HOW DO STUDENTS NAVIGATE AND LEARN FROM NONLINEAR SCIENCE TEXT: CAN METANAVIGATION SUPPORT AND PROMOTE LEARNING?

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ABSTRACT
In the past few years there has been an emphasis in the development and use of hypertext resources to promote science learning in interactive inquiry-based environments. Nonlinear resources such as hypertext and hypermedia systems afford learners the opportunity to interact with large integrated bodies of information presented in alternative representations and contexts by browsing through the space selectively and reading information in a manner relevant to students' current goals. Despite their flexibility, hypertexts pose challenges to learners. When reading nonlinear text each reader arranges her own unique text and the paths that she follows might affect text understanding. Hypertext users not only do they have to understand the information presented, but they should also be able to identify what information will further enhance understanding and how to access this information. In this paper we are proposing the use of metanavigation support to encourage readers to attend to multiple investigation paths and reflect on the paths that they follow while reading nonlinear science texts. We explain how metanavigation cues can be used to compel readers to think about the processes they employ while navigating a hypertext system and help them monitor and regulate these processes in order to accomplish their learning goals.

KEYWORDS
Hypertext, navigation, metacognition, reading comprehension, science learning

INTRODUCTION

Students have traditionally used books to find science information. Nonlinear resources such as hypertext and hypermedia systems introduce new ways to learn by allowing more learner control over sequence and content, diverging from a linear path. They afford the learners the opportunity to interact with large integrated bodies of information presented in alternative representations and contexts by browsing through the space selectively reading information in a manner that is meaningful to them (Bolter, 2001). Educational hypertexts support a nonlinear way of learning by emphasizing the understanding of the multiple interrelationships among concepts. In a subject area such as science it is important to encourage students to learn science concepts "as organized networks of related information not as random lists of unrelated facts" (Glynn, Russell & Gritton, 1991). Hyperlinks (words that are highlighted in the text) help learners to see concepts in different reading contexts, thus providing more opportunities for the learners to better integrate the new information with their prior knowledge. As described by Spiro, Feltovich, Jacobson and Coulson (1991) in the Cognitive Flexibility theory, "revisiting the same material, at different times, in re-arranged contexts, for different purposes, and from different conceptual perspectives is essential for attaining the goals of advanced knowledge acquisition"(p. 28).

Because of its flexibility, hypertext poses challenges to learners. The nonlinear representation of the multiple text fragments (nodes) and the large number of links in a hypertext environment require the user to constantly make decisions and evaluate progress (Marchionini, 1988). Hypertext users need to create both meaning and structure while reading. Not only do they have to understand the information presented, but they should also be able to employ certain decision making skills in order to decide what paths to pursue that will enhance understanding.

Hypertext research has demonstrated the importance of providing structure and navigational aids to guide hypertext users to make coherent transitions between concepts. However, recent studies have suggested that the navigational aids that are available in hypermedia systems might not always be intuitive to learners (Laurillard et al., 2000). Classroom implementations of an interactive nonlinear resource called CoMPASS (Concept Mapping Project-based Activity Scaffolding System) in middle school project-based science classrooms supported this assumption (Puntambekar & Stylianou, 2002).

The question that arises is what kind of support do hypertext users need to understand the affordances of the navigational aids in a hypertext system and enable them to create an integrated understanding of science ideas while processing nonlinear information? In this paper we are proposing the use of metanavigation support to encourage readers to attend to multiple investigation paths and reflect on the paths that they follow while reading nonlinear science texts. We explain how metanavigation cues can be used to compel readers to think about the processes they employ while navigating a hypertext system and help them monitor and regulate these processes in order to accomplish their learning goals.

