

Navigation Behaviors and Strategies Used by Middle School Students to Learn From a Science Hypertext

SARAH SULLIVAN, DANA GNESDILOW,
AND SADHANA PUNTAMBEKAR

University of Wisconsin-Madison, USA

sasullivan2@wisc.edu

gnesdilow@wisc.edu

puntambekar@education.wisc.edu

The incorporation of various textual resources into scientific inquiry is important for establishing background knowledge. Many of these resources are now presented in hypertext or hypermedia environments, which require students to comprehend and actively integrate information from multiple sources. Further, numerous practices employed by readers with good comprehension skills align with the practices necessary to successfully conduct scientific inquiry. This paper investigated the relationship between reading comprehension ability for traditional text and navigation behaviors in a hypertext environment within the context of an inquiry-based physics curriculum. Changes in navigation behaviors throughout the curriculum were also examined. Findings indicated that the relationship between reading comprehension ability for traditional text and hypertext comprehension is yet unclear. Study 1 showed no significant relationship between reading comprehension scores on a standardized test and goal-focused hypertext navigation behaviors. In contrast, Study 2 showed that higher comprehension ability students tended to use navigation and comprehension strategies more often and that this pattern also held true for strategy use at the end of the curriculum. Both studies showed that only some goal-focused navigation behaviors increased significantly throughout the unit. Implications for learning with hypertext and hypermedia environments, particularly in the context of inquiry-based science classrooms, are discussed.

The National Science Education Standards (NSES) stress the importance of students engaging in science as an “active process” in which they are able to engage not only in hands-on activities but also in actively establishing connections between their current science knowledge and scientific knowledge from many sources (NRC, 1996). In particular, the NSES emphasize that instruction should focus on preparing students to conduct scientific inquiry. An essential component of the inquiry process is gathering background information to understand and evaluate existing conceptual relationships in order to make predictions and develop connections between important ideas in a domain and current experiments or activities. As such, many researchers have begun to address the importance of texts and reading in science. The ability to read and evaluate textual information and engage in social conversation about the validity of the claims is an important part of scientific literacy (NRC, 1996). Reading text is a key component of the scientific process because it provides a means of storing and disseminating previous data and interpretations in order to facilitate the process of verification and knowledge construction (Kamil & Bernhardt, 2004). Educators in both reading and science have increasingly acknowledged the importance of engaging in active inquiry with multiple forms of text, including printed text as well as hypertext and hypermedia resources, to supplement hands-on learning. This textual information can be used as evidence to support or refute students’ multiple interpretations about scientific concepts based on their experiential activities (Alvermann, 2004). Further, the inclusion of text in science is important because students engaged in hands-on scientific inquiry tend to focus primarily on collecting the data related to their current activity. However, science texts allow students to supplement this in-the-moment experience with general information about scientific concepts or processes in order to help them link their concrete activities to understanding broader patterns and relationships (Varelas & Pappas, 2006). Thus, information gained from textual resources helps to ground the experiences that students have and data that they gather while doing hands-on activities.

In addition to the use of text-based resources to facilitate hands-on investigations, reading in science may also be important because the skills needed to be a successful reader align with scientific inquiry skills. For example, an important part of the inquiry process is the construction of meaning by integrating new information with prior knowledge (NRC, 2006). During the inquiry process, students are able to compare information from science texts with texts that they or others have produced during experiential activities. Learning to successfully integrate these multiple forms of text can aid in the process of building scientific reasoning skills and conceptual understanding (Hapgood, Magnusson & Palincsar, 2004; Magnusson & Palincsar, 2004). According to Pressley and Afflerbach (1995), students who tend to have the

most success comprehending texts are those who are active about constructing meaning from the text and understanding relationships between units of textual information as well as with what they already know. The overlap in skills needed to be a good reader with skills necessary for conducting successful scientific inquiry should be utilized to help improve both reading proficiency, particularly of expository texts, as well as inquiry practices (Baker, 2004).

The use of hypertexts, as well as other digital media environments, for learning is becoming increasingly ubiquitous in education today. All of these environments require, to a greater or lesser degree, the comprehension and integration of multiple sources of information, much of which is text-based. Recent research has focused on the ways in which students navigate and comprehend information presented in these environments (e.g., Coiro, & Dobler, 2007). However, there is still much work to be done in understanding under what conditions these environments can best aid learners and how individual characteristics interact with system design (Azevedo & Jacobson, 2008; Shapiro, 2008).

Hypertext can be defined as the linking of sections, or nodes, of text in a nonlinear way by means of semantic, or meaningful, links (Rouet, 2006b). These sections or nodes can vary in size and complexity and can potentially consist of different representations, such as a paragraph of text, an entire web page or graphics (Bolter, 2001). The degree to which the conceptual links between these nodes of information are made explicit for the reader will vary depending on the structure and navigational affordances of the hypertext environment. Due to the fact that students must actively choose their path through the information, hypertext environments support flexible access to information and multiple paths of inquiry. However, learners need to understand the information presented in each node as well as the relationships among them. This means that the information in the nodes of text and the way nodes are linked to show relationships both convey meaning to the reader.

PERSPECTIVES ON READING AND LEARNING FROM DIGITAL HYPERTEXT ENVIRONMENTS

The Construction-Integration (C-I) model of text processing (Kintsch, 1988) is often used to think about the comprehension of hypertext. The three stages of text processing that make up this model are the decoding of a word, construction of a textbase, which is a mental model of the factual information presented in a text, and the construction of a situation model, which requires integration of prior knowledge with the textbase formed from reading the new text (Kintsch, 1988). The two stages that are central to this discussion are the construction of a textbase and a situation model.

When forming a textbase, readers construct hierarchical mental representations of text as they read and are more likely to remember the general higher-level information than the lower-level details (Charney, 1987). Propositions are considered to be the building blocks of the textbase. In order to form propositions as they read new text, readers parse the text into concepts and determine the relationships between concepts. These relationships can be represented by a network of nodes, which in this case represent concepts, and associative links among these nodes. The structure of the text plays a substantial role in determining which propositions in the text are most important and also what the significant concepts are in those propositions (van Dijk & Kintsch, 1983; Charney, 1987). To the extent that propositional arguments that are important to the main idea of the text are repeated in successive sentences, the text will be more coherent and the textbase representation will be strengthened. The more times a proposition is cycled through working memory and used to provide links throughout the text, the more likely it is that it will be seen as a high level proposition and remembered by the reader (Charney, 1987). The textbase formed by the reader is a representation of both the local and the global levels of the organization of the text at the propositional level (Kintsch, 1988). Since readers often read through printed text in the order presented on the page, the propositions encountered in the formation of a textbase are relatively stable and predictable. However, when forming a textbase from hypertext, there is the potential that all readers will travel through the text in a different order. In this sense, they are constructing their own higher-level propositions as they read through the text, and they may encounter these propositions a different number of times and in different orders with each reading of the text.

In order to construct a situation model, a reader integrates the textbase that was just formed with prior knowledge or previously learned information. Kintsch proposes that information is stored in memory as a knowledge net and each node of the net is given meaning by the strength of the relationship of that node to others in the net. Further, the strength of the node to others in the net is determined by the context in which the node is activated. Once relationships are formed, they can be activated when encountering similar information in another context. Prior knowledge and experience have a great deal to do with the elements represented in the net and the relationships that are activated (Kintsch, 1998).

It has been found that reading comprehension ability is primarily related to textbase development rather than the development of a situation model (Voss and Silfies, 1996). However, since the situation model is formed by integrating the textbase with prior knowledge, reading comprehension may also impact the situation model. It is possible that readers with different levels of reading comprehension ability may differ in the textbase that they

form. This may be especially true for ill-structured hypertext if readers are each taking their own paths through the hypertext and are not visiting the same units of information.

Closely related to Kintsch's C-I model, the theoretical perspective of integrating multiple documents can be used to think about comprehending information presented in a hypertext environment. The processes involved in comprehending multiple documents are distinct from those involved in comprehending single texts in at least three ways (Rouet, 2006a). First, there is source information associated with each text. Second, comprehending multiple documents encourages readers to update their previous knowledge or situation models with each reading of a different text. Finally, multiple documents may complement each other in different ways, such as by filling in gaps in understanding left from reading previous documents. Therefore, in addition to understanding the semantic relationships as described by the C-I model of text processing, readers also need to understand the relationships among documents and how they are related to and complement each other in order to give a coherent global understanding and an integrated model of the situations represented by all of the documents (Rouet, 2006a). Consequently, when reading multiple documents, readers need to develop a documents model (Perfetti, Rouet, & Britt, 1999). The documents model is made up of two separate, yet complementary representations, i.e., the situations model and the intertext model. In the situations model, readers organize the contents from each of the individual documents or nodes of text into an integrated representation. In the intertext model, learners represent the source information, such as the author, of the texts as well as the ways in which the multiple sources of information that are being read inform one another and fit together. From this perspective, in order to fully understand information presented in a hypertext environment, not only does the reader need to comprehend the text in the individual nodes but also the overall structure of the hypertext. Readers need to understand the connections between the nodes of information, or the intertextual relations, and must also understand where a unit of information fits with respect to multiple other information nodes in the global structure of the system (Bolter, 2001; Puntambekar, Stylianou, & Goldstein, 2007; Rouet, 2006b). Prior knowledge or experience in a domain should facilitate comprehension and reasoning from multiple documents, and even students inexperienced in a domain have been found to be able to reason about multiple documents to some degree (Wineburg, 1991). However, students with less experience may have more difficulty self-organizing their activities to facilitate comprehension of multiple documents and may need more explicit study directions to focus on integrating multiple sources. Further, few studies have directly examined younger or teenage students' ability to understand and integrate multiple documents (Rouet, 2006a).

