task at hand. The organization component focuses on categorization of the selected information sources along with any pertinent external sources, such as learner’s notes and additional documents. The critical integration component emphasizes monitoring for consistency, detecting contradictions across information sources, and communicating the newly-gained knowledge. This process constitutes the conceptual framework guiding the proposed research. Table 2 shows the relationship between the cognitive skills and strategies for learning from multiple sources (Goldman, 1997), the corresponding intertextual learning process component and sample educational technologies supporting those skills.

<table>
<thead>
<tr>
<th>Learning from multiple sources skills (Goldman, 1997)</th>
<th>Intertextual learning process component</th>
<th>Sample educational technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Searching for relevant information</td>
<td>Location</td>
<td>Search engines, educational resource discovery services</td>
</tr>
<tr>
<td>Note-taking</td>
<td>Selection</td>
<td>Annotation tools, online field journals</td>
</tr>
<tr>
<td>Organizing and coordinating information</td>
<td>Organization</td>
<td>Concept maps and associated tools</td>
</tr>
<tr>
<td>Integrating and evaluating information</td>
<td>Critical Integration</td>
<td>Report and presentation construction tools</td>
</tr>
</tbody>
</table>

Table 2 - Intertextual learning process: skills and technologies

**Design and Development Work**

A number of academic research efforts have investigated the cognitive strategies associated with information location and selection. Both the NSDL (National Science Digital Library, n.d.) and DLESE (Digital Library for Earth System Education, n.d.)
communities have addressed research issues surrounding a variety of educational resource discovery services and interfaces, including innovative navigation mechanisms such as the Strand Maps (Sumner et al., 2003). Custom applications have also contributed to this area by providing support for document relevance analysis based on user’s profiles (J. Graham, 1999), and leveraging document subject organization for improved relevance in the retrieved document set (Crossen et al., 2001). By contrast, the cognitive strategies associated with the organization and critical integration of information across disparate sources in educational settings have only received limited attention. Recent research efforts have explored supporting generic long-term reading tasks through document and citation management capabilities to guide the user’s long-term research tasks (Bier et al., 2004).

The proposed research introduces scaffolding tools in SNO to promote the development of the cognitive skills and strategies necessary to effectively integrate knowledge from multiple sources. Previous research on using online science news in the classroom shows that teachers see proper referencing of online resources as an important pedagogical issue (de la Chica et al., 2005). The proposed research introduces concept maps as reference management tools promoting active processing and knowledge integration of multiple educational resources. These concept maps embody emerging learners’ scientific understanding based on the online references of interest. While concept maps have been previously studied as digital library navigational tools, the role of concept maps embedded in digital libraries as cognitive tools to promote knowledge integration from multiple sources remains largely unexplored. As learners construct concept maps representing newly acquired information from online educational resources and their current scientific understandings, these representations serve both as cognitive tools for learners and as assessment vehicles for teachers. Furthermore, this approach adapts the theoretical model proposing the existence of a document subspace and a knowledge subspace within digital libraries (Feng et al., 2005) by transferring the responsibilities for the creation of the knowledge subspace to the learners. In the context of the dual subspace digital library model (Feng et al., 2005), the proposed approach encourages the creation and sharing of a multitude of overlapping knowledge subspaces describing the digital library document subspace in the context of specific learning goals, educational tasks, personal perspectives, and social interactions, as illustrated in Figure 4.
The introduction of these references concept maps allows SNO to emerge as an online research tool that supports advanced learning in ill-structured domains as defined in cognitive flexibility theory (Spiro et al., 1994). The following table details how SNO’s design and capabilities align with this theory of learning.

<table>
<thead>
<tr>
<th>Cognitive Flexibility Theory</th>
<th>SciNews Online Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoid oversimplification and overgeneralization</td>
<td>Tools to manage web references and support knowledge creation</td>
</tr>
<tr>
<td>Multiple representations</td>
<td>Multiple concept maps and multimedia web report</td>
</tr>
<tr>
<td>Centrality of cases</td>
<td>Real-world news</td>
</tr>
<tr>
<td>Concepts as knowledge in use</td>
<td>References concept maps containing online news references</td>
</tr>
<tr>
<td>Schema assembly</td>
<td>References concept maps</td>
</tr>
<tr>
<td>Multiple interconnectedness</td>
<td>References concept maps</td>
</tr>
<tr>
<td>Active learner participation</td>
<td>Web report creation</td>
</tr>
</tbody>
</table>

Table 3 - Cognitive flexibility theory in SNO

Methodology
The proposed research methodology follows in the tradition of design-based research efforts in instructional technology research (Brown, 1992; Reeves et al., 2004, 2005). Design-based research requires balanced integration of controlled experimental design with classroom observations, focuses on addressing pressing educational issues in partnership with teachers, and promotes co-evolution of educational practice and technology design (Reeves et al., 2004, 2005).
Design-based research emerges as an appropriate methodology for this effort because the research aims to improve science education in realistic situations while simultaneously contributing to the development of a theory of contextualized science learning. Figure 5 illustrates the proposed methodology.