CHALLENGES OF READING NONLINEAR VS. TRADITIONAL TEXT

Navigating a nonlinear resource is different from reading a printed book. It requires more metacognitive effort and active involvement (Marchionini, 1988). When reading a traditional text, a reader can depend on knowledge of text structure to help create inferences that aid in text understanding (Kintsch & van Dijk, 1978). However, the reader of an electronic text must not only understand the information presented, but must also be able to identify what information will further enhance understanding and how to access this information (Thüring, Hannemann & Haake, 1995). The added responsibility of applying structure to the text changes the nature of learning that occurs with hypertexts when compared to more traditional texts. Each hypertext system has a different structure and global coherence (flow of the different sections in a text) depends not only on the authors/designers' decisions but also on the choices that the readers are making while navigating the space of a hypertext. According to Bolter (1998) the reader "seems to be collaborating with the author in the creation of text, in the sense that the choice of links determines what the reader will next see on the screen." Each reader arranges her own unique text and the paths that she follows might affect text understanding.

The navigational decisions that readers need to make while reading nonlinear texts may present difficulties and impose a higher cognitive load, especially to readers with low prior knowledge (Charney, 1987). As a result they may get lost in the hyperspace, unable to identify where they are, what links to follow and in what order information will be accessed. Conklin (1987) describes this dilemma as 'informational myopia'. In such rich environments there is a tradeoff between system flexibility and cognitive overload on the user. System flexibility does not guarantee better learning without the learner's active involvement and right decision making. Hypertext users should be able to plan certain cognitive learning activities and to manage to monitor these activities such as setting a learning goal or using a strategy (Jonassen, 1989).

NAVIGATIONAL AIDS IN HYPERTEXT

Hypertext research has demonstrated the importance of providing the reader with structural cues to facilitate readers' orientation and help them make coherent transitions between the different text units (Foltz, 1996). Hypermedia designers have used navigational aids such as outlines (Dee-Lucas, 1996; Shapiro, 1998), adaptive hypermedia systems (Eklund, Brusilovsky & Schwarz, 1997) and spatial maps (McDonald & Stevenson, 1999) to support effective decision-making during navigation and help users to select appropriate links.

However, providing navigation tools does not necessarily mean that students will make the right choices while using a nonlinear resource. A research study conducted by Dee-Lucas (1996) has shown that students often disregard important material even if structural cues are available in a nonlinear environment. A reason might be the fact that the affordances of the structural aids that are available in a hypermedia system are not always intuitive to readers (Laurillard et al., (2000). Therefore, they might not easily understand how to use them effectively while reading nonlinear information. Our empirical studies of CoMPASS, a hypertext system, in middle school science classrooms also seem to support this claim (Puntambekar & Stylianou, 2002).

WHAT IS CoMPASS

CoMPASS (Puntambekar, Stylianou & Jin, 2001; Puntambekar, Stylianou & Hübscher, 2003) is a science hypertext system that has two tightly integrated modes of representation: a textual representation of the content units and a visual representation in a form of concept maps. Concept maps are diagrams that graphically illustrate the relationships among key ideas in a text (Novak & Gowin, 1984). The maps are dynamically constructed and displayed with a fisheye view based on the strength of the relationships among concepts providing conceptual support to the readers as they traverse the domain and make choices (see Figure 1). The maps show the local subnetwork of the domain and where the links lead to, enabling readers to see the relationships among the text units (concepts) and make thoughtful decisions of what paths to follow without getting lost or confused. CoMPASS also supports readers to study a science idea in multiple contexts by changing views (top right of screen in Figure 1).

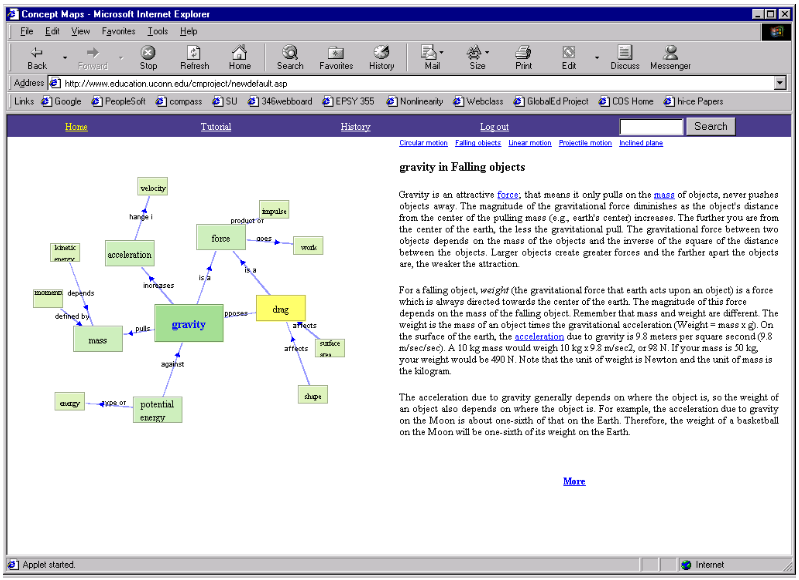

Figure 1: Textual and visual representation of information with ‘gravity’ as focus

