Supporting Middle School Students Use Nonlinear Science Texts in an Inquiry Classroom

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Abstract: The goal of this study was to investigate whether supporting sixth grade students to monitor and regulate their navigation behavior while reading from nonlinear science texts would lead to better navigation and learning. *Metanavigation support* in the form of prompts was provided to groups of students who used a system called CoMPASS to complete a design challenge. The metanavigation prompts aimed at encouraging students to understand the affordances of the navigational aids in CoMPASS and use them to guide their navigation. The results suggested that providing metanavigation support enabled the groups to make coherent transitions among the text units. Findings also revealed that reading comprehension, presence of metanavigation support and prior domain knowledge significantly predicted students' individual understanding of science principles and the relationships among them.

In recent years there is a push in science education to encourage students learn science in interactive inquiry-based environments (Blumenfield, Soloway, Marx, Krajcik, Guzdial, & Palinscar, 1991). Part of the inquiry process is to examine different sources of information to see what is already known and plan investigations. Researchers have expressed the need for development of science resources that will support the interactive nature of science and allow for exploration of unique investigation paths based on students' learning goals (Puntambekar & Stylianou, 2002; Wallace et al., 1998). Digital texts which are based on hypertext and hypermedia technologies provide the students with a more active role than is possible with traditional textbooks (Rouet & Levonen, 1996). However, recent studies have shown that students lack metacognitive knowledge and skills to use digital information resources (Soloway & Wallace, 1997). Students tend to focus on finding answers on a specific page instead of constructing the answers to the questions that drove their explorations by synthesizing and evaluating information from different resources. According to Soloway and Wallace (1997) students are accustomed to the textbook model and this mindset "transcends technology".

One might argue that navigating the web requires metacognitive skills because there is a plethora of links than can lead to multiple paths in the hyperspace. Learners need to make frequent and important decisions about the selection of relevant links that will enable them to pursue their learning goals. They need to engage in cognitive monitoring, to slow down and take a moment to consider various paths and question why they are considering some paths over others (Charney, 1994; Rouet, 1992). Our studies in middle school science classrooms have suggested that even when learners use nonlinear science texts that have been designed to show relationships among text units, they still need a metacognitive ability to relate navigation to their goals and to be able to visit related units (Puntambekar & Stylianou, 2002). Classroom implementations of an interactive system called CoMPASS (Puntambekar, Stylianou & Hübscher, 2003; Puntambekar, Stylianou & Jin, 2001) suggested that students needed support to make connections among the science principles they were reading even though the system provided a visual interface to show such relationships. Teacher support enabled students to focus on their goals and bridge their real-world experiences with the conceptual knowledge in CoMPASS by posing questions and providing explanations (Puntambekar & Stylianou, 2002). However, teacher's support did not help navigation per se. Thus, we believe that supporting middle school students to use a combination of reading comprehension and metacognitive strategies (i.e., monitoring and self-regulation) as well as make thoughtful navigational decisions while using nonlinear science texts may lead to a richer text understanding. We define one's awareness of and ability to utilize strategies for enhancing rich understanding of the domain while navigating a nonlinear text as *metanavigation* (Stylianou & Puntambekar, 2003).

Literature suggests that there might be other factors that relate to student learning while interacting with nonlinear texts even when support is given. Reading comprehension research suggests being aware of the metacognitive strategies that learners employ while reading can influence how well they plan and monitor their understanding from traditional texts (Brown, Armbruster & Baker, 1985; Jacobs & Paris, 1987). Prior research has also demonstrated the importance of prior knowledge for learning from traditional texts (Kintsch & van Dijk, 1978). According to McNamara (2002), readers need background knowledge to "fill contextual gaps within the text and to develop a global understanding" of the text. Even when reading from nonlinear texts, learners who are highly knowledgeable about a particular subject area have been found to be much more efficient at finding relevant information than those with low or moderate background knowledge (Rouet, 1992).

