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Learning with digital texts: Exploring the impact of prior domain knowledge and reading comprehension ability on navigation and learning outcomes

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ABSTRACT

Currently of great significance to the study of reading and text comprehension is the fact that learners now encounter many texts in digital formats. While making navigation decisions during reading digital texts, readers need to comprehend both the individual texts and the relationships among sources in the overall structure of the digital text environment. Prior knowledge and reading comprehension ability may impact the ways in which students are able to utilize the structure of the digital text system in order to navigate through the text content. This study further investigated the relationships among reading comprehension ability, prior content knowledge, navigation behaviors in a system of digital texts, and learning outcomes. We found no significant relationship between comprehension ability and navigation behaviors. Further, there were no significant relationships between prior knowledge and navigation or learning. Goal-relevant concept visits were positively related to coherent page transitions, and the proportion of time spent reading about goal-relevant concepts was significantly positively related to learning outcomes. We discuss these results in relation to some key areas for instruction, such as helping students to reflect on prior knowledge and plan their navigation strategies, and further research in terms of utilizing digital text structures to improve comprehension.

1. Introduction

Reading is an important part of learning and education, and becomes increasingly essential as learners progress from "learning to read" to "reading to learn" (Jacobs, 2008, p. 12). An essential element of what students do when they read to learn is text comprehension, which is the ability of the reader to construct a meaningful interpretation of the text. From the perspective of reading to learn, comprehension can be thought of as forming an integrated representation of text that is meaningful to learners so that they can then express and apply that information in relevant contexts. Examining how readers develop interpretations of texts and integrate knowledge in order to successfully apply what they have learned in relevant situations and understanding how the characteristics of the reader and text influence this process is an essential component of reading research (Pearson, 2009). Currently of great significance to the study of reading and text comprehension is the fact that learners now encounter many texts in digital formats, given that the proportion of students using computers and other digital devices in the classroom has steadily increased in the last two decades (e.g., U.S. Department of Education, 2010).

Hyperlinked digital texts can be defined as the linking of sections, or nodes, of digital text in a nonlinear way by means of semantic links (Rouet, 2006a). This means that the information in the nodes of text *and* the way nodes are linked in the digital text environment to show relationships both convey meaning to the reader. These nodes can vary in size and complexity and can potentially consist of different representations, such as a paragraph of text, graphics, or illustrations (Bolter, 2001). While making navigation decisions during reading digital texts, readers need to comprehend both the text in the individual nodes and the relationships among sources in the overall structure of the digital text environment. Further, readers 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; Rouet, 2006a). Thus, the reader must devote cognitive resources to navigating through

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the text as well as to understanding the relationships between nodes of information (Bolter, 2001; Sharples, 1999). Acknowledging this shift in the way in which texts are presented and read is essential because, although potentially more cognitively demanding, digital text environments can provide beneficial affordances, or tools and structures, for navigating and accessing text content that printed texts do not.

There are conditions under which allocating more cognitive resources to understanding relationships among texts are beneficial, particularly when using digital texts as tools to learn about complex content or processes. For example, given that in the domain of science there are numerous conceptual relationships that learners need to understand, digital text environments have the potential to be utilized in order to increase learners' meaningful interactions with texts and their conceptual understanding by making these conceptual relations apparent (Puntambekar, Stylianou, & Hübscher, 2003). For example, research has found that if learners are able to take advantage of maps overviewing the content in a digital text environment, this can increase students' knowledge of content structure and semantic connections among informational texts (Vörös, Rouet, & Pléh, 2011). By using these maps to increase their knowledge of structure and connections, students may be better able to understand conceptual relationships presented in separate but related texts, thus impacting learning outcomes. However, despite the potential benefits to learning that have been found for complex content presented in digital text environments, individual learner characteristics and text environment characteristics have been found to play a significant role in the comprehension of multiple digital texts (Hsieh-Yee, 2001; Lazonder & Rouet, 2008; Xie & Joo, 2012). Thus, the following sections specifically discuss characteristics of texts and characteristics of individual readers that have been found to influence text comprehension, namely the structure of the text environment and the prior knowledge and reading comprehension ability of the learner.

