EAGER: SAVI: Dynamic Digital Text: An Innovation in STEM Education
Project Summary

Science, technology, engineering, and mathematics (STEM) instruction in schools and colleges often uses print textbooks organized by topic, to be read and understood by students in a linear fashion. STEM content thus presented remains static, and the ways in which students use these materials stand in stark contrast with the rich interaction, navigation and visualization environments they are immersed in on the web and on mobile devices. Students nowadays are quite adept at non-linear navigation and dynamic interactions except in the formal learning environment of a classroom. We propose that research on knowledge organization techniques for visualizing and presenting STEM content digitally for engaging students and engendering deep learning needs to be (1) conducted, (2) applied toward the development of new presentation, interaction and navigation techniques for digital STEM content, and (3) evaluated in the context of an inquiry-based pedagogy designed around dynamic digital text. Our long-term vision is that of a cloud-based service architecture that will allow *anytime, anywhere, and as-needed access* to dynamic digital content across an extensive set of topics for school and college level STEM education integrated with a novel pedagogy that makes effective use of digital STEM content. This EAGER proposal takes the following steps toward the realization of this vision.

1. Develop a theoretical framework for dynamic digital text, with concept maps as the foundation for knowledge organization and navigation, embedded interactive exercises and engaging visualizations as the foundation for on-line assessments, and an inquiry-based pedagogy designed specifically around digital text as the foundation for teaching and learning in the classroom.

2. Test the theory by developing digital texts with rich interaction and navigation functionalities, with content for two domains (science and computing), for two levels (middle school and college), and in two languages (Finnish and English). We will design and conduct appropriate evaluation studies in two cultural/educational contexts (United States and Finland).

3. Develop a novel design and architecture for dynamic digital textbooks for STEM using data and knowledge created in the previous steps.

Intellectual Merits: This project aims to design the next generation of digital STEM content for school and college level education—which we call a *dynamic digital text*—by radically rethinking content, organization, and interaction. Given the rapid proliferation of affordable mobile technology (e.g., the percentage of US cellphone users with a smartphone exceeded 50% recently, and this is much higher in Finland; an Android tablet can be purchased for as little as USD 60), paper textbooks and their e-versions will soon be obsolete. Commercial offerings have not been pedagogically innovative, so we argue that now is the right time to conduct research that will lead to digital text and corresponding pedagogy design based on both sound theory, from learning science and human-computer interaction research, and robust experimentation. The proposed project will be a significant first step in this direction. A strength of this project is that it builds upon a strong foundation of ongoing projects and existing collaborations. The proposed joint project will expand and strengthen Finland-US collaboration on the important topic of learning science and technology, and lay the groundwork for a significant leap in electronic textbook design in the future. Project investigators have significant and complementary expertise in learning and cognitive sciences, computer science, educational research, and data analysis, as well as experience with large projects and international collaborations.

Broader Impacts: We propose an ambitious project within the cultural and educational settings of the United States and Finland. Success in this exploratory project should lead to a sustained longer-term effort involving the two countries in the important arena of developing digital STEM content and associated pedagogy for *both school level science education and college level engineering education*. Given the complementary strengths of the two countries (Finland ranks at the top in educational innovation and outcomes, and is also technologically advanced; the United States leads in technology and also carries out advanced learning science research), this project has a strong potential to develop content, pedagogy, and technology that incorporate the strengths of the two systems. This, in turn, can have far reaching implications for education in the United States and Finland, and will have a significant impact on the future of digital media in education. Moreover, this project will offer decision makers reliable information on how new technologies enhance learning. The project will also help improve international collaborative research in Alabama, an EpSCOR state.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

EAGER: SAVI: Dynamic Digital Text: An Innovation in STEM Education

1. Motivation

> Publishers will create apps that support their paper textbooks—or they will port their paper textbooks over to a PDF [and say they have] an eTextbook.…[But] we are using new technology to implement old pedagogy…we are not exploiting the affordances of the new technology (Soloway; quoted in Barseghian, March 2012).