In this paper we discuss our framework of providing metanavigation prompts to compel sixth grade students to monitor and regulate their navigation behavior in order to accomplish their learning goal. We then discuss the lessons learned as we used this framework in a real classroom setting in an effort to understand how groups of learners use nonlinear texts to find science information while engaging in inquiry-based activities and what kind of support they need in order to gain a rich understanding of science principles. The specific research questions we are exploring are:

Does metanavigation support lead to different navigation behavior? How does it influence students' navigation paths?

Given the support, what factors might affect student learning?

Integrating CoMPASS in the Science Classroom

This study was a part of the spring 2003 implementation of CoMPASS in sixth grade science classes. During this implementation students used CoMPASS to find information and read about the science concepts and principles that were involved in the unit of 'Simple Machines'. We developed a design-based curriculum in collaboration with two science teachers where students undertook different task challenges for each of the six simple machines (lever, wheel and axle, pulley, inclined plane, wedge, and screw) as well as an overall design challenge that was adapted from the Learning by Design ™ Curriculum at Georgia Tech. This study focused on one challenge, the 'pulley challenge'.

CoMPASS 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. The maps in CoMPASS 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. The maps also allow for exploration and support students to take multiple investigation paths based on their learning goals at any particular time.

The study involved four sessions of forty-five minutes that were conducted during the science class period. The first session involved an assessment of students' prior domain knowledge through a pre- science knowledge test and an assessment of students' metacognitive awareness and perceived use of reading strategies through the MARSI instrument (Mokhtari & Reichard, 2002). The second session started with the presentation of the task. The task was a design challenge that required students to build a pulley device that would lift a bottle of water that weighed 600 grams off a table using the minimum amount of effort. Students were allowed some time to think about the requirements of the task and write down their initial ideas. Then, they were asked to collaborate in groups to plan their quest of finding information to solve the challenge. Groups were asked to read the information that was available for pulleys in the 'Simple Machines' unit in CoMPASS. Groups used CoMPASS for approximately twenty-five minutes. The second session ended with a reading comprehension assessment task. During the third session students were asked to continue their quest of searching information about pulleys in CoMPASS and finalize their pulley designs. The groups in the metanavigation support condition received metanavigation prompts in a written format to guide their exploration in CoMPASS. The fourth session included an assessment of students' individual science knowledge through a concept map test.

One hundred thirteen sixth graders in six science classes participated in the study. The students were from different ethnic backgrounds and academic abilities. Approximately 47% (53 participants) of the sample were girls and 53% (60 participants) were boys. Each class was randomly assigned to one of two conditions (metanavigation support, no support). Students collaborated in groups of three or four while using CoMPASS to solve the design challenge. The metanavigation support condition included 12 groups of students and the no support condition 15 groups.

Intervention

Metanavigation support in the form of prompts was provided to the groups in the metanavigation support condition to encourage them to monitor and regulate their navigation strategies in order to gain a rich understanding of science principles while reading from hypertext. Metanavigation support was based on two indices that were informed by group's navigation path while interacting with the CoMPASS system. Our framework for providing metanavigation support was inspired by the artificial intelligence in education literature especially the guidelines that are provided in the development of intelligent tutors (del Soldato & du Boulay, 1995). Below we discuss this framework in detail.

Log file information that captured groups' navigation path enabled us to assess their navigation behavior and decide what metanavigation prompts would be given to each group. Computer log files recorded information about what science concepts the groups explored while using CoMPASS, how much time they spent on each concept and what navigation tools they used to make their navigation choices. Two main indices from group's navigation path informed our decision of what type of metanavigation support each group needed: navigation choices and transitions among text units. Specifically we were interested in whether or not the group members had chosen to read about the science principles that were relevant to their learning goal and whether the transitions they made among the text units that were available in the hypertext environment would enable them to gain a rich understanding of the domain. For example, did the group make coherent transitions while reading about science concepts? Coherent transitions were defined as the transitions among closely related concepts to the ones they had chosen. Considering the binary state of each of these categories, we could have four different cases, described in the "metanavigation support rules' cells of Table 1, as well as various combinations.