RELATIONSHIP BETWEEN READING COMPREHENSION AND HYPERTEXT NAVIGATION

Strategies used to successfully learn science from hypermedia environments (e.g., Azevedo, 2008; Azevedo, Cromley, Winters, Moos, & Greene, 2005) are similar to those used by successful readers to engage in the comprehension process (e.g., Pressley & Afflerbach, 1995). Strategies are the active processes engaged in by learners in order to make sense of, comprehend and learn from information presented in text or other formats in hypermedia environments. For example, it is important that learners are able to reflect on their learning goal, monitor their understanding and modify their learning strategies accordingly. Better comprehenders may be more active in the use of strategies that allow them to actively reflect on their learning processes, prior knowledge and goals. Active reflection may be even more important in hypertext or hypermedia environments in which multiple sources of information need to be comprehended and integrated.

In order to be active processors of texts, learners need to employ at least some level of self-regulated behavior (e.g., Pressley & Afflerbach, 1995). Self-regulated learning can be conceived of as the processes of evaluation and regulation that are part of the metacognition that occurs during successful reading comprehension. This may include practices such as the use of “fix-up strategies” when there is a breakdown in comprehension or evaluation of whether navigation and reading choices are helpful to reach the learning goal (Coiro & Dobler, 2007). However, research indicates that students often have difficulty in self-regulating their learning, particularly when learning in conceptually rich domains, such as science (Azevedo, 2005). Therefore, the use of self-regulation strategies by students engaging in scientific inquiry is an important area for study and assessment in order to help learners to improve their self-regulation skills, particularly when using hypermedia environments to learn about complex domains. Because learners must develop an individual textbase and situation model for each textual resource as well as an integrated documents model representing the multiple sources of information, the ability to self-regulate one’s learning and apply comprehension and navigation strategies may be even more important when learning from hypertext environments. Self-regulated learning processes are important components of learning from hypertext and hypermedia and learning through scientific inquiry (e.g., Coiro & Dobler, 2007; Moreno & Mayer, 2007; Craig & Yore, 1996; Azevedo, 2005).

GOAL OF THE PAPER

In summary, reading and comprehending texts is an important component of the scientific inquiry process. Information reporting and synthesizing

previous science findings and principles typically comes from multiple text-based resources that students must actively integrate. Further, hypertext and other digital media environments are increasingly used to access resources that students use to help them understand the scientific concepts related to their hands-on activities. The active strategies involved in conducting scientific inquiry are similar to those needed to comprehend text and, thus, may be particularly important for learning from multiple texts presented in hypertext environments. Additionally, skilled readers approach online reading as a problem-solving task and more successfully read and comprehend online resources when they are embedded in inquiry activities with content-specific goals requiring them to make connections across sources (Coiro, 2010). The Construction–Integration model and the theory of integrating multiple documents can help to understand the processes by which reading, integrating information and learning from hypertext environments takes place. However, these processes may be impacted by individual learner characteristics, such as prior knowledge or reading comprehension ability for traditional texts. Research that explores how learner characteristics relate to processes of learning from multiple text-based resources presented in hypertext environments is lacking, especially for younger learners (Rouet, 2006a). A variety of student and contextual variables have been found to impact learning from information presented in hypermedia environments. In particular, learners' levels of prior knowledge, metacognitive abilities, including self-regulation and comprehension skills, and hypermedia system structure appear to be important factors to consider (Shapiro, 2008).

Research comparing studies investigating how prior domain knowledge impacts comprehension has found that learners with more subject-matter knowledge are better prepared to process and navigate text (Alexander, Kulikowich, & Jetton, 1994). Therefore these learners are better able to increase their domain knowledge, whereas those without a sufficient base of knowledge tend to struggle and fall increasingly behind. Further, prior knowledge supports comprehension of information in hypertext environments by helping readers to follow more coherent reading sequences and reduce feelings of disorientation (Amadiou, Tricot, & Mariné, 2010). Readers with higher prior knowledge have been found to be more proficient with navigating to content directly related to the learning task and to conduct deeper investigations into the content and affordances of the hypertext system (e.g., graphics), thus increasing learning outcomes and comprehension (Lawless & Kulikowich, 1998; Lawless, Schrader, & Mayall, 2007).

Due to the complex and interactive nature of most hypertext environments, metacognitive skill, which is essential for text comprehension, has been found to be a strong predictor of learning outcomes (Schwartz, Anderson, Hong, Howard, & McGee, 2004). Many students need support to devel-

op metacognitive strategies in order to search information, monitor learning progress and evaluate search outcomes when learning in hypermedia environments (Lazonder & Rouet, 2008). Given that readers are not often shown how to search and integrate multiple documents, digital or otherwise, it is not surprising that their strategies in this area are often lacking (Azevedo & Cromley, 2004).

Hypertext and hypermedia environments also have the potential to make connections among concepts and multiple sources of information explicit through the use of hyperlinks and other visualizations. The way in which the organization of sources in a hypertext environment is represented may impact reading strategies and, in turn, learning from the presented material. Comprehension and learning may be facilitated as long as the reader is able to recognize and take advantage of the organizational function and navigational affordances of the representation (Rouet, Potelle, & Goumi, 2005; Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009). For example, recent research has found that providing a graphical interface (i.e. a concept map) that makes explicit the relationships among documents may facilitate intertextual inferences requiring learners to integrate information from multiple sources (Salmerón, Gil, Bråten, & Strømsø, 2010).

This paper attempts to add to the literature by investigating middle school students' processes of learning and integrating information about physics concepts from a primarily text-based hypertext environment. The focus was on examining the navigation behaviors and strategies exhibited by learners with differing levels of reading comprehension ability after controlling for prior domain knowledge. The change in navigation behaviors and strategies throughout an inquiry-based science unit was also investigated. The claim made in this paper is that students with higher comprehension ability will employ more metacognitive self-regulation and comprehension strategies that will enable them to successfully comprehend and integrate the information presented in the hypertext. Further, experience with the structure of the hypertext system and with active processes involved in scientific inquiry should help to facilitate navigation strategies that support the integration of the information in the multiple nodes of text.

RESEARCH QUESTIONS

The goal of this paper was to investigate the relationship of reading comprehension ability to students' navigation behaviors while learning from a hypertext environment as well as the impact of experience in an inquiry-based science curriculum on navigation strategies and behaviors. The research questions are:

1. Is there a significant relationship between reading comprehension ability and navigation behavior after controlling for prior knowledge?

2. Does navigation behavior change as students gain more prior knowledge and experience using a hypertext system in the context of active scientific inquiry from the beginning to the end of the physics curriculum?

METHOD

Participants

Participants for this study were students in three 6th grade science classes (N=60) at a Midwestern private Catholic middle school in the spring of 2009. There were 22 boys and 38 girls. Students were from predominantly white, middle-class backgrounds. The school was located in an area with a population of approximately 23,000 and a median household income of approximately \$43,000 (United States Census Bureau, 2009). Students participated in this study as part of the CoMPASS science curriculum on the physics of simple machines.

CoMPASS Curriculum

The CoMPASS curriculum (Puntambekar, Stylianou, & Goldestein, 2007) is an approximately 6-week, inquiry-based science unit designed to teach middle school students about physics concepts in the context of different simple machines, such as inclined planes and levers. The unit consists of learning about six different simple machines in order to design a device to help someone with a wrist injury lift a can off a table with the least amount of effort or applied force. Throughout the unit, all students worked individually, in groups and as a whole class to complete challenges by coming up with solutions to real-world problems related to each of the machines, beginning with inclined plane and ending with pulley. For each challenge, students began by conducting research using the CoMPASS hypertext system (Puntambekar, 2006) to help them establish a knowledge base of the physics concepts that were important for completing their challenge and to increase their understanding of how these concepts apply to simple machines. Before going on CoMPASS, students brainstormed individually and as a class to help them activate their prior knowledge related to physics concepts and simple machines and to collectively come up with questions that would help to guide their CoMPASS research. After individually conducting research on CoMPASS, students worked in groups to conduct hands-on activities as well as virtual investigations using simulations to gather information and data to complete their challenges.

CoMPASS Hypertext System

The CoMPASS (Concept-Mapped Project-Based Activity Scaffolding System) hypertext system was designed by experts in the domain of physics to dynamically represent the relationships among physics concepts. CoMPASS consists of navigable concept maps, a navigation bar and textual information with some graphics (see Figure 1). Students can navigate to different concepts in various simple machines using the concept maps, the navigation bar or hyperlinks in the text. The goal is to facilitate students' understanding of the connections between concepts and the application of these concepts in different simple machines. The concept maps are designed such that the concept that students are reading about is in the middle and the map shifts accordingly to represent the strength of relationships between concepts. The connections on the map are labeled with a description of the relationship between concepts and arrows to represent the direction of the relationship. Further, different colors, sizes and positions of the boxes in the maps are also used to provide visual cues of the relationships between concepts. The concept map is presented on the left of the screen and the textual information is presented on the right. Students are able to explore and integrate the information provided about topics (machines) and concepts in their own way and must establish connections between these concepts in order to apply what they are learning to their hands-on challenges. The CoMPASS hypertext system consists of information on 11 different concepts for each of the 6 simple machines. With definitions and descriptions of all concepts and machines, there are a total of 86 nodes of information in CoMPASS related to simple machines. Students used CoMPASS to learn about concepts such as *work* and *mechanical advantage* before completing their hands-on and virtual investigations for the challenges.