**Figure 5 - Research Methodology Components**

- **Collaborative Reflection and Planning**
- **Experimental Design**
- **Classroom Trials**
- **Final Reflection and Theoretical Formalization**

**Collaborative Reflection and Planning**

The collaborative reflection and planning component builds upon prior education research efforts associated with SNO. This component includes a collaborative study with science teachers who use ESS events in their classroom practices to identify learning goals, typical instructions, materials and deliverables associated with event-based educational activities. Finally, this workshop includes discussions on how SNO fits within the teachers’ current educational practices, including curriculum and assessment integration as well as relevant operational issues.

**Experimental Design**

The experimental design component focuses on how SNO changes learners’ scientific understandings of real-world ESS events. This experimental design aims to discern the significance and relative impacts brought about by the introduction of digital libraries and reference management cognitive tools on learner-generated concept maps created individually. To eliminate issues related to information location and selection, this experiment focuses on reference concept map construction activities based on a single online news report and a limited set of experimenter-selected online references. For evaluation purposes, this experimental design leverages concept map scoring techniques based on comparison with an expert-generated concept map using concepts and concept relationships evaluation (J. Novak & Musonda, 1991; Rye & Rubba, 2002). In addition, this experiment calls for the completion of a concept card sorting exercise (Rosenberg &
Kim, 1975) as an initial attempt at identifying common learner conceptions about ESS events.

**Classroom Trials**

In these classroom trials, I plan to introduce SNO to middle and high school students of science and collaborate with their teachers to support online assignments based on real-world ESS events. The investigative focus of these classroom trials converges on identifying changes in learners’ scientific understandings of ESS events as manifested via learner-generated concept maps and online web reports created collaboratively using SNO. During these trials, the evaluation of learner-generated concept maps utilizes the same rubric proposed for the controlled experiment and a propositional analysis of learner-generated claims about an ESS event. The propositional analysis examines the contributions provided in the online web reports, and it involves separating the textual web contributions into cohesive complex propositions (Chi et al., 1994) for coding amenable to the discovery of common patterns in learners’ scientific understandings. The coding activities leverage the classifications of individual scientific understandings obtained from the experimental design data analysis. The initial categorizations may have to be adapted to account for collaborative meaning negotiation taking place during the collaborative construction of the SNO web report.

The proposed research methodology includes a final reflection component in which I will generalize research findings and contribute to the development of a theory of contextualized science learning. These theoretical efforts aim to formalize key pedagogical characteristics and process dimensions necessary to make ESS events in the classroom an integral part of the curriculum for the meaningful learning of science. In addition, I will use this opportunity to reflect on the educational technology design process to identify architectural design and integration patterns that may prove useful for the construction of similar online educational environments. This reflection will lead to the formulation of educational software construction guidelines for educational researchers interested in leveraging the technology supporting the intertextual learning process under investigation here for their own research purposes.

**Intellectual Merit and Broader Impact**

The proposed research leverages existing empirical findings and theoretical contributions from text comprehension from multiple sources research to formulate an intertextual learning process appropriate for introduction into middle and high school science education practice. This process provides the motivation for the innovative integration of rich digital library interactions with new uses of concept maps as cognitive tools to support learners’ development of cognitive strategies for information organization and critical integration purposes. These scaffolds aid the construction of robust mental models through the integration of information from multiple sources via concept maps as online reference management and knowledge construction tools.

Using SNO as a research tool allows for the development of these cognitive skills anchored in real-world Earth system science events. SNO enables learners to interact with online news articles about recent ESS events, to integrate news reports with science
education resources from educational digital libraries, and to make connections to their prior knowledge and experiences. As learners acquire the necessary critical thinking skills to guide their inquiries about the science behind the news, this research effort contributes to the development of an educated citizenry capable of making informed political decisions about issues concerning the Earth as lifelong learners of science.
References