This quote illustrates the issue we address in this proposal. Research has emphasized that students should learn science as a connected body of knowledge rather than a set of discrete facts (e.g., Hmelo-Silver et al., 2007; Kozma, 2000; Ruiz-Primo & Shavelson, 1996). Yet such "connected" learning is lacking in many curriculum materials used in schools (e.g., Jacobson & Wilensky, 2006). Fortunately, advances in technology provide us with a powerful platform for presenting content in novel ways. As digital materials become ubiquitous and are adopted across school systems, textbooks are giving way to digital versions (Lewin, 2009). While publishers tout the cost benefits and portability of digital textbooks, those currently available are merely clones of their print counterparts, with only trivial added capabilities such as simple animations, sleek graphics, and the ability to highlight and annotate passages. They do not take full advantage of interactive presentation and navigation, the potential of visualization and simulation, or the analytic capabilities of technology. They provide only the most primitive support for practicing and demonstrating knowledge gains. Current eTextbooks also do not tap into the extant body of research on visualization, knowledge representation, and learning from text. The addition of multimedia capabilities may make current eTextbooks interactive and fun to use, but that alone does not make them transformative in any sense, nor do they harness the power of technology in ways that enhance learning. Therefore, the proposed project has the following three goals.

1. Develop a theoretical framework for dynamic digital text, with concept maps as the foundation for knowledge organization and navigation, embedded interactive exercises and engaging visualizations as the foundation for on-line assessments, and an inquiry-based pedagogy designed specifically around digital text as the foundation for teaching and learning in the classroom.

2. Test the theory by developing digital texts with rich interaction and navigation functionalities, with content for two domains (science and computing), for two levels (middle school and college), and in two languages (Finnish and English). We will design and conduct appropriate evaluation studies in two cultural/educational contexts (United States and Finland).

3. Develop a novel design and architecture for dynamic digital textbooks for STEM using data and knowledge created in the previous steps.

Our design will provide conceptually based content organized to illustrate the ideas and relations in a domain, as opposed to the linear presentation found in current eTextbooks. It builds on research in cognitive and learning sciences, and offers a radical rethinking of paper textbooks and eTextbooks. In science especially, there is a call for more in-depth coverage of science topics to achieve knowledge integration (Linn, 2006; Linn & Eylon, 2011; Kali, Linn, & Roseman, 2008; Slotta & Linn, 2009). Our design is based on a network representation of knowledge using concept maps to help students understand connections among key ideas in a domain. Further, visualizations will provide an active representation to drive students' interactions. In traditional textbooks and current eTextbooks, the form—linear, page-turning format—drives interactions (Shorb & Moore, submitted). Several recent reports, books, and articles have expressed concern that, while we have made significant progress in our understanding of how people learn, and while technological advances provide possibilities for new ways of learning, classrooms have remained relatively unaffected by these developments (e.g., Mäkitalo-Siegl, Zottman, Kaplan, & Fischer, 2010). Further, because administrators and school districts are beginning to allow digital materials into classrooms and are facing the reality that we live in a "digital world outside of the classroom" (Dede & Richards, 2012; p. 5), researchers emphasize the need for sound theory and pedagogy to inform the design of tools using next-generation technology. Our proposed project will use next-generation technology in the design of an educational tool informed by theory and pedagogy.

2. Scenario

Seventh grade students Kenisha, Emily, Raul, and Rose are excited about science class today because their teacher, Mr. Hernandez, told the students they would use a digital textbook and hands-on design challenges in their science classes for the next 7–8 weeks. Mr. Hernandez gave them a design challenge to start off their Work & Energy unit. The challenge was "Can you design a device that will help somebody move a heavy item like a pool table into a van?" Then he showed the class an interactive eTextbook that the students can use to navigate from concept to concept, instead of from chapter to chapter, and which they would use to research science principles and make design decisions. Mr. Hernandez started the unit with a discussion to generate questions about the science of inclined planes. The class was then divided into groups of students. Kenisha's group found relevant information in the eTextbook: concept maps that linked work, force, mechanical advantage, distance, etc., and explanations of these concepts in the context of inclined planes. As students in her group read the text, they used the concept maps to understand the relationships among key science ideas. They discussed the main ideas in the text and made judgments on how to use this information in their investigations. Kenisha found it helpful that the system gave her feedback on how to make navigation decisions related to the design challenge.

