Learning from Digital Text in Inquiry-Based Science Classes: Lessons Learned in One Program

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Abstract: In this paper, I present a synthesis of the lessons learned from a research program aimed at understanding how students learn from the multiple linked texts in hypertext environments in the context of scientific inquiry. I started with a research agenda intended to systematically understand the importance of several variables that affect learning from hypertext environments. Further, the goal of my research has not only been to understand how students learn from hypertext but also to identify how students use hypertext in the context of inquiry-based science classes. In my research program, I conducted a series a studies to explore these two issues in parallel. My studies have helped identify factors that affect student learning from digital text, moving toward a conceptual model of learning from multiple linked texts. In addition, they have also helped identify successful teacher strategies used to help students learn from hands-on investigations and digital resources.

In the last decade and a half, there has been much discussion about the divide between educational research and practice (Lagemann, 2002) and a need to understand learning in complex real-world contexts (Brown, 1992; Collins, 1992; Cobb, Confrey, DiSessa, Lehrer & Shauble, 2003); DBRC 2003). Design-based research methods in which researchers try to understand the ways in which learning occurred in a particular setting are increasingly being used to understand teaching and learning in classroom settings. Unlike traditional experiments that involve controlling variables, the thrust in design-based research is to characterize the environment in which the intervention is used by developing an understanding of the actors (e.g., teachers, students) and the social structures in a particular setting, in order to develop rich representations of teaching and learning. But challenges of this evolving paradigm have also been recognized, such as the large amounts of qualitative and quantitative data that are collected leading to problems of coordination and analysis, the emergent nature of the questions and issues, (Dede, 2003), and the validity of claims (Shavelson, Phillips, Towne & Feuer, 2003). Shavelson, et al. (2003) have recommended "coupling scientifically warranted knowledge and rich contextual information in some narrative form might lead to increased understanding and use if scientific research in practice" (p. 28). This requires a systematic understanding of learning outcomes as well as the environment in which learning occurs, which has been a goal of my research program in the past five years.

In this paper, I present a synthesis of the lessons learned from a research program aimed at understanding how students learn from the multiple, linked texts presented in a hypertext environment in the context of scientific inquiry. Along with my research group, I started with a research agenda intended to systematically understand the importance of several variables that affect learning from hypertext environments. Further, the goal of my research project, CoMPASS, has not only been to understand how students learn from multiple, digital texts, but also to identify how factors in the classroom context affect student learning. I conducted a series a studies to explore these two issues in parallel.

CoMPASS Project: Motivation and Background

Hands-on activities in which students experience and manipulate scientific phenomena are an integral part of current project- and design-based approaches to science learning (Kafai, 1994; Kolodner et al., 2003; Krajcik, Blumenfeld, Marx, & Soloway, 1991). A concern raised about the focus on hands-on activities is that students can concentrate on the construction activities, and build a working solution by trial and error without understanding the underlying deep science principles and phenomena (Kolodner et al., 2003). Further, as students begin to tackle complex scientific phenomena in higher grades, they increasingly encounter the necessity to utilize other ways to foster scientific reasoning, one of which is the use of text-based resources. But "text is seldom studied in the context of everyday classroom use . . . and there is little attention given to the integration of text with other modes of experiencing and learning science" (Palincsar & Magnusson, 2001, p. 152).

A problem with integrating text in scientific inquiry is the paucity of good science textbooks. Commercially available science textbooks have been criticized for merely imparting facts, emphasizing breadth of coverage over depth, and frequently including "errors, misconceptions, and confusing presentations" (Raloff, 2001). But with the proliferation of technology, electronic texts in the form of hypertext and hypermedia systems (e.g., Azevedo, & Cromley, 2004) as well as digital libraries (e.g., Hoffman, Wu, Krajcik, & Soloway, 2003) are increasingly being used in scientific inquiry. Digital or hypertext documents are nonlinear and flexible, and enable students to follow their own investigation paths. However, the flexibility also poses challenges because students have to make decisions and browse through the space selectively (Bolter, 2001). Successful integration of digital text resources in scientific inquiry requires (a) an understanding of the cognitive processes that students employ while reading from multiple texts in the context of a science classroom; and (b) an understanding of the ways in which electronic resources can be integrated with hands-on science activities. The focus of my research program has been on both these issues.