In Figure 1 the reader has chosen to read about gravity in falling objects. Gravity appears as the focal concept in the map and the text related to gravity appears in the right part of the screen. The concepts that are most closely related to gravity appear larger and closer to the focus whereas the concepts that are not as closely related to gravity appear in the periphery. The maps allow for exploration and support students to take multiple investigation paths based on their learning goals at any particular time.

CLASSROOM IMPLEMENTATIONS OF CoMPASS

Our empirical studies in middle school classes led us to believe that the functions of the navigational aids (maps) might not be intuitive to middle school students (Puntambekar & Stylianou, 2002). Middle school students used the maps in CoMPASS as a navigation tool to find information about science concepts in order to pursue their goal but they did not understand that the maps could help them see the connections described in the text and find the related concepts so that they would get a rich and integrated understanding of science ideas. Therefore, they were unable to use this function and make thoughtful navigation decisions. Analysis of students' navigation paths, students' discussions while using CoMPASS as well as classroom observations showed that sixth graders were able to use the textual representation to find information about single concepts but could not make connections with other concepts or view the same concepts via multiple routes. They were not able to integrate the different pieces of information presented in the CoMPASS system and relate them to their goal.

Using a nonlinear science resource in a classroom has shown that learners may need support to understand the structure of a hypertext system and regulate their navigation behavior in order take advantage of its affordances. The question that emerges is what kind of support do hypertext users need? Our classroom observations suggested that metacognitive support provided by the teachers enabled students to integrate science knowledge. Thus, we assume that a combination of reading comprehension and metacognitive strategies (i.e. monitoring and self-regulation) as well as thoughtful navigational decisions while reading nonlinear science text may lead to an integrated understanding of science ideas.

METACOGNITION AND TEXT COMPREHENSION

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. Research has been conducted to train students how to monitor and regulate their learning while reading traditional texts (Brown, Armbruster & Baker, 1985; Brown & Palinscar, 1987; Paris & Jacobs, 1984). Brown and her colleagues have studied how metacognitive strategies can be used as an aid to ongoing comprehension of a text (Brown & Palinscar, 1987). The reciprocal teaching studies have shown that talking about thinking while reading helped students to monitor their learning from texts.

The reading comprehension literature also suggests that there are individual differences among readers of different abilities in metacognitive knowledge, experience and strategy use (Pressley & Afflerbach, 1995). Good readers have been found to demonstrate metacognitive differences compared to poor readers in the way they process linear texts. Skilled readers often engage in deliberate activities that require planful thinking, flexible strategies, and periodic self-monitoring (Jacobs & Paris, 1987). They typically look over the text before they read, noting such things as the structure of the text and text sections that might be most relevant to their reading goals (Duke & Pearson, in press). Skilled readers also adjust their reading rates based on their goals, evaluate their own understanding as they pause, paraphrase, answer questions, or summarize information in text and monitor progress revising or modifying plans and strategies depending on how well they are working (Pressley & Afflerbach, 1995). On the contrary, unskilled readers often seem oblivious to these strategies and the need to use them. They are quite limited in their metacognitive knowledge about reading and tend to focus on reading as a decoding process than as a meaning-construction process (Garner, 1987).

Promoting self-awareness, monitoring and regulation of text comprehension are important aspects of skilled reading in the domain of physics (Koch, 2001). Being aware of the metacognitive strategies that readers employ while reading can influence how well they plan and monitor their understanding from science texts (Yore, Craig & Maguire, 1998). An important science reading strategy is to utilize efficient search-ahead and look back procedures that allow the reader to construct meaning from related information in the text and gain a rich understanding of the domain. Readers also need to be able to use visual representations in science texts, such as graphs, to help organize or enrich the meanings derived from the text.