Table 1. Conditions for providing metanavigation prompts

	Metanavigation support rules
Navigation Choices	If choice of non goal-related concepts ⇒ encourage goal-related navigation
	If goal-related navigation ⇒ encourage integration of science knowledge
Transitions	If transitions are not coherent ⇒ encourage regulation of navigation behavior to make coherent transitions between text units while reading
	If transitions are coherent ⇒ encourage integration of science knowledge

For example, let us consider the situation of a group that chose to read about science principles that were not important for solving the pulley challenge (i.e. kinetic energy, potential energy and power) and did not read about goal-related science principles such as mechanical advantage, distance and force. The log file information also indicated when the group made incoherent transitions among science principles while navigating. The metanavigation prompts that were given to the group encouraged students to think about their goal and use the concept maps to make thoughtful decisions of what paths to follow. It was pointed out that the concept maps could help students make connections and decide what science principles were related to what they were reading at any particular time.

Data Sources and Measures

Multiple sources of group and individual data were collected over four classroom sessions. Measures included student's individual performance in a pre- science knowledge test, the Metacognitive Awareness of Reading Strategies Inventory (MARSI), a reading comprehension test and a concept map test. Process measures included log file information that captured group navigation paths during the use of CoMPASS.

A pre- science knowledge test was administered at the beginning of the study to test whether the participants had any prior knowledge about science principles related to the Simple Machines unit. The test was delivered online and included thirteen multiple choice items and five open-ended questions. Student's responses to the open-ended questions were scored based on a three point scale: 0 point for an incorrect response, 1 point for a partial correct response and 2 points for a correct response. The open-ended questions were scored by two raters that were trained to use the scoring scheme. The inter-rater reliability was .95. A total score was calculated for each student and represented student's prior science knowledge.

Students' metacognitive awareness and perceived use of reading strategies while reading school-related materials was also assessed at the beginning of the study through the MARSI instrument (Mokhtari & Reichard, 2002). MARSI consisted of 30 Likert-type items with a 5-point response format which represented three subscales: Global Reading Strategies (GLOB), Problem-Solving Strategies (PROB) and Support Reading Strategies (SUP). An overall total average MARSI score was calculated for each student indicating how often the student uses reading strategies when reading academic materials.

Assessing reading comprehension is an important indicator of whether the reader has understood the information presented in a hypertext. It is also important to assess reader's ability to synthesize and integrate ideas and recognize connections that reflect the interconnected nature of science. In this study the reading comprehension of each student was assessed after the end of the first CoMPASS session through a multiple choice test that included ten questions.

Computer log files were used to look more deeply into the navigation paths of groups of learners in an attempt to detect differences in approaches to reading and learning from nonlinear texts when providing metanavigation support. Log files recorded information about what science concepts the groups explored while interacting with the CoMPASS system in a chronological order. Two primary dimensions were used for the analysis of group navigation paths. The first dimension was based on whether groups chose to focus on science principles that were related with their goal. A goal-relatedness index was calculated by dividing the total number of goal related concepts visited to the total number of concepts visited. The second dimension was based on whether the groups made coherent transitions among the different text fragments. A coherent transition index was calculated by dividing the number of coherent transitions to the total number of transitions among concepts.

A paper and pencil concept map test was used to assess students' understanding of science concepts at the end of the pulley challenge. The students were provided with a list of science concepts from which they were asked to create a concept map providing an explanation for each concept, making connections among concepts and stating how they are related. Students' concept maps were analyzed using a rubric that was developed in a study conducted by Puntambekar, Stylianou and Hübscher (2003). Two aspects of the maps were examined: the explanation provided for the concepts and the explanation provided for the connections among the concepts. Students' responses were scored on a scale of 0-3 based on the depth of science understanding that they demonstrated. A score of 0 indicated an incorrect explanation, while a score of 3 indicated a complete and clear explanation for the concept or the connection. A concept ratio was calculated for each student by dividing the score that was given for the explanation of the concepts by the number of concepts included in the concept map. This ratio was a measure of student's understanding of science principles. A connection ratio was calculated by dividing the score that was given for the explanation of the connections with the number of connections in the map. This ratio was a measure of the depth of understanding of the relationships among science principles.