The structure of the navigable concept map in CoMPASS has been found to be superior to other forms of graphical organizers for navigation, such as indexes, at helping students to form deep understandings of the connections between concepts (Puntambekar & Stylianou, 2005; Puntambekar & Goldstein, 2007). However, benefits of this structure have not been compared for students with different levels of reading comprehension ability for traditional texts. Further, changes in students' navigation behavior and interaction with the system from the beginning to the end of the curriculum have also not been examined.

The screenshot shows a web browser window titled 'CoMPASS - Mozilla Firefox' with the URL 'http://www.compassproject.net/compass/researcher/explore.php?uid=12'. The page content includes a navigation bar with 'Change unit', 'Change topic', and 'Go to: Inclined plane'. Below the navigation bar, there is a search bar and a 'Logout' link. The main content area is titled 'force in Inclined plane' and contains the following text:

You can refer to the [definition of force](#)

You can also read about [force](#) in other topics: [Circular motion](#), [Falling objects](#), [Linear motion](#), [Projectile motion](#), [Rotational motion](#), [Lever](#), [Pulley](#), [Screw](#), [Wedge](#), [Wheel and Axle](#)

force in Inclined plane

There are three forces you need to think about for inclined planes:

- Effort: The force pushing or pulling the object.
- Friction: The force that opposes the motion up or down the inclined plane.
- Load: The weight of the object.

An [inclined plane](#) can help make doing [work](#) seem easier by reducing the effort force necessary to raise the object.

Imagine moving a piano. A ramp helps you move the piano onto a truck with a lot less effort force than if you lifted the piano by hand. This is because your effort force is exerted over a greater distance. To make it easier to push the piano up the ramp into the truck, you have to push it a longer distance. The trade-off between force and distance gives you the [mechanical advantage](#) of the inclined plane. The forces of [friction](#) and [gravity](#) work against you as you push the piano up the ramp.

On the left side of the page, there is a concept map diagram. The central node is 'force'. It is connected to 'incline' (type of), 'work' (effort), 'weight' (force), 'piano', 'friction', 'gravity' (type of), 'm' (mass), and 'distance' (opposite of).

Figure 1. Screenshot of the CoMPASS hypertext system showing the concept of “force” in the topic of “Inclined Plane.”

Two studies were conducted analyzing students’ navigation at two different levels in order to investigate goal-focused navigation behaviors and strategies used while learning from the CoMPASS hypertext environment. Both macro (Study 1) and micro (Study 2) analyses were done analyzing navigation behaviors at both the beginning and the end of the curriculum.

STUDY 1 - MACRO ANALYSIS

Procedure

This study focused on students’ use of the CoMPASS hypertext system while conducting research for the inclined plane and pulley challenges. For the inclined plane challenge at the beginning of the curriculum, students investigated information on CoMPASS to help them determine which length of ramp would allow them to move a pool table into a van with the least amount of effort. For the pulley challenge at the end of the curriculum, students were asked to design a pulley system in order to lift a water bottle off of a table with the least amount of effort. Students were given approximately 30 minutes to navigate CoMPASS individually in order to investigate concepts for both challenges. For each of the two challenges, inclined plane and pulley, there are some concepts that are the most relevant for the

learning goal of the challenge and some that are related but are more peripheral to the learning goal. For example, while students were navigating for the inclined plane challenge, the concepts that were most relevant to the challenge were: force, work, mechanical advantage, friction and distance. All the other concepts were related, but more peripheral to the challenge. Each of the concepts may be included in different paths of navigation, and it is up to the learner to decide which navigational patterns are most appropriate for the learning goal.

Measurements and Data Sources

There were 3 data sources used for this study: 1) the Gates-MacGinitie Reading Test- Comprehension portion (GMRT-C), 2) Pre-tests of prior knowledge for both inclined plane and pulley, and 3) Navigation log files to record the order in which students navigated to concepts in CoMPASS and how long they were at each concept.

Reading Comprehension

As a measure of reading comprehension ability for traditional text, students took the comprehension portion of the Gates-MacGinitie Reading Test for grade 6, which is a standardized test that involves reading short passages and answering multiple-choice questions. The test included different genres of text, such as narrative and expository passages. Scores on the test could range from 0 to 48.

Prior Knowledge

Inclined plane pretest. In order to test students' prior knowledge of physics concepts related to inclined planes, a test consisting of 14 multiple-choice and one open-ended question was developed. There was a maximum possible score of 14 for the multiple-choice questions and 5 for the open-ended question for a total possible score of 19. The multiple-choice questions presented four choices and students were instructed to circle only one letter to indicate their answer for each question. Students' responses to the open-ended question were scored based on a rubric that evaluated the sophistication of their explanations of the concepts *effort*, or applied force, and *work*.

Pulley pretest. In order to test students' prior knowledge of physics concepts related to pulleys, a test consisting of 13 multiple-choice and 5 open-ended questions was developed. There was a maximum possible score of 13 for the multiple-choice and 10 for the open-ended questions for a total possible score of 23. The format for student responses and scoring was identical to the inclined plane test. The open-ended questions tested students' knowledge of *effort*, or applied force, *work* and *mechanical advantage*.

Navigation Log Files

The navigation log files recorded the nodes of information that students went to, the order that they visited them, and the amount of time spent on each. Instances in which students spent less than 10 seconds in a node of text were eliminated. From this information, three measures of students' goal-focused navigation behavior were calculated. The first was the percent of visits to goal-focused concepts. The second was the percent of transitions between goal-focused concepts, and the third was the percent of navigation time spent on goal-focused concepts. Goal-focused concepts were defined as those that were the most relevant for helping students to successfully complete the challenges out of all of the concepts that students could potentially visit.

Percent of visits to goal-focused concepts. The percent of visits to goal-focused concepts was calculated by dividing a count of the number of times concepts that were most relevant for the challenge students were working on were visited by the total number of concept visits during the CoMPASS session. This was used as a measure of goal-focused navigation behavior because it is important that students visit concepts related to the learning goal in order to construct and update their textbase and situations model with goal-related content and also develop an intertext model of relationships between nodes of text describing concepts they need to understand for their challenge.

Percent of transitions between goal-focused concepts. The percent of transitions between goal-focused concepts was calculated by dividing a count of the number of transitions between concepts that were most relevant for the challenge students were working on by the total number of transitions made between concepts during the CoMPASS session. This was used as a measure of goal-focused navigation behavior because thinking about the transitions made between concepts is especially important to development of an intertext model of the relationships among the multiple nodes of text and the ways in which texts complement each other with additional information about concepts that are important for completing the challenge.

Percent of navigation time spent on goal-focused concepts. The percent of time spent on goal-focused concepts was calculated by dividing the total time spent in concepts that were most relevant for the challenge students were working on by the total amount of time spent navigating during the CoMPASS session. This measure of goal-focused navigation is primarily related to reading the individual nodes of text in order to construct a textbase and understand the content of each of the individual nodes. This information can then be used to construct a documents model of the texts that discuss concepts that students need to understand to complete the challenge.

Analysis and Results of Study 1

Descriptive statistics for both the GMRT-C and the inclined plane and pulley tests of prior knowledge can be found in Table 1. Descriptive statistics for the percentages of inclined plane navigation behaviors and descriptive statistics for the percentages of pulley navigation behaviors can be found in Tables 2 and 3. Although 60 students participated in the study, given the constraints of collecting data in a classroom (students missing class due to illness, appointments, etc.), the N's are slightly different for the various data collection measures because students missed class for reasons beyond the control of the researchers.

Table 1
Descriptive Statistics for GMRT-Comprehension and
Tests of Prior Knowledge

Variable	N	Mean	SD	Min	Max
GMRT-Comprehension	56	36.73	7.46	17	47
Inclined Plane Pretest	54	8.24	2.74	3	15
Pulley Pretest	55	5.65	2.26	0	11

In order to answer the first research question about the relationship between goal-focused navigation behaviors and reading comprehension ability after controlling for prior physics knowledge, linear regression analyses were conducted for each of the six dependent variables related to navigation behavior discussed above (three for inclined plane and three for pulley). After using the pretest scores to control for prior knowledge, there was no significant relationship between any measure of goal-focused navigation behavior and reading comprehension scores on the GMRT-C. This was true for both the inclined plane and pulley navigation sessions. Further, there was no significant relationship between the measures of goal-focused navigation behavior and pretest measures of prior knowledge for either the inclined plane or the pulley navigation (see Table 4 for IP and Table 5 for pulley estimates and significance tests).