One would assume that it might be helpful to encourage readers to control and regulate their comprehension strategies while reading nonlinear science texts. However, it is still unclear what level of cognitive processing is actually involved while reading nonlinear information. Since nonlinear reading requires learners to make critical navigational choices, our definition and fundamental understanding of comprehension might not keep pace with the changing nature of text. Is it appropriate to use schemes or assumptions based on strategies used while reading in a linear system (printed materials) to analyze and describe reading in a hypertext system? There are still many questions that need to be answered to yield a better understanding of how people interact and learn from such complex information systems. In the following sections we raise some of these issues as we describe our framework about providing support that will encourage students to be reflective while constructing meaning from hypertext.

METANAVIGATION SUPPORT

As we have seen in the previous section being a mindful and metacognitive reader depends on how well you keep in track of what you are doing and how well (if at all) you use input from such observations to guide your actions. We have also discussed the challenges that are presented to readers by the hypertext medium. Readers will have to learn how to take advantage of different presentation formats of information and in doing so they might need to acquire new text comprehension strategies. Some researchers have suggested that it is likely that "text navigation may walk hand in hand with text comprehension" (Duke & Pearson, in press). Bolter (1998) claims that the technology of hypertext makes the process of meaning construction partly visible. According to the author "what becomes visible are the choices that the reader makes in following links, as each link followed indicates part of the reader's construction of the meaning of the text." Readers' navigation paths might be windows into thinking while processing nonlinear materials. Therefore, we suggest that studying navigation behavior might help us not only to gain some insights about the strategies that readers employ while reading hypertext but also to decide what kind of support they need in order to become mindful readers and gain a rich and in-depth understanding of the domain.

Since hypertext assumes a world of multiple texts we think that it is important for readers to be aware and regulate both their comprehension and navigation strategies while learning from nonlinear texts. Hypertext readers need to make thoughtful decisions about what paths to follow and be able to integrate the knowledge acquired from the different text fragments. They need to be encouraged to ask the following questions as they read nonlinear text: What are my goals? How do I get information from multiple texts? How do I decide where to go? How do I monitor my navigation path? How do I improve myself so I will be more effective in finding and synthesizing information? We define one's awareness of and ability to utilize strategies for enhancing rich understanding of the domain while navigating a hypertext as *metanavigation*.

Metanavigation cues can compel readers to think about the processes they employ while navigating a hypertext system and help them monitor and regulate these processes in order to accomplish their learning goals. Readers can become aware of their navigation strategies by explaining their navigation paths to others or to themselves, reflecting on their navigation decisions and revising them so that the next time they engage in nonlinear reading they can draw upon improved navigation processes for assistance. Such reflections may unveil judgments about the reader's thinking processes that serve as descriptions of metanavigation.

Deciding what metanavigation support to provide to each individual reader is a challenge for hypertext designers. In the following sections we describe the framework that we have developed about when and what metanavigation support should be provided to hypertext readers. We also describe our future research plans of conducting an empirical study with middle school students to inform our understanding of metanavigation.

CONCEPTUAL FRAMEWORK FOR METANAVIGATION SUPPORT

Our framework for providing metanavigation support has been informed by the artificial intelligence in education literature especially the guidelines that are provided in the development of cognitive tutors (del Soldato & du Boulay, 1995). There are three different sources that enable us to assess learner's metacognitive state during navigation and decide whether to provide metanavigation support.

Performance in ongoing reading comprehension assessment tasks
Assessing reading comprehension is an important indicator of whether the reader has understood the information presented in multiple nonlinear texts. It is also important to assess reader's ability to synthesize and integrate ideas and recognize connections that reflect the interconnected nature of science. Readers can be assessed on their ability to explain relationships among science concepts either by writing a paragraph, or by creating concept maps. Concept maps can be effective assessment tools because they engage students in a thoughtful way where they must reflect on relationships among concepts and consider the complexity of ideas. Jonassen (1996) argues that students show some of their best thinking when they try to represent something graphically. 'Representing' information and 'knowing' have been closely intertwined in the science domain (Novak & Gowin, 1984). A number of studies have shown that concept mapping is a powerful and psychometrically sound method for assessing conceptual change. Research has demonstrated that concept maps can yield to reliable and valid results (Ruiz-Primo, Schultz, Li & Shavelson, 1998)