Results: Understanding Metanavigation

To address the research questions of this study, we used a mix of group and individual data. We investigated groups' navigation behavior in each condition and drew conclusions about the overall effectiveness of the metanavigation support. We also investigated whether the effects of individual characteristics and the type of support students received on their performance in the concept map science knowledge test. Both types of data contributed to understanding the effects of metanavigation support.

Effects of metanavigation support on navigation

The first research question focused on whether metanavigation support provided to the group of students had any effect on their navigation behavior. To address this question we studied groups' navigation paths based on the log file information that was collected as the groups interacted with CoMPASS. Descriptive statistics and a factorial multivariate analysis of variance (MANOVA) were conducted to study changes in group navigation behavior throughout the two CoMPASS sessions.

Group navigation paths were analyzed based on the two navigation indices (goal-related navigation index and coherent transition index) to investigate whether metanavigation support encouraged groups to read about concepts that were relevant to their goal and make coherent transitions among concepts, thereby making their navigation more focused as opposed to random. Table 2 presents the means, standard deviations, and effect sizes for the two navigation indices over the two days groups used CoMPASS (day 1 and day 2). The means are also displayed graphically in Figures 1 and 2.

Table 2. Means and standard deviations for navigation indices

		Metanavigation support			No support				
		Day 1	Day 2	Overall	Day 1	Day 2	Overall	$d_{day\ 1}$	$d_{day\ 2}$
Coherent	Mean	.62	.65	.64	.80	.48	.64	-.86	.59
Transition Index	SD	.37	.24	.30	.21	.29	.29		
Goal-related	Mean	.70	.64	.67	.71	.66	.68	-.04	-.06
Navigation Index	SD	.27	.30	.28	.25	.32	.28		

Note. Effect size guidelines are as follows: small = .20, medium = .50. large = .80

Figure 1 indicates that the groups in the metanavigation support condition made more coherent transitions during the second day they used CoMPASS than the first day. On the contrary, the groups in the no support condition made less coherent transitions during the second day compared to the first day. The first day the coherent transition index was lower in the metanavigation support condition (M = .62) compared to the no support condition (M = .80). This difference represents a large effect size (d = -.86). The second day, groups who received metanavigation support made more coherent transitions (M = .65) than groups who did not receive any support (M = .48). The difference in the coherent transition index between the two conditions during the second day represents a moderate effect size (d = .59). This implies that groups who received metanavigation support tended to make more meaningful transitions among science principles that were related to each other than groups who did not receive any support.

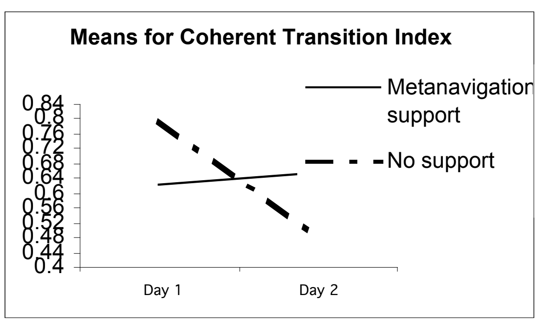

Figure 1. Means for Coherent Transition Index Throughout Days of Navigation

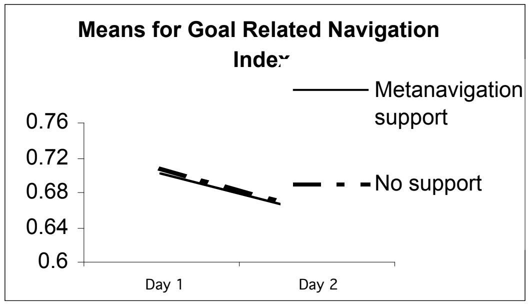

Figure 2. Means for Goal Related Navigation Index Throughout Days of Navigation

Figure 2 indicates that the goal-related navigation index was lower in the metanavigation support condition compared to the no support condition during both days of using CoMPASS. The differences in the goal-related navigation index between the two conditions during the two days represents a small effect size (d_{day1}=-.04, d_{day2}=.06). The goal related navigation index was also higher in the first day than the second day for both the metanavigation support condition and the no support conditions. Groups in both conditions seemed to have visited more science principles that were not directly related to their goal during the second day. Even though the metanavigation prompts encouraged groups to focus on their goal, groups had to think which science principles were important for solving the pulley challenge. It seems that directing groups attention at the affordances of the concept maps in CoMPASS enabled them to make meaningful transitions but did not promote goal-related navigation behavior.