1.1. Characteristics of the text: Text structure and visual affordances

1.1.1. Printed texts

Text structure impacts students' interactions with and comprehension of texts. When related units of information are not organized closely in proximity within a text, the information can be more difficult to integrate, particularly for readers who are already struggling with comprehension and may be using inefficient text processing strategies (Cain, Oakhill, & Elbro, 2003). Using text features to signal the causal structure of elements in a text or training in understanding and identifying text structure can help improve comprehension for both more and less-skilled readers (e.g., Linderholm et al., 2000; Meyer, Brandt, & Bluth, 1980; Meyer et al., 2002) and positively affect comprehension and memory for text (Meyer & Poon, 2001; Meyer et al., 2002). Research has also found that text structure interacts with learner variables such as reading ability and domain knowledge (Meyer, 1999; Voss & Silfies, 1996), with explicit structure often aiding less-skilled readers or those with low domain knowledge (Meyer et al., 1980). Therefore, how information is structured should be considered when trying to understand how learners process texts.

1.1.2. Digital texts

A hierarchical or relational representation of text content can be useful for signaling relationships to make explicit the connections among concepts. However, this structure cannot always be effectively displayed in linear texts but can be made more explicit and easily accessible by providing links within digital texts (Sasot & Suau, 2000). Similar to printed texts, signaling the content of digital text documents through both global and local headings that provide the reader with clues about the text structure can facilitate location of and memory for important information (Lacroix, 1999). According to a study by Dee-Lucas and Larkin (1995), interactive overviews increased learners' memory of and representation of ideas presented in digital texts. Moreover, richer visual structural cues may increase learners' efficiency with finding desired information in a digital text system, but more extensive mental effort might need to be expended to figure out how to navigate this structure (Hsu & Schwen, 2003). Although this visualization presents additional text-processing demands (Wenger & Payne, 1996), comprehension and learning may be facilitated as long as readers are able to understand the organizational structure of the representation of the text environment and use this structure to effectively control navigation (Cuddihy & Spyridakis, 2012; Gerjets, Scheiter, Opfermann, Hesse, & Eysink, 2009; Rouet, Potelle, & Goumi, 2005; Shaw, 2010). For example, incorporating a visual cue map of the elements of the text into e-books has been found to reduce navigation times and improve learning outcomes (Li, Chen, & Yang, 2013). Also, when readers use graphical navigation overviews of the digital text structure to follow a navigation pattern that reflects the structure of the domain, propositional knowledge about relationships between concepts as well as knowledge of the overall configuration of the domain is aided (de Jong & van der Hulst, 2002). Further, a study by Castek, Zawilinski, McVerry, O'Byrne and Leu (2011) found that some students who typically struggle with reading comprehension are able to take advantage of representational and organizational affordances of online text spaces in order to compare information and manage multiple resources. In addition, visualizations that clearly represent to the learner the meaningful relationships underlying content can facilitate metacognition and reflection on relationships and, in turn, comprehension (Scott & Schwartz, 2007). In sum, a digital text navigation structure that readers can use to understand the relationships among sources and navigate texts in a goal-directed way can support comprehension and learning.

Despite the potential usefulness of structuring content in digital text spaces, it has been argued that increasing the structure in a digital text environment may not impact learning that goes beyond factual information (Wells & McCrory, 2011) or may actually impede learning in certain instances (Hübscher & Puntambekar, 2001) by decreasing the need for thought about how to integrate information into a coherent representation (Nilsson & Mayer, 2002). For example, studies have found that for learners with sufficient prior knowledge in a domain, over structuring can lead to decreased learning outcomes (McNamara & Shapiro, 2005). Further, continuous use of dynamic overviews may put unintended additional demands on the learner in terms of cognitive processing, which may negatively impact learning outcomes (Bezdan, Kester, & Kirschner, 2013). Therefore, it is essential that the structure of texts in the digital system is appropriate for the learner as well as the content area or context. Given that appropriate structure is important for fostering reading comprehension, one needed area of research is further investigation into learner factors, such as prior knowledge and reading comprehension ability, that may impact readers' capabilities to take advantage of the navigational structure of a system of multiple digital texts (Shapiro, 2008).