Table 2
Descriptive Statistics for Inclined Plane Navigation Behaviors (N=54)

Variable	Mean	SD	Min	Max
Percent Goal-focused Concept Visits	40.74	17.75	5.26	77.42
Percent Transitions Between Goal-focused Concepts	19.73	14.60	0.00	60.00
Percent Time on Goal-focused Concepts	46.12	19.53	7.72	92.67

Table 3
Descriptive Statistics for Pulley Navigation Behaviors (N=52)

Variable	Mean	SD	Min	Max
Percent Goal-focused Concept Visits	48.11	21.36	0.00	84.62
Percent Transitions Between Goal-focused Concepts	26.91	22.32	0.00	100.00
Percent Time on Goal-focused Concepts	58.89	26.17	0.00	96.37

Table 4
Results of Multiple Regression Analyses for Inclined Plane with Prior Knowledge and Reading Comprehension Ability as Predictors of Goal-focused Navigation Behaviors

Variable	β	SE β	Standardized β	t	p
1. Percent Goal-focused Concept Visits for IP (N = 45)					
Inclined Plane Pretest	-.018	1.090	-.003	-.016	.987
Reading Comprehension	.182	.401	.080	.454	.652
R ² = .006					
2. Percent Transitions Between Goal-focused Concepts for IP (N = 45)					
Inclined Plane Pretest	-1.245	.894	-.232	-1.392	.171
Reading Comprehension	-.317	.329	-.161	-.964	.341
R ² = .116					
3. Percent Time on Goal-focused Concepts for IP (N = 45)					
Inclined Plane Pretest	.242	1.231	.034	.197	.845
Reading Comprehension	.565	.452	.215	1.248	.219
R ² = .055					

Table 5
Results of Multiple Regression Analyses for Pulley with Prior Knowledge and Reading Comprehension Ability as Predictors of Goal-focused Navigation Behaviors

Variable	β	SE β	Standardized β	t	p
1. Percent Goal-focused Concept Visits for Pulley (N = 44)					
Pulley Pretest	1.167	1.521	.119	.767	.447
Reading Comprehension	-.229	.429	-.083	-.534	.597
R ² = .020					
2. Percent Transitions Between Goal-focused Concepts for Pulley (N = 44)					
Pulley Pretest	-2.378	1.566	-.231	-1.519	.137
Reading Comprehension	-.142	.442	-.049	-.321	.750
R ² = .057					
3. Percent Time on Goal-focused Concepts for Pulley (N = 44)					
Pulley Pretest	1.383	1.927	.112	.718	.477
Reading Comprehension	-.085	.544	-.024	-.156	.877
R ² = .013					

In order to answer the second research question about the change in goal-focused navigation behaviors from the beginning to the end of the curriculum, three paired-samples *t*-tests were used to compare goal-focused navigation between the inclined plane and pulley challenges. The criterion for statistical significance was set at $\alpha = .05$. Due to the use of multiple tests, the Bonferroni-Holm method was used to control Type 1 error. The percent of visits to goal-focused concepts increased significantly from the inclined plane ($M = 40.13$, $SD = 17.79$) to the pulley challenge ($M = 48.60$, $SD = 21.35$); $t(46) = -2.335$, $p = .024$. There was no significant difference in the percent of transitions among goal-focused concepts between the inclined plane ($M = 19.19$, $SD = 13.57$) and the pulley challenge ($M = 24.89$, $SD = 19.27$); $t(46) = -1.725$, $p = .091$. Finally, the percent of time spent on goal-focused concepts increased significantly from the inclined plane ($M = 45.67$, $SD = 20.15$) to the pulley challenge ($M = 59.60$, $SD = 25.97$); $t(46) = -2.670$, $p = .010$. See Figure 2 for a comparison of the percentages of navigation behaviors from the inclined plane to pulley challenge.

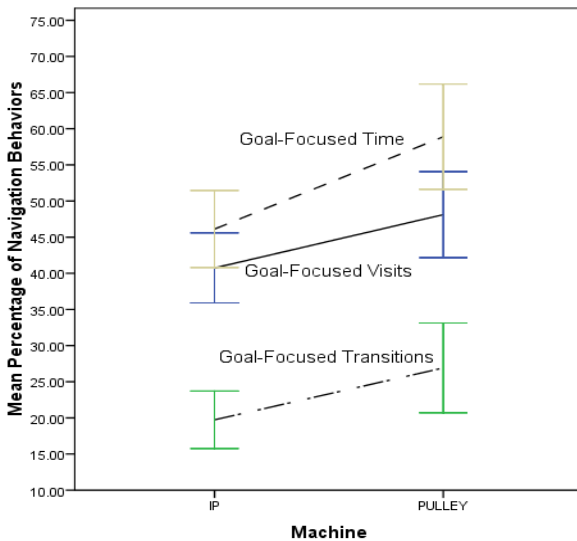


Figure 2. Comparison of the percentages of navigation behaviors from the inclined plane to pulley challenge with error bars representing 95% confidence intervals

Summary of Findings for Study 1

Contrary to what was expected, there was not a significant positive relationship between reading comprehension scores and goal-focused navigation behaviors after controlling for prior knowledge. Further, as hypothesized, there was an increase from the beginning to end of the curriculum in students' goal-focused navigation behaviors as measured by visits to and time spent in concepts that students needed to understand to complete the challenge. On the contrary, there was not a significant increase in transitions between goal-focused concepts, which may indicate that students were not thinking about the relationships among the nodes of text and the concepts presented in each node. However, these results only give a broad picture of the post hoc analysis of students' navigation behaviors. A more in-depth discussion of these findings will be provided and integrated with the results from Study 2.

STUDY 2 - MICRO ANALYSIS

Study 2 was done in order to conduct a more in-depth investigation into the ways in which students with varying levels of reading comprehension ability used CoMPASS. Further, this study also investigated changes in the strategies that students were using to make navigation decisions and comprehend the information presented in CoMPASS.

Procedure

Think-alouds (Erickson & Simon, 1998) were conducted with a subsample of students (N=12) who participated in Study 1. Five boys and seven girls participated in this second study. Students were selected on the basis of their reading comprehension scores. The six students with the highest GMRT-C scores and the six students with the lowest GMRT-C scores out of the sample of students who had agreed to participate in interviews were picked to participate in the study. To balance the opposing concerns of the time constraints for interviewing students with the need to interview enough students of differing comprehension abilities in order to identify differences in strategy use, twelve students were interviewed.

The twelve students used CoMPASS individually on two separate occasions in order to solve two additional challenges related to simple machines using the CoMPASS hypertext system as a resource. The first challenge was related to levers and occurred at the beginning of the curriculum. The second challenge was an additional challenge related to pulleys and occurred at the end of the curriculum. For each of these challenges, students were asked to think-aloud as they used CoMPASS to investigate concepts in order to

complete their challenges. Think-alouds were conducted individually by the first author with each of the 12 students once at the beginning and once at the end of the curriculum, with about four weeks between interviews.

Students participated in the additional lever challenge during the first think-aloud. All students then participated in the additional pulley challenge during the second think-aloud. Before the first think-aloud session, the procedure for thinking-aloud was explained to the students and they were given a chance to practice. Students were informed that the investigator was interested in finding out what students think and do as they navigate a hypertext system. The procedure for the think-aloud was adapted from work by Hofer et al. (2009). Students were given the instructions: *“I would like you to think aloud as you work on the task. What I mean by think aloud is that I want you to tell me everything you are thinking during the task. I would like you to talk aloud constantly. I don’t want you to try to plan out what you say. Just act as if you are alone in the room, speaking to yourself. It is very important that you keep talking. If you are silent for any long period of time, I may prompt you to keep talking. Do you have any questions?”*

After students had practiced thinking aloud, they were given their lever challenge and instructed to think-aloud while using CoMPASS. Their challenge was presented as follows:

Your challenge is to figure out how a student in the class can lift your teacher using a seesaw. How is this possible? Please use the CoMPASS hypertext system to help you solve your challenge. What placement of the load, effort force and fulcrum will best help you to lift a heavy load? Why?” The investigator then reviewed the instructions for thinking aloud presented above and, after any clarification questions about the challenge were answered, the student navigated CoMPASS to complete the lever challenge. If students were silent for a long period of time, they were prompted to think aloud. See Appendix A for a list of prompts used by the investigator. Students were provided with a separate page to take notes if they chose to do so. When students indicated that they were finished navigating CoMPASS, they were asked to orally solve their challenge. Navigation times ranged from approximately 10 to 20 minutes.

Think-alouds for the pulley challenge were conducted with students approximately four weeks after the think-alouds for the lever. A procedure identical to the one for the lever challenge was used. However, students did not practice thinking aloud during this session given that they had practiced during the first interview. The think-aloud procedure was reviewed using the same instructions. The pulley challenge was presented as follows: *“Your challenge is to figure out how a student in the class can lift a couch from the ground outside up to a big balcony window in order to put it in your room on the second floor. How would this be possible using a pulley system? You*

then have to move the old couch down to the ground. What happens to the energy as the couch is moved from the window on the second floor to the ground? What are some factors that may help you as you move the couch down to the ground? Please use the CoMPASS hypertext system to help you solve your challenge.”

After the think-aloud instructions were reviewed and clarification questions answered, students navigated CoMPASS for the pulley challenge and again were able to take notes if they chose to. When students indicated that they felt they were finished using CoMPASS, they were asked to solve the challenge orally. Navigation times ranged from approximately 10 to 20 minutes.

Measurements and Data Sources

The think-alouds were audio taped and amounted to approximately six hours of audio for the lever challenge and six hours of audio for the pulley challenge. All of the audio from the think-alouds was transcribed for a total of 114 pages of transcripts.

Coding of the Think-alouds

A coding rubric was developed based on prior work on active, constructively responsive reading by Pressley and Afflerbach (1995), and work by Azevedo and colleagues (e.g. Azevedo, 2008; Azevedo et al., 2005; Azevedo, Guthrie, & Seibert, 2004) looking at learners' use of self-regulated learning strategies while working in hypermedia environments. A process of axial coding (Strauss & Corbin, 1998) was then employed whereby the existing coding rubric was applied to the transcripts and was modified based on the patterns of strategy use that emerged from the analysis of the think-aloud protocols.

Through this process, a coding rubric was developed to capture both the strategies that students used to navigate and comprehend the information in CoMPASS and the ways in which the investigator prompted students to help them during the think-aloud process. The first and second authors worked together to refine the coding rubric (see Appendix B for a list and examples of the codes) and then independently coded 10% of the transcripts. An inter-rater reliability of 82% was established and disagreements were resolved through discussion. The first author then scored the remaining transcripts.

The dialogue of the think-alouds of students engaging with CoMPASS was analyzed using a method adapted from Chi, Siler, Jeong, Yamauchi, and Hausmann (2001), which allowed for the identification of varying approaches to interacting with the system in order to investigate differences in strategies used by students with differing levels of comprehension ability and changes in the use of strategies from the beginning to the end of the curriculum. Codes were used to capture (a) navigation strategies such

as the use of the concept map and other navigation features; (b) reference to prior knowledge or prior experience; (c) reference to the goal of the challenge while reading and navigating; and (d) making inferences and giving scientific explanations based on prior knowledge or based on information in CoMPASS.