Before class next day, Mr. Hernandez scanned the eTextbook's log file summary that teachers could use to track student work and found that all but one group had missed reading about mechanical advantage and potential energy. So he discussed this with students and gave them more time to read the eTextbook. After all groups were finished gathering information from the eTextbook, Mr. Hernandez led a whole-class discussion to help students decide which variables they will test in their investigations, and generate hypotheses. The class then split into groups again and used a program to simulate different kinds of inclined planes to test some of these hypotheses. Kenisha's group entered data they collected and discussed their results. The teacher then provided each group with materials for investigating their hypotheses in the real world: a block to represent the van, a green block for the pool table, different lengths and surfaces of boards for the ramp, and spring scales. Kenisha and her group collected data about applied force, load, and distance, and calculated work and mechanical advantage. They learned how to use formulae, apply information, and test their hypotheses. They entered data in their journals and compared their results with those they had obtained from computer simulations. Mr. Hernandez led a whole class discussion again, in which students in each group presented their data and justified their designs based on what they had read in the eTextbook, and what they had found in their simulations and hands-on investigations. Following this, all students completed their journals by writing down how they could get a pool table into a van, and explaining their design decisions citing evidence from hands-on investigations, from simulations and from the eTextbook. Kenisha's group felt a real sense of accomplishment, and talked excitedly with each other about ideas they were already forming about the next design challenge.

This scenario highlights the fact that our vision encompasses more than a cloud-based architecture and interactive technologies for dynamic digital text. It also illustrates how an inquiry-based pedagogy that combines explorations of digital text with hands-on and/or simulation-based experimentation will be enacted in a middle school science classroom. Furthermore, this approach would easily scale to STEM college-level classrooms as well. It is conceivable to teach a problem-based or project-based engineering course supported by an eTextbook, along with a real or virtual laboratory allowing experimentation, in which groups of students will engage in inquiry, discovery and learning guided by the teacher. In fact, we will test this hypothesis by implementing and evaluating eTextbook use in the context of an inquiry-based pedagogy in middle school science classrooms and college-level computer science classrooms in the United States and Finland in this project.

3. Related Work

3.1 Prior NSF-supported Work

This project will produce an innovative eTextbook design by building upon prior NSF-supported research on data mining and visualization (Hübscher, Puntambekar, & Nye, 2007), learning from visualizations (Myneni & Narayanan, 2012; Hansen, Narayanan, & Hegarty, 2002), the CoMPASS science hypertext system (Puntambekar, 2006; Puntambekar, Stylianou, & Goldstein, 2007), and the OpenDSA active-eBook project (Shaffer, et al., 2011) in the United States and work on the TRAKLA project (Korhonen, et al., 2003; Laakso, Myller & Korhonen, 2010; Malmi, et al., 2004; Malmi & Korhonen, 2008) in Finland.

CoMPASS is a hypertext system for middle schools that presents physics concepts as a concept map linked to hypertext. It is used in a classroom with accompanying design activities broadly based on the pedagogical principles of Learning By Design™ (Kolodner et al., 2003). Each page in the system represents a conceptual unit such as force or acceleration. A conceptual map of the science concept and other related concepts takes up the left half of the screen, and a textual description takes up the right half (see Figure 1). The maps are dynamically constructed and displayed with the fisheye technique (Bederson & Hollan, 1995; Furnas, 1986) when a student selects a concept. The selected (focal) concept is at the center of the map, with the most closely related concepts at the first level of magnification and those less closely related at the outer level of the map. The fisheye view is organized in such a way that the concepts most related to the focal concept are displayed close to each other spatially. The maps mirror the structure of the domain to aid deep learning and are designed to help students make connections, giving students alternative paths to pursue for any particular activity, so that they can see how different phenomena are related. The system is used in conjunction with design challenges that provide students with a context for their investigations and help them see the connections among concepts.

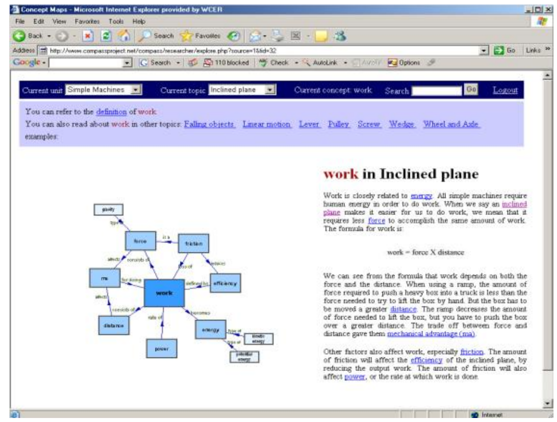

***Figure 1*. CoMPASS interface.**

The initial work on CoMPASS was undertaken with support from an NSF CAREER award (DRL-9985158), when 16 sixth- and eighth-grade classes used the materials over 4 years. Results showed that students gained a deeper understanding of the connections among the science concepts and principles when they used the concept maps in the CoMPASS system. The CoMPASS materials were revised based on classroom studies, leading to the next phase of the project (IERI DRL-0437660). In this project, replication studies conducted to understand how the intervention worked in different contexts (in Wisconsin and Connecticut) found additional evidence for the effectiveness of the approach.