The CoMPASS project consists of a hypertext system, CoMPASS (Puntambekar, Stylianou & Hübscher, 2003) and curriculum modules based on the pedagogical framework of Learning By Design (Kolodner, et al., 2003). The CoMPASS system is designed with two tightly integrated representations: a textual representation of the content units and a visual representation in a form of concept maps. Each screen in CoMPASS represents a concept such as *mass* or *gravity,* providing both a concept map (left half of the screen) and a textual description (right half of the screen). The maps are dynamically constructed and displayed using the *fisheye* technique (Bedersen & Hollan, 1995)—that is, the focus concept the student has chosen is at the center of the map, with the most closely related concepts displayed in the first ring and the less closely related concepts displayed at the outer ring. The maps in CoMPASS show connections between science phenomena, giving students alternative paths to pursue for any particular activity, so that they can see how different phenomena are related to each other. CoMPASS also supports alternative views of concepts. For example, a student might be interested in learning about the phenomenon of force in the context of objects falling in air. The student can change views at any time to study the same phenomenon (e.g., force) in other contexts, such as linear motion or simple machines.

The CoMPASS software environment is used in conjunction with the curriculum units that we have designed. We have developed a ten-week Simple Machines unit and a Roller Coasters Unit. The "Simple Machines" unit starts by introducing students to the "Can Lift Challenge," in which they are presented with the problem of building a device using simple machines to lift a 16-ounce can of food. In the first couple of days, students brainstorm their initial design ideas and draw plans of their designs. After this, they are introduced to each of the simple machines by way of activities such as using a ramp to raise a heavy object to a certain height. Each activity is designed to enhance students' understanding of science phenomena and revisiting underlying scientific principles. Students go back to the Can Lift designs approximately halfway through the unit and again at the end. Students use CoMPASS throughout the design process. For example, after the initial brainstorming, they refer to the information in CoMPASS to refine their questions. Once they have generated questions they use the system again to find the information and apply it to their designs. They use the software again as they are working on their designs to find out more about the specific topic so that they can revise and optimize their designs and interpret the data that they are collecting.

Summary of Research

In the past five years, I have been working on systematically building an understanding of the variables that affect learning, both how students process texts and factors in the environment that affect learning. In doing so, I have used as the conceptual framework, both theories in comprehension of expository texts as well as lessons recent work in inquiry-based science learning. A range of qualitative and quantitative measures was used, depending on the complexity of the research questions for each study. Some such measures were: (a) a pre-post test with multiple-choice items and an essay question to study change in students' knowledge of Physics; (b) concept-mapping post-test to analyze the richness of students' conceptual understanding; (c) a post-test survey to understand students' use of CoMPASS; and (d) process measures of navigation through CoMPASS, in the form of log files. The navigation data were analyzed using the pathfinder algorithm (Schvaneveldt, 1990) to study the transitions that students make between concepts, relationship to goals, and richness and focus of their navigation patterns.

Four teachers in 40 sixth and eighth grade classrooms by over 800 students have used the CoMPASS materials. While each study examined students' learning outcomes (pre and post test scores and scores on concept mapping tests) in all of the classrooms, I focused on a few questions in each study, incrementally building an understanding of how students learn from digital resources in an inquiry classroom. I conducted studies to understand the role of coherence and metacognition in hypertext, as well as the role of teacher facilitation as students used the CoMPASS materials in the classroom. In the next few sections, I will summarize the key findings.

Learning from multiple texts: Role of structure and coherence

The Construction-Integration model of text learning distinguishes between two levels of understanding – a textbase and a situation model. The textbase can be described as the "the text as it is" (Kintsch, 1998). It reflects the organization of the text as contained in the macro and micro propositions. Text coherence, created by the relatedness and overlap of the propositions that make up a text play a vital role in comprehension. In hypertext systems, a key feature of text structure, global coherence (i.e. coherence between sections), is lost due to the multiple linked texts (nodes). Hypertext environments are different from traditional expository text in two important ways. First, hypertext environments are "multilinear" (Bolter, 2001) in that each text segment can be linked to many others, providing multiple paths to access any node. Second, in traditional text, the organization is embedded in the text itself. In hypertext, however, the organizational information (overviews, outlines, etc) is separate from the text (Dee-Lucas & Larkin, 1995), making it harder to establish global coherence. Learners therefore need to integrate Information from two sources, the text and its organization. In the CoMPASS hypertext system, I have addressed the issue of providing global coherence by using two concept maps that show relations between science concepts. My first set of studies was an attempt to understand how providing maps affect students' navigation and learning. With my graduate students, I conducted studies in sixth and eighth grade classes, that used different versions of the system, one the navigable maps, and the other with an outline in the form of a list, to understand how providing structure affects navigation and learning.

In the eighth grade study, students in two classes (N=36) used the system to learn about 'Forces and Motion' for three days. Students did not use their textbooks for this unit but used CoMPASS as a resource. On each of the days, students used CoMPASS for forty-five minutes. Both classes were taught by the same teacher and followed the same activities. Student understanding was measured with a pre-post test that had multiple choice items and open-ended questions to test students' scientific reasoning. In addition, students drew concept maps at the end of the describing their understanding of the concepts and the relations between them. We found that the version of CoMPASS (map or outline) did not affect students' scores on the multiple-choice portion of the pre and post tests. This showed that as far as the knowledge of factual information as measured by the pre and post tests was concerned, the coherence provided did not affect learning outcomes. However, significant differences between the two groups were found in the open-ended questions in the Physics post test, with the maps group performing significantly than the outline group (ES=.82). Similarly, analysis revealed that while there was no difference in the two groups for the explanations provided for the concepts, there was a significant different in the depth of the science that described connections between concepts (ES=.38). The connections that they made between concepts showed that they had gained a deeper understanding of the relationships between concepts, for example mass and acceleration. Their maps were richer and they also used more formulas.