1.2. Characteristics of the reader

1.2.1. The role of prior domain knowledge in reading comprehension

A reader's prior knowledge is a central factor in reading comprehension. Learners with prior domain knowledge have more information with which to relate what they are reading in order to build a mental model of the situation described in the text

(Kintsch, 1988). Although the Internet makes opportunities to interact with multiple text resources available to anyone with online access, simply getting online does not ensure equal access to resources because prior knowledge can influence the degree to which individuals are able to utilize information (Hargittai, 2008). Research comparing numerous studies that looked at domain knowledge and interest as variables impacting comprehension has found that learners with more subject-matter knowledge are better prepared to process or navigate digital text and therefore are apt to increase their domain knowledge whereas those without a sufficient base of knowledge tend to struggle and thus fall increasingly behind (Alexander, Kulikowich, & Jetton, 1994). Further, prior knowledge can help support comprehension of information accessed in digital environments by helping readers to follow more coherent reading sequences as well as reduce feelings of disorientation (Amadieu, Tricot, & Mariné, 2010). Often, readers with more prior knowledge have more efficient navigation paths, are more proficient with navigating to content directly related to the learning task and disregarding pages with tangential information, conduct deeper investigations into the content, and are more apt to utilize digital text presentation aids (e.g., graphics), thus increasing learning outcomes and comprehension (Lawless & Kulikowich, 1998; Lawless, Schrader, & Mayall, 2007).

Additionally, at times prior knowledge in a domain may lead to overconfidence in one's level of understanding and actually decrease navigation to goal-related texts. For example, a study conducted to look at individual factors that impacted the navigation behaviors of 8th grade students found that there was actually a negative (though not significant) relationship between students' prior knowledge and the amount of time spent on goal-relevant nodes of digital text (Sullivan & Puntambekar, 2011). This finding has been supported by other work in which adolescent readers with higher domain knowledge were found to be more apathetic in terms of their navigation through multiple digital documents, exploring very little relevant information and not making use of the affordances of the online system (Lawless, Mills, & Brown, 2002). Clearly, the effect of prior domain knowledge on navigation and learning from digital texts is not fully clear and requires further research. However, although prior domain knowledge is a principal factor to consider, other variables are also important to explaining how students learn with digital information sources. One such variable that requires additional investigation is reading comprehension ability.

1.2.2. Reading comprehension ability and learning with digital texts

Previous research has found that reading comprehension ability is a significant predictor of comprehension when learning with multiple digital texts (e.g., Coiro, 2011). A pilot study conducted with 6th grade students engaged in learning from a digital text system found that students with lower comprehension ability (as measured by a standardized test of reading comprehension) scored significantly lower on a test of comprehension asking them to integrate information from multiple digital texts than students with higher comprehension ability. Additionally, there was a significant positive relationship between reading comprehension ability and the number of goal-related texts that students navigated to within the digital text system (Sullivan & Puntambekar, 2009). However, more work is needed to investigate the kinds of processes that may differ among better and poorer comprehenders when working with digital texts in an online environment. Goldman, Braasch, Wiley, Graesser, and Brodowinska (2012) found that when undergraduate students were asked to read and integrate information from multiple digital texts, both better and poorer learners infrequently made explicit intertext connections among digital texts while reading, and the number of explicit intertext connections participants made was quite variable among learners within each group.