In order to investigate whether the metanavigation support provided to the groups had any effect on their navigation behavior a 2 x 2 factorial multivariate analysis of variance (MANOVA) was performed using the two navigation indices (coherent transition index and goal related navigation index) as dependent variables. Independent variables were the type of support that was given to the groups (metanavigation support and no support) and the day of navigation (day 1 and day 2). The results of the factorial MANOVA indicated that there was evidence for significant interaction effect across the combined set of dependent variables (coherent transition index and goal related navigation index), Wilk's Λ=.883, $\underline{F}(2,49)=3.233$, $\underline{p}$=.048. The results reflected a modest association, partial $\_^2$=.117. 11.7% of the generalized variance on the collection of dependent variables could be explained by the interaction effect. The Wilk's Λ test did not find any multivariate statistically significant main effect for the type of support (Wilk's Λ= .999, $\underline{F}(2,49)=.007$, $\underline{p}$=.993) or the day of navigation (Wilk's Λ=.932, $\underline{F}(2,49)=1.787$, $\underline{p}$=.178).

Univariate F-tests found a statistically significant interaction effect on the coherent transition index, $\underline{F}(1,50)=5.325$, $\underline{p}$=.025, with small effect size $\_^2$=.096. No univariate differences were found on the goal related navigation index, $\underline{F}(1,50)=.001$, $\underline{p}$=.981. Roy-Bargmann stepdown analysis revealed that the multivariate findings seemed to be driven primarily by a univariate factorial interaction on the coherent transition index, $\underline{F}(1,50)=5.325$, $\underline{p}$=.025. After adjusting for the coherent transition index, no statistically significant differences were found for the goal related navigation index, stepdown $\underline{F}(1,49)=1.128$, $\underline{p}$=.293.

Predictive Models of Science Learning Measures

Multiple regression analyses were conducted to study the extent to which individual performance in the concept map science test could be predicted from measures of prior domain knowledge, reading comprehension, metacognitive awareness of reading strategies and the presence of metanavigation support that aimed at encouraging regulation of comprehension and navigation strategies while interacting with a hypertext environment.

Predicting Concept Ratio in the Concept Map Test

The first regression model used the concept ratio in the concept map test as the dependent variable. Students' prior domain knowledge, reading comprehension, metacognitive awareness of reading strategies and presence of metanavigation support were used as independent variables. A hierarchical regression technique was used forcing the independent variables into the equation in two blocks. The first analysis was conducted to predict the concept ratio from the metacognitive awareness of reading strategies, the reading comprehension and the presence of metanavigation support. The results of this analysis indicated a statistically significant overall model explaining approximately 28% of the variance in the concept ratio, R^2 =.28, $F(3,109)$ =14.35, $p<.001$. This can be considered a large effect size according to Cohen's criteria (Cohen, 1988). Examination of the regression coefficients revealed that metacognitive awareness of reading strategies was not a significant predictor of the explanation of concepts rating, $F(1,109)=1.52$, $p=.22$. Reading comprehension was a statistically significant predictor of the concept explanation rating, $F(1,109)=27.88$, $p=.00$, uniquely explaining 18% of the total variance in the concept ratio after adjusting for metacognitive awareness of reading strategies and presence of metanavigation support. This represents a large effect size. The presence of metanavigation support was also a statistically significant predictor, $F(1,109)=7.93$, $p=.01$, uniquely explaining 5% of the total variance in the rating of concept explanation after adjusting for metacognitive awareness of reading strategies and reading comprehension. According to Cohen's criteria this is a small effect size (Cohen, 1988). A second analysis was conducted to evaluate whether prior domain knowledge predicted the concept ratio over and above metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support. Students' science knowledge in the pretest uniquely accounted for a significant amount of the variability of the concept ratio after controlling for the effects of metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support, R^2change=.09, $F(1,108)=16.14$, $p<.001$. By including pre science knowledge in a model that contains metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support 9% of additional unique variance in the concept ratio was obtained. This represents a medium effect size.