Shaffer and colleagues have many years of experience developing algorithm visualizations for college-level computer science courses. The AlgoViz Portal at http://algoviz.org (NSDL DUE-0836940 and TUES DUE-0937863) and the OpenDSA project (http://algoviz.org/OpenDSA, TUES DUE-1139861) involve participation of Finnish collaborators at Aalto University. OpenDSA seeks to provide complete content for teaching courses in Data Structures and Algorithms, a core content area for Computer Science. The key innovation of OpenDSA is that it deeply integrates three aspects: content, algorithm visualizations for presenting the inherently dynamic content of algorithms, and interactive exercises (with automated assessment). One type of interactive exercise is the "proficiency exercise" in which students demonstrate their understanding of an algorithm by simulating its steps on sample input. This approach was pioneered by Finnish collaborators at Aalto University (Laakso, et al., 2005). Also relevant is the research of Narayanan and colleagues, in which it was found that college students working with algorithm visualizations embedded in a knowledge and context-providing hypermedia environment learned better than those learning from a printed textbook or from a lecture (REC-9815016).

3.2. Learning from Text and Concept Maps

Researchers have discussed the important role of language in STEM classrooms, emphasizing that reading and writing are essential aspects of constructing a scientific understanding (e.g., Lemke, 2004; Saul, 2004; Yore, Bisanz, & Hand, 2003; Krajcik & Sutherland, 2010). Text facilitates science learning by providing an "effective means of introducing students to a more precise lexicon" (Palincsar & Magnusson, 2001, p. 20) and a "theoretical framework that helps [students] interpret evidence" (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000). Text provides a means of storing and disseminating data and interpretations to facilitate knowledge construction (Alvermann, 2004; Kamil & Bernhardt, 2004; Norris & Phillips, 2009; Varelas & Pappas, 2006). Therefore, inquiry-driven literate practices with texts are investigations in their own right that require students to actively make meaning and integrate information (Pearson, Moje, & Greenleaf, 2010). The proposed eTextbook design and associated pedagogy will promote precisely such practices.

With the increase in technology to support science learning, researchers have acknowledged the potential of digital text in science and literacy (Dobson & Willinsky, 2009; Magnusson & Palincsar, 2004). A recent review of research on digital text has called for research at the intersection of literacy and learning sciences (Palincsar & Ladewski, 2006). However, van den Broek (2010) argued that texts should be designed to help readers identify the relationships that matter. The need for helping students learn STEM content as a related, cohesive body of knowledge and not a set of isolated facts is well documented in research (e.g., Hmelo-Silver, Marathe, & Liu, 2007; Kozma, 2000; Ruiz-Primo & Shavelson, 1996). According to Glynn, Yeany, and Britton (1991), "without the construction of relations, students have no foundation and framework on which to build meaningful conceptual networks" (p.6). Yet such a focus is lacking in many science curricula used in schools (e.g., Jacobson & Wilensky, 2006), with the result that students' ideas are often fragmented. Bransford, Brown, & Cocking (1999) emphasized that for meaningful learning to occur students must concentrate on the central ideas and conceptual relationships. Such elements reflect the domain structure or expert understanding of the discipline and foster the development of knowledge. According to several researchers, a key aspect of science understanding is the integration of knowledge (Linn, 2006; Linn & Eylon, 2011; Kali, Linn, & Roseman, 2008; Slotta & Linn, 2009) into a framework consisting of relationships among concepts and principles (diSessa, 2000; Heibert & Carpenter, 1992; Ruiz-Primo & Shavelson, 1996; Newton & Newton, 2000). This provides the impetus for proposing concept maps as the basis for knowledge organization and presentation in digital dynamic text.

Visual representations (Tufte, 2001), such as concept maps, can help encapsulate knowledge elements and accentuate their interrelationships. Visualizations that represent the meaningful relationships underlying content can facilitate learning and comprehension (Scott & Schwartz, 2007). Recent research has found that providing a graphical interface that makes the relationships explicit may facilitate learners in integrating information from multiple sources (Salmerón, Gil, Bråten, & Strømsø, 2010). According to Novak and Gowin (1984), concept maps represent meaningful relationships among concepts and serve as a way to structure or organize knowledge in an integrated manner (Edmondson, 2000; Novak & Cañas, 2006). Novak and Gowin held that these representations are visual maps of pathways that connect meanings and concepts and can offer "a schematic summary" of ideas. Nesbit and Adesope (2006) have argued that because concept maps eliminate redundant information and co-locate similar concepts, their use in the classroom can facilitate students' understanding of text. When combined with zooming techniques, fisheye views, and techniques used in the hyperbolic browser (e.g., Cockburn, Karlson, & Bederson, 2008; Tergan & Keller, 2005), concept maps can help visualize the interrelations among science phenomena by enabling students to zoom in on their selected topics without losing the context.