From the approaches to engaging with CoMPASS identified above, two subsets of codes were developed that captured a) differences in student navigation behaviors and use of the CoMPASS system features in order to facilitate orientation and understanding of the text, and b) differences in the comprehension strategies students used that focused on reflection on the content of the text rather than on navigation. See Appendix B for examples of all codes.

Navigation Strategies

Navigation strategy codes were used to look at differences in the strategies that students applied for making navigation decisions in CoMPASS and their use of the features of CoMPASS to help make sense of the text content.

Reflection on navigation (RN). This code refers to comments made by students referring to using CoMPASS system features, such as the concept maps, to orient navigation or when the student gave a goal-related reason for navigating to a particular concept.

Exploring (EX). This code refers to navigating to multiple nodes of text in CoMPASS just to “see what’s there” without a clear articulation of how the concepts visited related to the goal of the challenge.

Reference to text pictures or diagrams (RD). This code refers to instances in which students referred to diagrams or pictures in the text in order to help them make sense of the text content.

Comprehension Strategies

Comprehension strategy codes were used to look at differences in the strategies that students used to comprehend the information about physics concepts presented in the nodes of text in CoMPASS. Further, these codes also captured the ways in which students integrated what they were learning on CoMPASS with their overall goal for the challenge.

Reference to prior knowledge (PK). This code refers to students’ explicit reference to prior knowledge about information presented in the text, prior knowledge or experience related to science concepts or prior knowledge of the CoMPASS hypertext system features.

Referring to the goal (RG). This code refers to instances in which students explicitly referred back to the goal for the challenge while navigating or reading.

Summarizing (SU). This code was used when students summarized the text content in their own words.

Making inferences based on text content (MIT). This code was used when students made inferences about science concepts and how concepts applied to their challenge based on information contained in the CoMPASS text.

Making inferences based on prior knowledge (MIP). This code refers to instances in which students made inferences about science concepts and how concepts applied to their challenge based on their prior experience or knowledge of the concepts and not on information contained in the text.

In addition to navigation and comprehension strategies, two other student approaches to engaging with CoMPASS were also coded. *Giving science explanations (SE)* was used in instances in which a student provided an idea for solving the challenge that included the use of the science concepts that were a part of the curriculum and were included in CoMPASS. *Stating misconceptions (SM)* was used when students' ideas included misconceptions about the physics or concepts that they were reasoning about for their challenges.

The frequency of the use of prompts by the investigator to engage students in actively thinking about their challenge and thinking aloud was also analyzed. Prompts used by the investigator focused on asking students to explain their thinking and navigation behavior and also on helping them to focus on the goal of the challenge and concepts that may help them with their challenge. See Appendix A for a list of the prompts used by the investigator.

Three categories of prompts that the investigator used were coded to investigate differences in frequency of use. *Goal orientation (GO)* was used when the investigator prompted the student to maintain goal orientation by helping the student to focus on the overall challenge or some aspect of the overall challenge. *Using generic or content free prompts (UC)* was applied when the investigator used generic prompts, such as asking "what else," to encourage the student to engage with the CoMPASS system. *Explanation of navigation (EN)* was used when the investigator prompted students to explain why they navigated to a particular node of text about a concept.

Analysis and Results of Study 2

All of the student and investigator turns in the think-alouds were coded using the coding rubric described above. A turn in the think-alouds could be multiply coded or assigned more than one code. After coding, a frequency analysis of the turns in each coding category for both the investigator and the student was conducted. The percentage of turns in each category was calculated by taking the number of turns that were assigned a particular code and dividing by the total number of turns that occurred during the

think-aloud. Finally, an average percentage of turns in each coding category was calculated for the six higher comprehension ability students and the six lower comprehension ability students for both the lever and pulley think-aloud sessions (see Figures 3 and 4).

Investigator Prompting

Lever Challenge: An inspection of the prompts used by the investigator to assist students with actively thinking about the challenge and thinking aloud revealed that for the lever think-aloud (see Figure 3), there was a difference in the percentage of turns in which the investigator used prompts related to goal orientation (GO) between the two groups (High [H] = 11.34%, Low [L] = 20.19%). However, there was only a slight difference reflected in the percentage of turns in which content free (UC) prompts were used (H = 8.21%, L = 8.03%) and the difference in the use of explanation of navigation (EN) prompts was minimal (H = 16.81%, L = 13.91%).

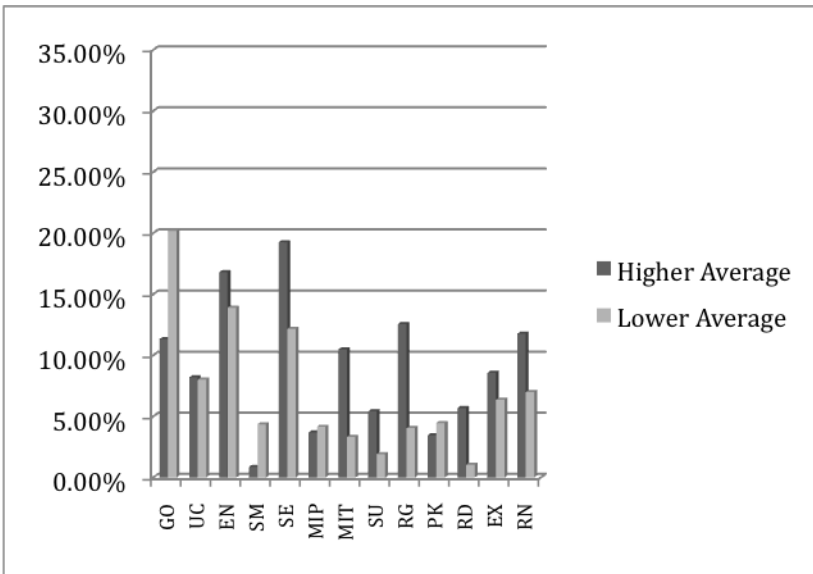


Figure 3. Average percentage of think-aloud turns assigned to each coding category for high and low comprehension ability students' strategies and interviewer prompting for the lever challenge

Pulley Challenge: For the pulley think-aloud (see Figure 4), there were only small differences between the groups in the percentage of goal orientation (H = 23.57%, L = 26.04%) and content free (H = 11.17%, L = 11.11%)

prompts. There was a slightly larger difference in the percentage of explanation of navigation prompts (H = 15.12%, L = 21.06%) used with students in the two groups.

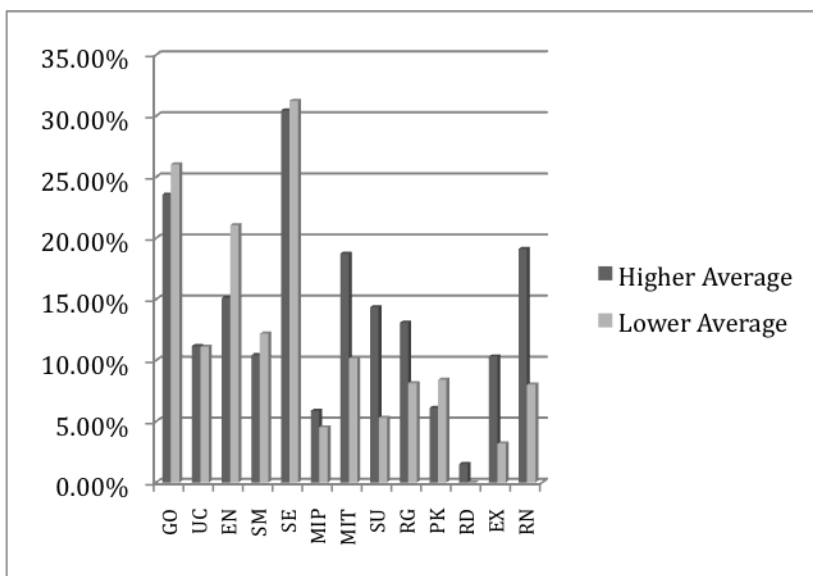


Figure 4. Average percentage of think-aloud turns assigned to each coding category for high and low comprehension ability students' strategies and interviewer prompting for the pulley challenge

Comparison of the Use of Navigation and Comprehension Strategies by Students

Lever Challenge: For the lever challenge (see Figure 3), which took place at the beginning of the curriculum, higher comprehension ability students tended to have a higher percentage of both navigation and comprehension strategy use during the think-alouds, particularly in terms of reflection on navigation (RN) (H = 11.77%, L = 7.01%), reference to text pictures or diagrams (RD) (H = 5.70%, L = 1.04%), referring to the goal (RG) (H = 12.57%, L = 4.06%), summarizing (SU) (H = 5.43%, L = 1.92%), and making inferences based on text content (MIT) (H = 10.48%, L = 3.32%). There was a slight difference in terms of exploring (EX) (H = 8.57%, L = 6.36%), and very small differences in terms of reference to prior knowledge (PK) (H = 3.46%, L = 4.47) and making inferences based on prior knowledge (MIP) (H = 3.70%, L = 4.16%).

In terms of *giving science explanations (SE)*, higher comprehension ability students had a higher average percentage of turns that incorporated sci-

ence explanations ($H = 19.26\%$) than lower comprehension ability students ($L = 12.17\%$). In addition, lower comprehension ability students had a higher percentage of turns *stating misconceptions (SM)* ($L = 4.36\%$) than the higher comprehension ability group ($H = 0.88\%$).