Logfile information that captures learner's actual navigation path
Navigation patterns can be important indicators of learning from hypertext. According to Cognitive Flexibility theory, learning with hypertext materials involves the cognitive reconstruction of a domain space through repeated traversals across that space (Jacobson & Spiro, 1995). Therefore, the paths that users choose have a powerful influence on learning outcomes in hypertext. A comprehensive analysis of navigational patterns can provide useful insight into hypermedia processing and be used to better explain the effects of self-regulated learning in such environments (Niegemann, 2001). Researchers have used computer log files to look more deeply into the navigation paths of learners in an attempt to detect differences in approaches to reading and learning from hypertext (Barab, Young & Wang, 1999).

A navigation path represents a complete measure of user navigation and thus affords an important window for search process and the strategies readers apply in acquiring information (Lawless & Kulikowich, 1996). One important aspect of the path record is that it creates a unique opportunity to non-intrusively capture the dynamic processes of hypermedia navigation as they unfold and gain insights into the learning process (Barab et al., 1996).

Table 1. Actual navigation based on log file data

Log file information (actual navigation)	Type	Description
Concepts visited	Random Goal related	Do students visit concepts that are relevant to their learning goal?
Time spend on concepts	< threshold ≥ threshold	Do readers spent different time on concepts that are meaningful to their goals than other concepts? Do they spend enough time on the goal-related concepts?
Dimensionality	1 situation >1 situations	Is the navigation unidimensional (visit concepts in one context) or multidimensional (visit the same concept in many contexts)?

Table 1 shows what type of information can be collected in a log file as the reader interacts with the hypertext environment to inform our assumptions of the navigation strategies that are employed during hypertext reading. Analyzing these pieces of information can help us determine whether reader's navigation behavior is goal oriented or not, whether she changes views to read about a science idea in multiple contexts and whether she adjusts reading time spent on reading about concepts that are important to accomplish the goal. The time spent on goal-related concepts is evaluated based on whether it is above or below a threshold value that is determined based on the average reading time that each individual reader needs to read and comprehend a certain amount of text.

Learner's self-evaluation of awareness of navigation strategies employed

We have developed a questionnaire that assesses learner's awareness of the navigation strategies while using the CoMPASS system. Students' responses in the questionnaire will be labeled as high/low based on how frequent they use the navigation strategies that are described in each item of the inventory. Another self-report measure that can provide insights into the learner's metanavigation state is to prompt learners to provide explanations of their navigation paths right after their interaction with the hypertext environment. The evidence that will be collected from the self-reports can be organized in similar categories as the information collected from the log file information (see Table 2).

The decision of whether or not to provide metanavigation support is based on the learner's performance in the ongoing reading comprehension assessment tasks. A successful performance indicates that the reader has acquired knowledge about the science ideas that are important to the learning goal and how they are interconnected. Therefore, at this point the reader is not given any metanavigation support. She is just provided with feedback rewarding her successful performance.

Table 2. Awareness of navigation strategies based on self-reports

Self-report (awareness of navigation strategies)	**Type**
Goal-directed navigation	Random vs. thoughtful choice of topics/concepts, hyperlinks in text and hyperlinks in navigational aids (i.e. maps)
Adjusting reading rate	Skim text for content Adjust time spent while reading text for goal related concepts
Dimensionality	Change views of concepts for reading in-depth information

Now let us consider a situation of a learner who fails in the reading comprehension assessment tasks. In such a case there is a negotiation between actual navigation and awareness of navigation strategies to decide what kinds of metanavigation prompts should be provided (see Table 3). If there is a conflict between reader's responses in the self-report and the log file information that reflects the actual navigation path, then the decision of what metanavigation support will be given to the reader is based primarily on the evidence from the log file.