Predicting Connection Ratio in the Concept Map Test

Multiple regression analyses were also conducted to examine the relationships among the connection ratio in students' concept maps, prior domain knowledge, reading comprehension, metacognitive awareness of reading strategies and presence of metanavigation support. A hierarchical regression technique similar to the one used for the concept ratio was also used here forcing the independent variables into the equation in two blocks. The first analysis was conducted to predict the connection ratio from the metacognitive awareness of reading strategies, the reading comprehension and the presence of metanavigation support. The results of this analysis indicated a statistically significant overall model explaining approximately 18% of the variance in the connection ratio, R^2 =.18, $F(1,109)=7.99$, $p<.001$. This can be considered a large effect size according to Cohen's criteria (Cohen, 1988). Examination of the regression coefficients revealed that metacognitive awareness of reading strategies was not a significant predictor of the connection ratio, $F(1,109)=3.49$, $p=.06$. Reading comprehension was a statistically significant predictor of the connection ratio, $F(1,109)=10.62$, $p=.00$, uniquely explaining approximately eight percent of its variance. This represents a medium effect size (Cohen, 1988). The presence of metanavigation support was also a statistically significant predictor, $F(1,109)=8.32$, $p=.01$, explaining 6% percent of the variance in the connection ratio. According to Cohen's criteria this is a small effect size. A second analysis was conducted to evaluate whether prior domain knowledge predicted the connection ratio in the concept map test after adjusting for the other predictor variables (metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support) in the regression model. Pre science knowledge uniquely accounted for a significant amount of the variability of the connection ratio after controlling for the effects of metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support, R^2change=.03, $F(1,108)=4.69$, p = .03. Also 4% additional explanation of variability in the connection ratio is achieved by including pre science knowledge in a model that already contains measures of metacognitive awareness of reading strategies, reading comprehension and presence of metanavigation support. 3% of the variability in the connection ratio was explained uniquely by prior science knowledge. Although statistically significant, according to Cohen's criteria this represents a small effect size.

Conclusion

The goal of our research was to investigate what role metacognition plays in the process of making navigation decisions and integrating knowledge acquired from the different text units in nonlinear science texts. We hypothesized that supporting middle school students to reflect on their navigation processes enables them to navigate in ways appropriate to their learning goals and gain a rich understanding of science principles. We used diverse levels of analysis to investigate the effects of metanavigation support on navigation behavior across groups of learners and on learning outcomes across individuals. The findings of this study revealed that the metanavigation prompts we provided to groups of learners who used a non-linear resource encouraged them to attend to the different functions of the navigational aids and used them to make coherent transitions among text units. Regression analyses also revealed that reading comprehension, presence of metanavigation support and prior domain knowledge significantly predicted students' understanding of science principles and the relationships among them based on the concept maps they created. The predictive models for both the concept and the connection ratios suggests that after controlling for prior knowledge differences, the variability in concept maps scores (explanations of concepts and explanations of connections) was accounted for by student's individual reading comprehension and presence of metanavigation support. Students who had high reading comprehension scores and were in groups that received metanavigation support were more likely to give better explanations about the science principles that they included in their concept maps (concept ratio) and the connections they made among them (connection ratio). Our future research plans are to study groups' navigation behavior in depth and provide rich descriptions that will contribute to our understanding of the reading comprehension processes employed while interacting with nonlinear texts. More empirical evidence from research studies conducted in control settings and for extended time periods can also provide insights about how we can make our metanavigation support framework more rigorous.

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