Pulley Challenge: For the pulley challenge at the end of the curriculum (see Figure 4), overall strategy use increased for both higher and lower comprehension ability students in terms of navigation and comprehension strategies. However, higher comprehension ability students reflected on navigation by referencing CoMPASS navigation features and provided reasoning for their navigation decisions related to the learning goal more often ($H = 19.13\%$) than lower comprehension ability students ($L = 8.08\%$). Interestingly, they also did more exploring in CoMPASS ($H = 10.32\%$) than the lower comprehension ability students ($L = 3.19\%$). Overall, there was not much active reference to text pictures or diagrams ($H = 1.52\%$, $L = 0.00\%$). As for comprehension strategies, on average, higher comprehension ability students did more referring to the goal ($H = 13.08\%$, $L = 8.13\%$), made more inferences based on text content ($H = 18.74\%$, $L = 10.17\%$) and did more summarizing of the text content ($H = 14.35\%$, $L = 5.29\%$) than lower comprehension ability students. However, there was still not much difference between the groups in terms of their reference to prior knowledge ($H = 6.12\%$, $L = 8.41\%$) or making inferences based on prior knowledge ($H = 5.88\%$, $L = 4.52\%$).

Finally, in terms of *giving science explanations* during the pulley challenge at the end of the unit, the groups had a very similar average percentage of turns that incorporated science explanations ($H = 30.45\%$, $L = 31.24\%$), with both groups increasing from the lever challenge. Further, although the percentage of *stating misconceptions* increased from lever for both groups, they were relatively evenly matched ($H = 10.44\%$, $L = 12.19\%$) in the frequency with which their turns in the think-alouds contained misconceptions.

Summary of Findings for Study 2

In contrast to Study 1, the results from Study 2 provide support for the idea that students with high versus low comprehension ability differ in how they use strategies to navigate and comprehend the information in multiple nodes of a hypertext. As previously hypothesized, at the beginning of the curriculum, higher comprehension ability students tended to have a higher percentage of turns in which they used navigation and comprehension strategies and this pattern also held true for strategy use at the end of the curriculum. Overall strategy use increased from the beginning to end of the curriculum for both higher and lower comprehension ability students in terms of comprehension strategies. In terms of navigation strategies, higher comprehension ability students increased their use of strategies that involved reflecting

on navigation choices substantially more than lower comprehension ability students. However, the percentage of turns incorporating various types of strategy use was relatively low overall, under 20% for most strategies. Therefore, although providing support that higher comprehension ability students may be better prepared to navigate and comprehend information in hypertext environments, the results of Study 2 also show that all students could benefit from scaffolding.

DISCUSSION

The incorporation of textual resources into active scientific inquiry practices is important for establishing background knowledge of a domain. Many of these resources are now presented in hypertext or hypermedia environments, which require and make explicit the need for students to actively integrate information from multiple sources. Additionally, many of the practices employed by readers with good comprehension skills align with the practices necessary to successfully conduct scientific inquiry. The goal of the studies in this paper was to investigate the relationship between reading comprehension ability for traditional text and navigation behaviors and comprehension strategies used in a hypertext environment. Further, changes in navigation behaviors from the beginning to end of an inquiry-based physics curriculum were also examined. It was hypothesized that reading comprehension ability would be positively related to navigation behaviors that reflected the learning goal. Moreover, navigation behaviors were expected to become more goal-focused as students gained experience with learning from the hypertext system in the context of a curriculum that emphasized active inquiry practices. The main findings of Studies 1 and 2 were:

- There were no significant relationships between reading comprehension ability and any of the measures of goal-focused navigation behaviors in Study 1. However, Study 2 revealed differences in the strategies that higher and lower comprehension ability students used to make navigation decisions and comprehend the information presented in the hypertext.
- In Study 1, not all goal-focused navigation behaviors improved significantly from the beginning to the end of the curriculum. In addition, Study 2 indicated that the use of only some strategies increased throughout the curriculum. The results of both studies illustrate the need for scaffolding of navigation and comprehension strategies, as goal-focused navigation and the use of effective strategies was relatively low overall.

In the following sections, these findings and their implications for learning from hypertext and hypermedia environments, particularly in the context of inquiry-based science classrooms, are discussed in more detail.

Relationship Between Reading Comprehension Ability and Goal-Focused Navigation Behaviors

The results of Study 1 indicated that there was no significant relationship between reading comprehension ability and goal-focused navigation behavior after controlling for prior knowledge. This was true at the beginning of the curriculum when navigating for inclined plane and the end of the curriculum when navigating for pulley. Further, there was no significant relationship between prior knowledge and goal-focused navigation behavior for either the inclined plane or pulley challenge navigation. Both of these outcomes are interesting in terms of the theoretical perspectives of the C-I Model and integrating multiple documents. From these perspectives, one would expect that students with more prior knowledge would be able to make informed navigation decisions to focus on reading content that reflected the learning goal and that students with higher reading comprehension ability would be able to actively employ strategies that would allow them to effectively navigate and integrate the information found in the multiple nodes of text. Unlike the results of Alexander and colleagues (1994) and Lawless and colleagues (1998; 2007) students with higher levels of prior domain knowledge did not appear better prepared or more proficient in their navigation. Further, perhaps even students with higher comprehension abilities lacked the metacognitive skills to employ appropriate comprehension strategies and may need help to develop their metacognitive abilities when reading hypertext, as proposed by Lazonder & Rouet, 2008.

One reason for these incongruous results may be that reading comprehension ability for traditional text does not necessarily reflect a student's ability to make good navigation choices when working in a hypertext or other hypermedia environment. The comprehension portion of the Gates-MacGinitie test primarily looks at a student's ability to comprehend and make inferences about information presented in short passages. Although students must be able to attend to the relevant information in the passage in order to answer the questions, they are not required to choose between or integrate multiple passages to help them answer the questions. In relation to the theoretical perspective of integrating multiple documents, although a student may be good at comprehending a section of text, he or she may have difficulty with reflecting on the individual contributions of multiple sources and integrating them to support the learning goal. Reading multiple documents requires specific comprehension strategies that are typically overlooked in theories of reading competence and instruction (Rouet, 2006a). These include identifying the source of the information, comparing information across sources and understanding the relationships among sources in order to integrate information. These processes are also important components for conducting scientific inquiry (NRC, 2006). Perhaps even if students do ac-

tively engage in strategies to comprehend multiple traditional texts, they are not able to apply these strategies in the ways necessary to actively navigate and integrate multiple nodes of information found in a hypertext environment. The results of Study 1 highlight the need for the continued investigation of the similarities and differences between the skills needed to actively comprehend traditional texts and those needed in hypertext and hypermedia environments.

According to the results of Study 1, students with higher reading comprehension ability as measured by the GMRT-C did not appear to exhibit navigation behaviors that were more goal-focused than lower comprehension ability students. However, a slightly different picture of strategy use emerges from the data from Study 2.

There were several differences between the groups that persisted throughout the curriculum. Higher ability comprehenders tended to use more navigation and comprehension strategies than lower comprehenders. Specifically, they tended to use the CoMPASS system features to orient navigation and provided reasons for their navigation choices that were related to the learning goal, reflected on their learning goal, summarized the text content, and made inferences from the text more often than the lower comprehension ability group. Further, students in the higher comprehension ability group also made relatively more references to pictures and diagrams, although use of this strategy was low overall. These students also explored more of the concepts in CoMPASS, particularly during the pulley navigation. A possible explanation for the increase in exploring concepts in pulley may have been that students had become familiar with the more challenge-focused concepts and wanted to see how other concepts they were not as familiar with apply to pulleys. In terms of the prompts provided by the investigator, the biggest difference between the groups was that lower comprehension ability students needed more help at the beginning of the curriculum in order to maintain goal orientation. Thus, students with lower comprehension ability may have initially needed more assistance to self-regulate their comprehension and integration of the information presented in multiple nodes in the hypertext. The results from Study 2, even though on a relatively small sample of students, allowed for the identification of some possible differences between the two groups, and highlight some areas for further investigation in terms of supporting navigation behavior and strategies.

Goal-focused Navigation Behaviors at the Beginning and End of the Curriculum

The results of Study 1 indicate a significant increase in goal-focused navigation from the beginning to the end of the curriculum in terms of visits to and time spent in goal-focused concepts. By the end of the unit, students

had more experience to help them determine which concepts were most related to their learning goal. Although it may be expected that students with more experience with the concepts would spend less time navigating to and reading about goal-focused concepts, the physics information within pulley is contextualized and different from the inclined plane. In relation to the Construction-Integration model, since students had more knowledge about physics concepts to incorporate with the pulley text, they may have been working to combine the pulley information with what they learned about the other simple machines in order to update their situation model. Perhaps students were more aware of what concepts they should apply to their challenge, but still were not able to generalize from other machines to the pulley and therefore made more visits to goal-focused concepts at the end of the curriculum. Further, the material related to the pulley is more conceptually challenging than inclined plane, and therefore students may have required more visits to goal-focused concepts to update their situations and intertext models in order to understand what each node of text was saying about a concept and how all of the individual concepts are related in the context of a pulley.

There was no significant increase in the number of goal-focused concept transitions, which was lower than the other two measures overall. This may reflect the idea that although students knew which concepts were relevant, they were still not thinking about the relationships between concepts and how the relationships between concepts were applicable to and could help them with their challenges. Even though the CoMPASS hypertext system is designed to facilitate understanding of relationships among concepts, students may not have recognized the organizational function and navigational affordances of the CoMPASS system, which according to Rouet and colleagues (2005) and Gerjets and colleagues (2009) is essential in order to facilitate comprehension and learning. From an integrating multiple documents perspective, the lack of coherent, goal-focused transitions may have impacted students' ability to form an integrated documents model, particularly the intertext portion of the model, which highlights the relationships among the nodes of text and the information about concepts presented in each. In addition, it is not clear based on their transitions during navigation that students had a clear representation of or were thinking explicitly about conceptual relationships at the end of the curriculum. This is a topic for further investigation.