In education research, concept maps have been used to facilitate students' learning and engagement. Of particular interest here is their application in scaffolding students' learning from text and in shaping students' writing. Knowledge models such as concept maps can be used to organize large repositories of information and provide an effective navigational tool (Cañas, et al., 2004). Students who have learned to create and read concept maps appear more capable both of extracting meaning and identifying concepts and their relations within (Nesbit & Adesope, 2006). Several research studies reviewed by Nesbit and Adesope (2006), have suggested that even students with lower verbal ability may better comprehend and construct concept maps because map syntax is usually comparatively standard and straightforward, and easier to make sense of, than the often dense language offered in textbooks or scholarly texts. In addition, concept maps can serve as useful metacognitive aids and scaffolds for integrating and fostering students' learning (Trowbridge & Wandersee, 1998; Novak & Cañas, 2008; Biswas, Schwartz, Leelawong, Vye, & TAG-V, 2005). Fisher et al. (2000) discussed the effectiveness of various mapping techniques that have a positive impact on learners' understandings of complex topics, a critical aspect of which is nonlinearity, and the interrelatedness of phenomena (Kinchin, 2000; Sabelli, 2006).

3.3. Visualization, Simulation, and Exercises

Computing education faces two particular problems that are typical in STEM disciplines, and which can be addressed by technology. First, much of the content that is taught involves dynamic processes. Traditional textbooks are limited in their ability to convey dynamic processes (Narayanan & Hegarty, 2002). Second, students do not get enough practice doing exercises for which they receive feedback. To deal with the first problem, there have been many efforts to employ visualization in computing education (Fouh, Akbar, & Shaffer 2012; Hansen, Narayanan, & Hegarty, 2002; Naps, et al., 2003a; 2003b; Shaffer, et al., 2010; 2011), The lack of practice exercises has perhaps been best addressed by the K-12 math education community. Sophisticated exercise systems such as the Khan Academy exercise infrastructure (http://www.khanacademy.org/exercisedashboard) and commercial sites such as IXL (http://www.ixl.com/) allow students to get immediate feedback on as many problem instances as they feel necessary to grasp the subject. In contrast, current print and eTextbooks from commercial publishers include merely static end-of-chapter questions. A third key technological innovation is simulation. Through simulation, students can effectively explore a concept with experimentation that would be difficult or time consuming in the real world (Huang & Gramoll 2004; Myneni & Narayanan, 2012).

4. Project Plan

4.1 Dynamic Digital Text Design

The theoretical framework for dynamic digital text that we have conceived, which will be further developed and refined during the project, is to use concept maps as the foundation for knowledge organization within the system and for student navigation on the interface. It will also include engaging simulations and visualizations, and embedded interactive exercises as the foundation for on-line assessments. It will be employed in the classroom within the context of an inquiry-based pedagogy designed specifically around digital text as the basis for teaching and learning in the classroom. This pedagogy will be adaptable to the needs of school and college classrooms, as well as to approaches like problem-based learning (Hmelo-Silver et al., 2007) and project-based learning (Kraijcik, et al., 1998). Here we sketch our preliminary ideas about the design and architecture of a novel eTextbook.

The initial presentation interface we will use for evaluation is based on the existing CoMPASS system. It will contain a navigable concept map that shows students how domain concepts are related, and text descriptions of domain principles and phenomena (similar to Figure 1). Textual descriptions will be coupled with dynamic, navigable concept maps, embedded exercises and simulations/visualizations. The maps mirror the structure of the domain to aid deep learning and are designed to help students make connections and integrate knowledge, and understand how different phenomena are related. The system saves log files of students' navigation. The log data can be used to provide adaptive support to students and to generate charts that provide teachers with real-time summary data to guide instruction.

The initial architecture will be that of a web-based system in which the knowledge organization framework (concept maps), textual descriptions, interactive exercises and simulations/visualizations will all be stored in a server database, which will process requests from client browsers running on classroom computers or student devices. Students will see a presentation and navigation interface that will link to embedded exercises and visualizations on their browsers. Teachers will see an instructor interface that will allow them to track student interactions and to make content updates. This architecture will be further developed jointly by the partners in the US and Finland based on evaluation studies.