Table 3. Rules for providing metanavigation support

	Metanavigation support rules	Metanavigation Prompts
Reading rates	If time spent on goal related concepts < threshold ⇒ encourage adjusting time spent on reading goal related concepts	You can adjust the time that you spend reading information depending on what science ideas you think are more important to your goal
	If time spent on goal related concepts ≥ threshold ⇒ encourage regulation of navigation behavior	Think about your goal as you make decisions of where to go next. It will save you a lot of time and effort. Try to make thoughtful decisions of what paths you follow using the maps
Navigation choices	If random choice of concepts ⇒ encourage goal-related navigation	Think about your goal as you make decisions of where to go next. It will save you a lot of time and effort. Try to make thoughtful decisions of what paths you follow using the maps
	If goal-related navigation ⇒ encourage Integration of knowledge	Use maps to make connections among the multiple pieces of texts in order to put all the pieces of information together.
Dimensionality of navigation	If unidimensional navigation ⇒ encourage multidimensional navigation	Change views to read about science ideas in different contexts
	If multidimensional navigation ⇒ encourage integration of knowledge	Use maps to make connections among the multiple pieces of texts in order to put all the pieces of information together.

The next step is to decide what type of metanavigation support each reader needs. There are three main sources that enable us to make this decision: reading rates, navigation choices and dimensionality of navigation. Specifically we are interested whether or not the reader has chosen to read about science ideas that are relevant to her learning goal and whether she spent enough time reading about these concepts. Adjusting reading rates is a strategy that skilled readers employ while reading linear texts and we assume that could be employed in hypertext reading to enhance text comprehension (Pressley & Afflerbach, 1995). We are also looking into the dimensionality of navigation. For example, did the reader change views while reading about science ideas or did she focus in one context? We consider the existence of alternative views as an indicator of acquiring in-depth understanding of science information. Considering the binary state of each of these categories, we could have six different cases, described in the 'metanavigation support rules' cells of Table 3, as well as various combinations.

We are also considering applying some hierarchical priority to the rules that inform our decisions of what metanavigation support should be given to students. For example, one might argue that it might be more important to check whether navigation is goal related than multidimensional and prompt the learner to focus on reading about many concepts that are related to their goal rather than reading about the same concept in multiple contexts. A pilot study with seventh grade students is currently underway to evaluate this scheme of metanavigation support test whether it has any effect in regulating learner's navigation behavior. After analyzing the pilot data we will be able to decide whether there is a need to consider a hierarchical priority scheme in the metanavigation support rules.

RESEARCH PLAN

Our future research plan involves at looking at how the learner's navigational decisions and text understanding change as they receive metanavigation support and navigate the CoMPASS system over time. We are interested in exploring questions such as: Does metanavigation support lead to regulating navigation behavior? How does it influence students' navigation paths? Does metanavigation support enable students to construct an integrated understanding of science concepts while reading nonlinear texts?

We are planning to use ongoing assessment procedures over a five-week period in order to find out how reader's text comprehension and science learning changes as they process nonlinear information to solve a problem solving challenge about roller coasters. The study will employ a quasi-experimental design and will be conducted in an after school science club during spring 2003. Multiple sources of data will be collected and both quantitative as well as qualitative research methods will be utilized so as to gain more information about the cognitive processes that are involved in learning from nonlinear science texts. We are optimistic that this empirical study will shed some light on our understanding of the cognitive processes utilized in hypertext systems and enable us to move one step forward to a more rigorous, detailed, and well defined scheme to support navigation behavior in hypertext reading.

CONCLUSION

The intriguing part in hypertext is that the reader can have a flexible view of texts. As Perfetti (1996) described, "texts are points in space that a learner can explore". It is the links interconnections among text fragments which extend the text beyond the single dimension of linear flow. In hypertext environments there are more degrees of freedom, more dimensions in which one can move, and hence a greater potential for the reader to become disoriented or face the dilemma of 'informational myopia'. We have argued why it is important to encourage metanavigation as readers engage in the cycle of selecting relevant pieces of texts and evaluate their achievement of learning goals. We have proposed a conceptual framework for metanavigation support and we aim to make it more rigorous based on the analysis of the empirical data in our research study. Our efforts is an attempt to start addressing some of the interesting research questions that still remain to be answered in hypertext research.

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