Overall, the means of the percent of visits to goal-focused concepts, goal-focused transitions, and time spent in goal-focused concepts, are all under 50% for both inclined plane and pulley, with the exception of the percentage of navigation time spent in goal-focused concepts for pulley (see Tables 2 and 3). Thus, students spent only half of their navigation time, or less,

focusing on the concepts that are most related to their challenge. In particular, the results from Study 1 indicate that only a small average percentage, approximately 20% for inclined plane navigation and 27% for pulley navigation, of students' transitions are between goal-focused concepts that are closely related to each other. These results indicate that all students have room for improvement in their navigation behaviors.

The results from Study 2 indicate that the percentages of strategy use did increase for both lower and higher comprehension ability students, even though higher comprehension ability students had greater percentages of strategy use overall. Students increased their use of navigation and comprehension strategies during their think-alouds at the end of the CoMPASS curriculum as compared to the beginning of the curriculum. For example, all increased their use of prior knowledge and use of the CoMPASS text to make inferences and the frequency with which they summarized text content and referred to the learning goal. These are practices that may have been facilitated by participation in the inquiry-based science curriculum. However, lower comprehension ability students still reflected relatively little on their navigation at the end of the curriculum, which may indicate that they need more support not only in terms of comprehension strategies, but also with actively reflecting on their navigation decisions than their higher comprehension ability peers. Students in the two groups differed relatively little and had low percentages of references to prior knowledge and making inferences based on prior knowledge throughout the curriculum. The use of prior knowledge to help understand the text is a strategy that students could be helped to increase, particularly in the pulley unit in which they have prior knowledge of the concepts within other simple machines that they can refer to. Regardless of reading comprehension ability, students were able to take what they had learned throughout the unit and apply it to what they were learning on CoMPASS for their pulley challenge, which is evidenced by the overall increase in science explanations in the pulley challenge. However, students also had misconceptions and still had low use of many of the strategies that could have been helpful for learning from the multiple nodes of information in CoMPASS and for conducting inquiry in general. By the end of the curriculum, for the pulley challenge, lower comprehension ability students required about the same percentage of goal orientation as the higher comprehension ability students, which may provide support for the idea that they learned some helpful strategies throughout the unit. Although there were improvements in strategy use for both reading comprehension ability groups, a conclusion similar to Study 1 is still drawn, that overall there is room for improvement in students' active reflection on their navigation behaviors.

Contribution of Both Studies

Although these studies did not look at learning outcomes as measured by a more traditional measure, such as pre and posttests of content knowledge, learning can be thought of as the growth that students made in terms of the strategies that they used to actively integrate sources of information while doing the inquiry science unit. In particular, there was an increase in some of the active navigation and comprehension strategies that students used to navigate CoMPASS. However, although students did make some increases in their goal-focused navigation behaviors and their use of navigation and comprehension strategies, all students had room for improvement and could benefit from scaffolding of navigation and comprehension strategies. Some possible differences in the support needed by different comprehension ability learners, such as the need to actively reflect on navigation decisions and make inferences from the text, that could not be captured by the macro level analysis of the log file data in Study 1 were captured in the micro level analysis of the think-alouds in Study 2. These results reflect the ability of multiple sources of data to shed light on differences in navigation behavior that may otherwise be missed. This speaks to the importance of using multiple data sources and methods of analysis when trying to understand students' use of hypertext and other hypermedia environments as learning resources.

Implications for Teachers and the Classroom

The results of these studies highlight the numerous ways in which students could be supported in order to improve their navigation behavior and their use of inquiry skills throughout the curriculum. First, although students did reflect on their navigation, there is room for improvement and more focused reflection on navigation choices and use of the features of CoMPASS to help make navigation decisions. Second, the results also show that students may need support in applying reading comprehension strategies to hypertext and hypermedia environments. These findings align with what has been found in other studies (e.g., Coiro, & Dobler, 2007; Azevedo, 2005) on learning with hypertext and hypermedia. Further, although student use of strategies did appear to improve from the beginning to the end of the curriculum, it is clear that support is needed, particularly in terms of reflecting on the relationships between units of information in the system to help understand conceptual relationships. Lower comprehension ability readers may need more support than higher comprehension ability readers, although all students may benefit from this support.

The multiple forms of data collected also help to highlight the different problems that students may have with their navigation processes at the beginning and end of the unit to inform areas that teachers can focus on im-

proving throughout the unit. The different types of data reveal that navigation patterns may be related to different navigation processes depending on the characteristics of the students, such as reading comprehension ability. Thus, in addition to instruction aimed at students' understanding of science content, explicit teaching and modeling of strategies to help students navigate and comprehend information from multiple sources is also important.

Study Limitations

The results of this study can help inform our understanding of the relationship between reading comprehension ability for traditional text and navigation behavior in a hypertext environment designed to facilitate conceptual understanding in physics. However, many factors related to the classroom environment that could potentially have impacted the results could not be accounted for by these studies. These include the degree to which the teacher reminded students of the affordances of the CoMPASS hypertext and explicitly encouraged understanding of the relationships among concepts throughout the curriculum. Further, perhaps the measures used to assess goal-focused navigation were not sensitive enough to differences in navigation decision making or comprehension processes among students with varying levels of comprehension ability. Finally, differences in students' level of comfort with the think-aloud protocol, although all students were given time to practice, may have lead to some differences in the processes that were reported.

Future Directions

Based on the results of these studies, future research will investigate the incorporation of scaffolding of navigation and comprehension strategies for CoMPASS into the curriculum based on our increased understanding of the areas in which students may need help. For example, there is a need to focus on helping students to actively think about the relationships between nodes of information, and lower comprehension ability students in particular may need help with this as well as with comprehension strategies, although there appears to be room for improvement for all students. What was learned from this study will be used to provide navigation support for future implementations and can help to address the question of how hypertext and other hypermedia environments can be incorporated into and supported in inquiry science classrooms. The connections between strategies used for navigation and integration of information from these environments and strategies in general that promote active scientific inquiry processes is also an area for further investigation. A next step will be the development of a more struc-

tured study of the effect of using different kinds of navigation support on student navigation patterns and strategies and the impact this has on learning outcomes. Data have been collected to study how students integrate the multiple sources of information from CoMPASS with other informational sources throughout the unit, such as data from the experiments and texts produced during group analysis and discussion.

CONCLUSION

These results are informative in light of thinking about learning in science not only in terms of students' knowledge of science content but also in terms of their active participation in the processes of scientific inquiry. In order to use textual resources as part of the inquiry process, students need to be able to integrate and comprehend information from multiple sources and documents. The ability to do this is similar to the skills required to successfully navigate and comprehend information found in hypertext and hypermedia environments. However, it is important not only to be able to comprehend the information in a single node of text, but also reflect on navigation choices in order for learners to understand and build representations of how multiple sources of information are related to each other. The results of these studies indicate that students with higher comprehension ability for traditional text may not necessarily possess these skills or know how to apply them to integrating sources from hypertext environments, although they appear to be further along in their development of the use of active comprehension and navigation strategies than their lower comprehension ability peers.

Multiple forms of science texts allow students to supplement their classroom, hands-on experiences with general information about scientific concepts or processes in order to help them understand broader patterns and conceptual relationships in scientific domains. Many forms of science texts are now accessed via digital hypertext and hypermedia environments. Because of this, the study of the processes that students use to integrate, comprehend and understand the conceptual relationships among multiple sources of scientific information from these environments, and the influence that individual student factors, such as reading comprehension ability, have on these processes is an important area for study in order to facilitate inquiry-based learning and scientifically literate practices.

References

- Alexander, P. A., Kulikowich, J., & Jetton, T. (1994). The role of subject-matter knowledge and interest in the processing of linear and nonlinear texts. *Review of Educational Research*, 64, 201-252.
- Alvermann, D. E., (2004). Multiliteracies and self-questioning in the service of science learning. In E.W. Saul (Ed.) *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 226-238). Newark, DE: International Reading Association, & Arlington, VA: National Science Teachers Association.
- Amadiou, F., Tricot, A., & Mariné, C., (2010). Interaction between prior knowledge and concept-map structure on hypertext comprehension, coherence of reading orders and disorientation. *Interacting with Computers*, 22, 88-97.
- Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist*, 40(4), 199-209.
- Azevedo, R. (2008). The role of self-regulated learning about science with hypermedia. In D. H. Robinson & G. Shaw (Eds.), *Recent innovations in educational technology that facilitate student learning* (pp. 127-156). Charlotte, NC: Information Age Publishing.
- Azevedo, R., Guthrie, J.T., & Seibert, D. (2004). The role of self-regulated learning in fostering students' conceptual understanding of complex systems with hypermedia. *Journal of Educational Computing Research*, 30(1&2), 87-111.
- Azevedo, R., Cromley, J.G., Winters, F.I., Moos, D.C., & Greene, J.A. (2005). Adaptive human scaffolding facilitates adolescents' self-regulated learning with hypermedia. *Instructional Science*, 33, 381-412.
- Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia. *Journal of Educational Psychology*, 96, 523-535.
- Azevedo, R., & Jacobson, M. (2008). Advances in scaffolding learning with hypertext and hypermedia: A summary and critical analysis. *Educational Technology Research & Development*, 56(1), 93-100.
- Baker, L. (2004). Reading comprehension and science inquiry: Metacognitive connections. In E.W. Saul (Ed.) *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 123-139). Newark, DE: International Reading Association, & Arlington, VA: National Science Teachers Association.
- Bolter, J. D. (2001). *Writing space: Computers, hypertext and the remediation of print*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Charney, D. (1987). Comprehending non-linear text: The role of discourse cues and reading strategies. In J. Smith & F. Halasz (Eds.), *Hypertext '87 proceedings* (pp.109-120). New York: Association for Computing Machinery.
- Chi, M. T. H., Siler, S. A., Jeong, H., Yamauchi, T., & Hausmann, R. G. (2001). Learning from human tutoring. *Cognitive Science*, 25, 471-533.
- Coiro, J. (2010). Talking about reading as thinking: Modeling the hidden complexities of online reading comprehension. In Hansfield, L. J. & Jaminez, R. T. (Chairs) *New Perspective in Comprehension Strategy Instruction*. Alternative session presented at the annual meeting of the American Educational Research Association, Denver. CO.
- Coiro, J., & Dobler, E. (2007). Exploring the online reading comprehension strategies used by sixth-grade skilled readers to search for and locate information on the Internet. *Reading Research Quarterly*, 42(2), 214-257.