4.2 Project Team and International Collaboration

The proposed project is tightly coupled with a similar effort by collaborators in Finland, so that together the research will span multiple contexts: the cultural and educational settings of the United States and Finland; grades 7-9 and first 2 years of college; and the domains of science and computing/engineering. The combined project will involve a collaboration among seven individuals from four Finnish institutions and three US institutions, with complementary expertise: Dr. Ari Korhonen (Senior Research Scientist in Computer Science, Aalto University), Dr. Mirjamaija Mikkila-Erdmann (Professor of Education, University of Turku), Dr. Hari Narayanan (Professor of Computer Science & Software Engineering, Auburn University), Dr. Jenni Paakkonen (Senior Researcher, Government Institute for Economic Research), Dr. Sadhana Puntambekar (Professor of Learning Sciences, University of Wisconsin–Madison), Dr. Roope Raisamo (Professor of Computer Science and Human-Technology Interaction, University of Tampere), and Dr. Cliff Shaffer (Professor of Computer Science, Virginia Tech). This team brings together decades of significant research experience in college level computing education research (Aalto, Auburn, Virginia Tech), school level science education research (Turku, Wisconsin, Tampere), science and computing content development (Aalto, Auburn, Tampere, Turku , Virginia Tech, Wisconsin), experimental design and data analysis for evaluation of educational innovations (Aalto, Auburn, Government Institute for Economic Research, Wisconsin, Turku), human-computer interaction, computer science, and artificial intelligence research (Aalto, Auburn, Tampere, Virginia Tech). Research and development activities that we will undertake in the United States will be mirrored on the Finnish side. See Section 4.5 for a description of research coordination and management.

4.3 Technical Approach

We propose concept maps as a foundational organizing framework for dynamic digital text, and an associated inquiry-based pedagogy in which students learn by solving complex problems in cycles of inquiry-research-experimentation: raising questions, doing research on digital text resources to find answers, forming tentative solutions, testing the solutions with hands-on experimentation or computer simulations, and taking embedded assessment tests when appropriate. Efficacy of the proposed methods will be experimentally tested.

1. *Theoretical Framework*: We will begin the development of the framework (project goal 1) starting with the foundation laid by three existing projects: concept maps and hypertext from the CoMPASS project (Wisconsin), and interactive and engaging assessment exercises and visualizations from the OpenDSA project (Virginia Tech) and the TRAKLA project (Aalto). The first step of the project will be to merge ideas from these projects, and results from concept map visualization research (Aalto), algorithm visualization research (Auburn and Virginia Tech) and human-computer interaction and interface research (Tampere) to develop this theoretical framework. (January–July 2013)

2. *Technology Development*: We will begin with the interactive software technologies developed in the CoMPASS (Wisconsin), OpenDSA (Virginia Tech), TRAKLA (Aalto), and Active Learning Spaces (Tampere) projects, merging and extending them as necessary, to build a technological platform for digital dynamic text. (January–July 2013)

3. *Content Development and Pedagogy Design*: We have already developed content at Wisconsin for middle school science and by Aalto University and Virginia Tech for computing. We can reuse these materials in the proposed project, developing additional content and translations to Finnish as necessary. The pedagogy developed around CoMPASS for middle schools will be adapted to suit the needs of the college curricula in the United States and Finland and school curricula in Finland, thus obtaining an inquiry-based pedagogy designed specifically around digital text as the foundation for teaching and learning in the classroom. (January–July 2013)

4. *Evaluation Studies*: As far as we are aware, the evaluation studies proposed are innovative in that this is the first instance of a systematic evaluation of an eTextbook in the classroom. Furthermore, the design of the studies in two content domains at two levels and in two linguistic and cultural contexts make them unique. User experience and interaction studies will be conducted as part of the Finnish project at the University of Tampere. Steps 2, 3, and 4 will together accomplish project goal 2. (April 2013–August 2014)

5. *Digital Dynamic Text Design*: The final step (project goal 3) is refining and extending both the theory and technology based on evaluation results. At this point we expect to have created sufficient knowledge about the benefits and limitations of digital dynamic texts in two content domains at two levels and in two cultural contexts that we feel confident of being able to propose an innovative design for eTextbooks that offers rich interaction and navigation functionalities to students and differs significantly from both printed textbooks and eTextbooks currently in vogue. This will be the prime deliverable of this exploratory project. (May–November 2014)

4.4 Evaluation Studies

These are slated to take place from April 2013–August 2014, during which there will be two project meetings, one in the United States and the other in Finland. Designing these experiments will be challenging, as it entails quantitative and qualitative data collection and analysis methods to address the different levels, content, cultural and educational contexts, in order to examine variables such as learning, motivation, engagement, cross-cultural use of materials, and teachers' roles. This section describes our initial ideas, which will be further refined during the first 6 months of the project. In particular, the measures and analysis methods described below should be considered preliminary.