In the sixth grade study, students used CoMPASS over a seven week period during the simple machines unit. As students engaged in investigations designed for each simple machine (e.g., wedge, pulley, lever), the used CoMPASS to find the information that would help them in their investigations. A total of 80 sixth-grade students from four classes participated in this study. Two of the classes used a maps version of the system and the other two used an outline version. During the 7-week unit, there were a total of 18 sessions in which all the students used CoMPASS, each lasting approximately 20-25 minutes. Similar to the eighth grade study, a multiple choice pre and post physics test and a concept-mapping test were used to measure students' knowledge of physics concepts and principles. We found that there were no differences in the pre and post test scores between the maps and the outline groups. Results suggested that in so far as knowledge of physics principles as measured in the multiple choice pre and post test was concerned, there was no significant difference between the maps-group and the outline-group, indicating that to the extent that knowledge of the factual information represented in science text is concerned, the coherence in the system did not affect learning. However, analysis of students' performance on a concept-mapping test showed that students in the maps-group had a significantly deeper and richer understanding of the science content (ES=.09). Students in the maps-groups seemed to have understood the interconnected nature of the concepts and principles that they were learning across the set of simple machines (Puntambekar & Goldstein, submitted).

These studies suggested that similar to traditional texts, providing coherence plays an important role in learning from hypertext systems. I have described three levels of coherence in CoMPASS – intratextual (within a node), intertextual (between two nodes) and metatextual (among several nodes) (Puntambekar, submitted). The maps provide both intertextual and metatextual coherence by showing the relations between two nodes and by illustrating how a particular node can be placed in relation to several related nodes.

Metacognition in Hypertext: Metanavigation Support

Metacognition, which refers to the knowledge that we have about our own cognitive processes, has been proved to be a significant factor for text understanding. According to Brown and her colleagues (e.g., Brown et al., 1985) important metacognitive differences exist between good and poor readers in the way they process texts. Campione, Brown and Connell (1988), believe that successful learners can reflect on their learning activities, have available powerful strategies for dealing with novel learning situations, and oversee and regulate those strategies efficiently.

In two studies, I examined whether metacognition was a factor that affected student learning from multiple linked texts. The first study (N=74) involved an analysis of students' navigation patterns to group them into clusters, using a k-means clustering technique. Based on this analysis, navigation patterns were grouped into four clusters, enabling us to understand the kinds of support that students needed. This analysis showed that although the maps provided structure, the affordances of the maps were not always obvious to low-knowledge students. Students needed further support to select nodes that were related to (a) the current node and (b) to their goals (Puntambekar & Stylianou, 2005). This formed the basis of the next study that I conducted a study, with one of my doctoral students, in which students' navigation was supported by providing metacognitive prompts for navigation in CoMPASS – metanavigation support (Stylianou, 2003). The metanavigation support enabled students to (i) select concepts based on their goals (ii) make transitions that are coherent, and (iii) understand the nature of the relationships between concepts. Results of the study suggested that providing metanavigation support enabled students to make coherent transitions among the text units. In addition to metanavigation prompts, reading comprehension and prior knowledge significantly predicted students' understanding of science principles and the relationships among them (Stylianou & Puntambekar, 2004).

CoMPASS in Science Classrooms: Understanding the Context

Understanding the elements of a context and addressing research questions relating to the enactment of interventions in varied contexts have been emphasized as important goals for education research (Brown, 1992; Design-Based Research Collective, 2003). Proponents design based methods have advocated the importance of characterizing the situation, understanding the synergistic nature of classroom life (Brown, 1992) and understanding of the classroom as a "learning ecology" (Cobb, et al., 2003) consisting of several interacting components. Very often, this means a systematic analysis of enactments in a setting, in an effort to understand the factors in a local context that may or may not have lead to the success of an intervention. One of the main aspects of such an analysis is studying classroom interactions to develop an understanding of the factors that might contribute to student learning. In our studies, teacher facilitation of class discussions, as well as discussions in student groups were analyzed.