- Craig, M.T. & Yore, L.D. (1996). Middle school students' awareness of strategies for resolving comprehension difficulties in science reading. *Journal of Research and Development in Education*, 29, 226-238.
- Ericsson, K. A., & Simon, H. A. (1998). How to study thinking in everyday life: Contrasting think-aloud protocols with descriptions and explanations of thinking. *Mind, Culture, & Activity*, 5(3), 178-186.
- Gerjets, P., Scheiter, K., Opfermann, M., Hesse, F. W., & Eysink, T. H. S. (2009). Learning with hypermedia: The influence of representational formats and different levels of learner control on performance and learning behavior. *Computers in Human Behavior*, 25, 360-370.
- Hapgood, S., Magnusson, S.J., & Palincsar, A.S. (2004). Teacher, text and experience: A case of young children's scientific inquiry. *Journal of the Learning Sciences*, 13(4), 455-505.
- Hofer, B. K., Harris, A., Greis, K., Lam, J., Nykiel-Bub, K., Higgins, M., & DeLisi, A. (2009, April). Knowing who and what to believe: Epistemological development during adolescence. Poster presented at the annual meeting of the American Educational Research Association, San Diego, CA.
- Kamil, M.L., & Bernhardt, E.B., (2004). The science of reading and the reading of science: Successes, failures, and promises in the search for prerequisite reading skills for science. In E.W. Saul (Ed.) *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 123-139). Newark, DE: International Reading Association, & Arlington, VA: National Science Teachers Association.
- Kintsch, W. (1988). The role of knowledge in discourse comprehension: A construction-integration model. *Psychological review*, 95(2), 163-182.
- Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York: Cambridge University Press.
- Lawless, K. A., & Kulikowich, J. M. (1998). Domain knowledge, interest, and hypertext navigation: A study of individual differences. *Journal of Educational Multimedia and Hypermedia*, 7(1), 51-70.
- Lawless, K. A., Schrader, P. G., & Mayall, H. J. (2007). Acquisition of information online: Knowledge, navigation and learning outcomes. *Journal of Literacy Research*, 35, 911-934.
- Lazonder, A. W., & Rouet, J-F. (2008). Information problem solving instruction: Some cognitive and metacognitive issues. *Computers in Human Behavior*, 24, 753-765.
- Magnusson, S.J., & Palincsar, A.S. (2004). Learning from text designed to model scientific thinking in inquiry-based instruction. In E.W. Saul (Ed.) *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 316-339). Newark, DE: International Reading Assn., & Arlington, VA: National Science Teachers Assn.
- Moreno, R., & Mayer, R. E. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, 19, 309-326.
- National Research Council (NRC). (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
- Perfetti, C. A., Rouet, J-F., & Britt, M. A. (1999). Toward a theory of documents representation. In H. van Oostendorp & S. Goldman (Eds.), *The construction of mental representations during reading* (pp. 99-122). Mahwah, NJ: Erlbaum.
- Pressley, M., & Afflerbach, P. (1995). *Verbal protocols of reading: The nature of constructively responsive reading*. Hillsdale NJ: Erlbaum.

- Puntambekar, S. (2006). Learning from digital text in inquiry-based science classes: lessons learned in one program. *Proceedings of the 7th International Conference of the Learning Sciences* (pp. 564-570).
- Puntambekar, S., & Stylianou, A. (2005). Designing navigation support in hypertext systems based on navigation patterns. *Instructional Science*, 33, (5-6), 451-481.
- Puntambekar, S., & Goldstein, J. (2007). Effect of visual representation of the conceptual structure of the domain on science learning and navigation in a hypertext environment. *Journal of Educational Multimedia and Hypermedia*, 16(4), 429-459.
- Puntambekar, S., Stylianou, A., & Goldstein, J. (2007). Comparing classroom enactments of an inquiry curriculum: Lessons learned from two teachers. *The Journal of Learning Science*, 16(1), 81-130.
- Rouet, J-F. (2006a). Comprehending multiple documents. In J-F. Rouet, *The skills of document use: From text comprehension to web-based learning*, (pp. 62-91). Mahwah, NJ: Lawrence Erlbaum Associates.
- Rouet, J-F. (2006b). Using hypertext systems. In J-F. Rouet, *The skills of document use: From text comprehension to web-based learning*, (pp. 122-138). Mahwah, NJ: Lawrence Erlbaum Associates
- Rouet, J-F., Potelle, H., & Goumi, A. (2005). The role of content representations in hypermedia learning: Effects of task and learner variables. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and Information Visualization* (pp. 343-354). Berlin: Springer-Verlag.
- Salmerón, L., Gil, L., Bråten, I., & Strømsø, H. (2010). Comprehension effects of signaling relationships between documents in search engines. *Computers in Human Behavior*, 26, 419-426.
- Schwartz, N., Anderson, C., Hong, N., Howard, B., & McGee, S. (2004). The influence of metacognitive skills on learners' memory of information in a hypermedia environment. *Journal of Educational Computing Research*, 31, 77-93.
- Shapiro, A. M. (2008). Hypermedia design as learner scaffolding. *Education Technology Research Development*, 56, 29-44.
- Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Grounded theory, procedures and techniques*. Newbury Park, CA: Sage.
- United States Census Bureau. (2009). Population finder. Retrieved from <http://www.census.gov/>
- van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. New York: Academic Press.
- Voss, J. F., and L. N. Silfies. (1996). Learning from history text: The interaction of knowledge and comprehension skill with text structure. *Cognition and Instruction*, 14, 45-68.
- Wineburg, S. S. (1991). Historical problem solving: A study of the cognitive processes used in the evaluation of documentary and pictorial evidence. *Journal of Educational Psychology*, 83(1), 73-87.

Author Note

CoMPASS research is supported by grants to the third author from the National Science Foundation: IERI #0437660 and the Institute of Education Sciences: CASL #R305A08050.

Acknowledgements

We wish to thank the teacher and students who made this research possible.

Appendix A

Prompts used by the investigator in order to encourage students to think aloud:

- *Remember to think aloud.
- *What are you thinking?
- *Can you say more?
- *What do you mean by _____?
- *Why did you navigate to that page?
- *What are you doing as you read this page?
- *Why did you click on that link?
- *Was that page helpful?
- *Did you learn what you expected to from that page?
- *Where are you going to navigate to next?
- *Are there any concepts that you learned about for your inclined plane challenge that you feel might be important?
- *Is there anything else that you are interested in?
- *Why?

Appendix B

Student Navigation Strategies

Strategy	Definition	Example
Reflecting on navigation decisions and/or using navigation features to focus on the goal (RN)	Referring to using system features to orient navigation or goal-focused reasoning for making navigation decision.	"...probably gonna go to work...distance, because distance usually affects the effort, work, MA, all that stuff, so."
Exploring (EX)	Navigating to multiple nodes in the hypertext in order to "see what's there."	"I'm gonna check pulley and see what it says in here. I'm going to check efficiency."
Reference to diagrams or pictures in the text (RD)	Comments referring to looking at the diagrams or pictures in the text.	"I'm just looking at this picture. Because, like, this could like, probably do this. "

Student Comprehension Strategies

Strategy	Definition	Example
Reference to prior experience or prior knowledge (PK)	Explicitly referring to prior experience or prior knowledge about text information, the science concepts or the hypertext system.	"...Yeah, I remember that the fulcrum is like the center of the seesaw that, like, rests on."
Referring to the goal (RG)	Explicitly referring back to the goal while reading and/or making navigation decisions.	"Ok...I'm supposed to be figuring out placement of the load."
Summarizing (SU)	Summarizing the text content.	"...when there's work, there's always gonna be effort...and distance..."
Making inferences (MIT) based on the text (MIP) based on prior knowledge	Making inferences or justifying ideas based on text information or prior knowledge.	"Well, the friction will make it so that it doesn't slip out of your hand."
Giving science explanations (SE)	Giving an explanation that uses scientific concepts.	"...lifting the object then the gravity's working against you but putting the object back down, gravity's working with you so that would make it easier..."
Stating misconceptions (SM)	Making a statement that contains a misconception	"...the load is the board itself or the seesaw part..."

Interviewer Prompting Strategies

Categories of Prompts	Definition	Example
Explanation of navigation (EN)	Prompting student to explain navigation decisions.	"So why did you decide to go to energy?"
Using generic or content free prompts (UC)	Using content free prompts to encourage students to engage with the system in order to help them with their challenge. Asking "what else."	"Do you think there's anything else on CoMPASS that might help you with your challenge?"
Goal orientation (GO)	Maintaining goal orientation or helping the student to focus on some aspect of the challenge.	"So, um. So, maybe we wanna take a look in lever and see if we can find anything to help us with our challenge."