We propose five quasi-experimental pilot studies to evaluate the digital resources we will develop: three in the United States and two in Finland. Here we describe the U.S. studies. The two studies in Finland, one on science content in a school and the other on computing content in a university, will follow a similar design. Details of these studies will be presented in the proposal to be submitted by our Finnish colleagues to the Academy of Finland or Tekes. The three studies in the United States will take place in a school in the Milwaukee, Wisconsin school district on science content, and at Auburn University and Virginia Tech for computing content. These studies will share a similar design elaborated below, though adjustments will be made to suit local conditions.

The same teacher will implement a set of course units for which digital dynamic texts have been developed in a course (a middle school science course and a sophomore/junior level computer science course on algorithms). At the school level, one class taught by the teacher will be assigned to the digital text condition and the other to the traditional teaching condition. At the university level, the teacher in one semester (Fall 2013 or Spring 2014) will use the eTextbook and associated pedagogy and in the other semester (Spring 2014 or Fall 2013) use a print textbook and traditional teaching. We expect approximately 30 students per classroom/term, yielding about 180 students with half (N = 90) in each condition.

Descriptive information regarding the schools and their teachers—demographics information, teacher knowledge and experience, etc.—will be included in reporting to richly describe the context of the classrooms. Our research questions and measures are related to learning outcomes and feasibility.

Learning Outcomes

Our research questions are:

(1) Do students understand connections among science concepts and principles better when using an eTextbook with integrated exercises than in the comparison condition?

(2) What difficulties do students have in using the eTextbook and integrated exercises?

Measures. We will use pre- and posttests of domain knowledge and a concept-mapping test. We will develop pre- and posttests of domain knowledge. In the concept-mapping test, students will be asked to draw a concept map, provide an explanation for each concept, make connections among concepts, and state how the concepts are related. Student maps at two points (pre and post) will be analyzed for growth of science knowledge. Research has shown that concept mapping is a powerful method for assessing conceptual change (Ruiz-Primo & Shavelson, 1996). Creating concept maps engages students in a thoughtful way, encouraging them to reflect on relationships among concepts and on the complexity of ideas (Novak & Gowin, 1984). Log files of students' use of the eTextbook will be recorded. We will record the time and sequences of student navigation among various components of the eTextbook.

Analysis. To examine students' learning outcomes, we will score the pre- and posttests and concept-mapping tests. Each multiple-choice item in pre- and posttests will receive one point. Responses to the open-ended questions will be scored as incorrect, partial, or complete. In concept maps, we will examine three aspects: (a) the number of concepts, (b) the number of accurate connections among the concepts, and (c) the explanation provided for the connections. We will score the explanations based on a rubric modified from previous work (Puntambekar, Stylianou, & Goldstein, 2007). We will then compute two ratios: the depth ratio (ratio of number of concepts and number of connections) and the richness ratio (ratio of the score for connections and the number of connections). Thus, we will have three dependent variables: post test score, richness ratio, and depth ratio.

We will use descriptive statistics and graphical analyses to support our initial quantitative data reduction efforts. Inferentially, we will use two analytic approaches to investigate our research questions. First, we will conduct multivariate factorial analysis of covariance (MANCOVA) for the three outcomes (posttest score, richness ratio, and depth ratio); the pretest of knowledge will serve as a covariate. Transformations to achieve normality of the proportion measures (depth and richness ratios) will be conducted as necessary to ensure validity of the statistical tests.

Feasibility and Usability

Research questions:

1. Are teachers able to effectively integrate an eTextbook into their teaching? What difficulties do they face in switching from traditional text to the eTextbook and inquiry-based teaching?

2. Are students able to effectively use the interactive and navigational features of the eTextbook? What difficulties do they face in non-linearly navigating through and interacting with content?