Role of Teacher Facilitation

I have been studying classroom enactments of the COMPASS materials by different teachers (Puntambekar, Stylianou & Goldstein, accepted). Examining how teachers structure the activities in a unit and how they facilitate classroom discussion is important to understand how innovative technology rich curricula work in the context of classroom instruction. In one of our recent studies, we examined students' learning outcomes in classes taught by two teachers. We then analyzed enactments by the two teachers, Mrs. J and Mrs. L, to understand the differences in the learning outcomes. Our quantitative data showed that there were significant differences in the learning outcomes of students in classes taught by the two teachers, with Mrs. J's students significantly outperforming Mrs. J's students in measures of deep understanding. We then analyzed the enactments of the curriculum by the two teachers to understand whether the differences in the enactments might have lead to differences in learning outcomes. We specifically focused on how teacher led discussions can help (a) connect the activities within a curriculum unit and (b) enable deeper conceptual understanding by helping students make connections between science concepts and principles. Analysis of teacher led discussions helped understand (a) the role teacher facilitation played in integrating the software with the design activities and (b) the kinds of facilitation that enabled students to make better connections between their hands-on science exploration and the more abstract activity of finding and making sense of science information.

One of the main differences in the two enactments was that all the different phases of the unit were carried out as an interconnected set of events in Mrs. J's classes, while in Mrs. L's class each activity seemed to be an end in itself. While Mrs. L had all the parts of inquiry, the deep structure that connected all the phases was lacking. Students in Mrs. L's class were on task and completed all of the investigations in the curriculum, Mrs. J's students seemed to have been encouraged to think about the purpose of every activity and how it was connected to the others in the unit. The second major difference was that Mrs. J's strategies during facilitation of whole class discussions were different for the different phases of the unit. In the early part of the unit, Mrs. J focused more on enabling students to ground the current topic in what they already knew about simple machines, while in the later discussions, she asked questions that encouraged students to reason about the science that they were learning, helped make connections between abstract science principles and their concrete hands-on experiences, and connections between concepts. In particular, the two enactments differed in terms of: (a) helping students raise questions that are related to the overall goal of the challenge, (b) helping students see how abstract ideas are related to their experience with physical objects (c) enabling an understanding of how each activity in the unit is connected to the rest of the unit (d) reinforcing the connections between concepts that they are learning and enabling students to understand core principles by reiterating big ideas. While no causal claims can be made based on this study, results of this study have helped me unpack aspects of teacher facilitation that might affect learning, helping with future studies.

Other Studies

I have also conducted other studies, which I cannot discuss in any detail due to space constraints. For example in one study to understand gender differences (Goldstein & Puntambekar, 2004), we analyzed the group conversations during students' work on CoMPASS and their hands-on investigations. The analysis showed that girls might actually be more dominant in a small group setting. Girls generated most of the discussion during both activities in three of the four groups analyzed. The data also indicated that girls generated more novel suggestions than the boys in both activities and that boys asked more questions and generated higher rates of non-goal related talk. In another study, a case study approach was used to examine the relation of metacognitive awareness in reading from traditional expository text and reading from hypertext. Results revealed that there might be a positive relationship between the metacognitive awareness of reading strategies and the navigation behavior while reading from hypertext (Stylianou & Puntambekar, 2003). A study in which high knowledge college students used CoMPASS, I found that the maps were not used by high knowledge students. Interestingly, high knowledge middle school students also did not use the maps, but they missed important information and did not complete their investigation successfully. After each of our implementations, we also worked closely with teachers to get their feedback on the curriculum units, which we have revised over the years.

Lessons Learned and Future Work

Studies conducted in my research program have helped further our understanding of how students learn from digital, multiple texts as well as the classroom factors that facilitate learning. I believe that design based research methods can describe studies within a research program, rather than a single study within a program of research. I have conducted studies in the classroom as well as smaller, more focused studies, and knowledge of how students learn has been accumulated over several studies. A key aspect of my studies has been the use of measures of student outcomes as well as rich narrative descriptions from the classrooms. Each study has helped identify variables that affect student learning. These were then explored further in subsequent studies, and have also provided the groundwork for the next phase of the project. For example, knowledge gained through the studies has helped me move toward formalizing a conceptual model for learning from digital text, describing levels of coherence and understanding the support that students need. In future studies, I will be conducting studies to refine this model to understand the role played by coherence in hypertext systems and its interplay with learner and task variables. With access to digitized content growing rapidly, because of the WWW, the need to understand how students learn from multiple, linked texts is an important line of research. Similarly, my studies have also helped understand factors such as teacher facilitation. Again, in the current phase of the project, I am building on the lessons learned about the role of teacher lead discussions. A study is currently underway to examine how teachers in four different schools implement the CoMPASS intervention. The schools are in different states in varied areas such as inner city, rural and suburban. Each site is different in student population, teacher experience and preparation, and teaching styles and practices. Starting with the strategies identified in this study, we will find evidence for these, or derive new successful strategies that teachers may have used. Multilevel contextual models will be used to include derived variables from the qualitative synthesis of the enactments that may help to explain differential outcomes across conditions.

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