Measures. We will use the following measures to examine feasibility and usability: logs of students' interactions with digital text and visualizations, user experience questionnaire with Likert-type multiple choice questions and open ended questions, and teacher journals. Interaction logs will help us understand what students do and for how long. The user experience questionnaire will help us understand how students used digital text in the context of learning in a classroom, any difficulties they might have had, and their attitudes toward eTextbooks. We will have the teachers keep a journal to write down issues or concerns that arose when using the eTextbook and their attitudes and opinions on the feasibility of using eTextbooks within an inquiry-based pedagogy.

Analysis. We will use learning analytics, such as Google Analytics, to study students' navigational paths. Google Analytics' latest custom variables feature allows us to designate page views and events to both collect and visualize navigation and content information. These measures will allow us to understand whether and when students visited related concepts and the time they spent on concepts. These measures will allow us to understand whether students visited many related concepts. We will examine the correlation between the navigation measures and learning outcome measures.

Student responses to Likert-style questions will be scored and quantitatively analyzed. Their open ended responses will be coded to understand what features they like, what they do not, interface features and content that they had difficulty with, and any other suggestions that they provide.

We will use two approaches for coding teacher journals. One is phenomenographic analysis (Marton, 1986), in which categories will not be determined a priori but will emerge from the analysis of the responses. Thus, the categories for coding the data will be based on teachers' ideas rather than researchers' preconceptions. Based on this analysis, we will conduct the second approach, a thematic analysis (Miles & Huberman, 1994), to examine common themes that emerge from the categories.

4.5 Project Coordination and Management

The PI in the US project described in this proposal will be Dr. Puntambekar. She is the originator of CoMPASS and has significant experience leading large projects and conducting large-scale classroom implementations and evaluation. The project also involves two highly experienced and senior investigators as co-PIs. The PI for the Finnish project will be Dr. Raisamo, a similarly experienced researcher. The two PIs will be responsible for reporting to NSF and Finnish funding organizations (Academy and Tekes), respectively. All project investigators will collaborate and coordinate through a variety of means. Specific individuals will use Skype, telephone calls, and emails as needed, and a platform like Google Docs to collaboratively author documents. The US team of three investigators and the Finnish team of four investigators will use these means to collaborate and coordinate activities. The entire team will engage in monthly videoconferences using Skype. There will also be week-long biannual project meetings alternating between Finland and the United States. This proposal includes funds in the budget for the US investigators to visit Finland for these meetings once each year. There will be a corresponding budget request in the Finnish proposal. The Finnish proposal may also include additional personnel exchanges (students and postdocs) to further the coordination.

4.6 Appropriateness for EAGER

Even though concept maps have been around since the 1970s, the CoMPASS project was the first to investigate their use as a foundation for digital text. Similarly, OpenDSA is the first project to incorporate integrated visualizations and assessments into an eTextbook. However, the proposed project will be the first to systematically evaluate *across content domains, learner levels, and cultures* an eTextbook architecture founded on concept map-based organizations of domain knowledge. This unique aspect of the proposed project makes it both risky and capable of having a transformative impact. A challenge is coordination of research, technology development, implementation, and evaluation across seven investigators and institutions in two countries and three time zones. These risks are mitigated by the following. (1) Key individual components of the proposed design, concept maps and visualizations, have been shown to be effective in a variety of contexts by extant literature. (2) CoMPASS materials have been evaluated and found to be pedagogically effective for American middle school students. (3) The investigators have prior experience coordinating large scale and multi-institutional projects. (4) The US and Finnish investigators (Puntambekar and Narayanan, and Shaffer and Korhonen) have a prior history of collaboration. The potential payoff of the project is that if significant results are obtained, the design we will develop at the end of the project can form an alternative technological foundation for eTextbooks of the future.

5. Conclusion

We propose an exploratory project with potential high impact to design and evaluate a theoretically well-grounded and empirically tested next generation eTextbook through a productive international collaboration involving three US investigators and four Finnish investigators with significant combined expertise in learning and cognitive sciences, computer science, educational research, and human-computer interaction. We will conduct research on knowledge organization techniques for visualizing and presenting STEM content digitally, apply that research toward the development of dynamic digital text with STEM content, and evaluate it in multiple domains, levels, and cultural/linguistic contexts. Our long-term vision is that of a cloud-based service architecture that will allow *anytime, anywhere, and as-needed access* to dynamic digital content across an extensive set of topics for school and college level STEM education integrated with a novel pedagogy that makes effective use of digital STEM content. This EAGER proposal includes initial exploratory steps toward the realization of this vision.

EAGER: SAVI: Dynamic Digital Text: An Innovation in STEM Education

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