Additional work has not found significant relationships between reading comprehension ability for printed texts and navigation and reading behaviors in digital text environments. Work by Naumann and colleagues (2007) found that reading ability did not predict learning outcomes when students read in a digital text environment in which the graphical structure of the system aided in navigation through the digital documents. And in contrast to the pilot study discussed above, another study with 6th grade students found that when conducting research about physics concepts as part of an inquiry-based physics unit, visits to and transitions among goal-relevant documents in a digital text environment were not related to comprehension ability (Sullivan, Gnesdilow, & Puntambekar, 2011). This study also found that, across levels of reading comprehension ability, there was a significant increase in navigation to goal-relevant texts over time, but not a significant increase in meaningful transitions among digital texts. Interestingly, a qualitative analysis revealed that although students with both lower and higher comprehension ability increased their use of comprehension and navigation strategies for reading in the system of digital texts over time, higher comprehension ability students tended to use more of both comprehension and navigation strategies. Nevertheless, regardless of comprehension ability, the use of productive strategies, particularly strategies for navigating among digital texts in order to make connections, could have been improved for all students (Sullivan et al., 2011). Therefore, although comprehension ability may help to predict which students might struggle with comprehending digital texts due to poor general comprehension skills, knowing a student's comprehension ability may not provide information about the learner's ability to effectively navigate and understand the relationships among multiple digital texts. In fact, our previous research has found that regardless of ability, adolescent readers frequently do not attend to the relationships among digital texts when making navigation choices in an online digital textbook (Bopardikar, Sullivan, & Puntambekar, 2010; Sullivan, 2010).

1.2.3. Maintaining coherence in digital texts

This lack of attention to relationships is problematic given that skilled readers attend to relationships and attempt to form a coherent representation of the information presented in a text or across multiple texts. Thus, the ability to take advantage of explicit structural affordances in order to follow a coherent reading order and form a coherent textual representation is important for comprehension. Coherence can be defined as, "the degree to which the reader's navigation path (or reading order) follows a coherent line of arguments or ideas" (Madrid, Van Oostendorp, & Melguizo, 2009, p. 67). Research with adult readers has found variability in the ways in which learners navigate and establish coherence of information in digital text environments. Two primary navigation styles that have been investigated for navigating digital texts linked in a structured environment are coherence versus interest. When using coherence selection, readers select information sources that are semantically or conceptually related to each other. Conversely, learners employing interest selection read texts based on what interests them. Employing coherence selection can lead to a more conceptually coherent representation of the text than using interest, which in turn, impacts learning outcomes if the goal is to understand conceptual relationships in a domain (Salmerón, Cañas, Kintsch, & Fajardo, 2005; Salmerón, Kintsch, & Cañas, 2006). Thus, if one wants to emphasize understanding relations among concepts, something that is essential to developing scientific understanding, then there is evidence to support that coherence selection should be employed while navigating in digital text environments. A coherence rather than an interest navigation strategy can benefit readers' comprehension because navigating based on interest will not necessarily allow learners to read information in a conceptually coherent way that allows for the strengthening of one's understanding of conceptual relationships, which is important in many domains, such as science.

The above findings are important because when reading online, learners need to comprehend not only individual texts but also the relationships among the individual texts. Thus, although comprehension ability provides information about how well learners are able to comprehend the text within each of the digital documents, it is less clear how comprehension ability as measured by current standardized comprehension tests reflects students' aptitudes for navigating and integrating multiple digital texts. Previous work suggests that learners with higher comprehension abilities may be better at searching texts based upon the underlying big ideas related to their reading goal and consequently, read fewer units of non-relevant or distracting information than less-skilled comprehenders (Cerdán, Gilabert, & Vidal-Abarca, 2011). Work by Salmerón and colleagues has found that for young learners (6th grade students), reading skill directly impacted comprehension of digital texts and also indirectly impacted comprehension by its relationship with coherent navigation (e.g., Salmerón & García, 2011). According to the authors, "…good readers navigate better in terms of link cohesiveness, and because of this they can understand the hypertext better" (Salmerón & García, 2011, p. 1149). This study seeks to further investigate the impact of comprehension ability on navigation behavior in a digital text environment.

In sum, digital text systems offer affordances for reading that are not found in printed texts. One of the primary affordances is the way in which digital texts can be hyperlinked and their contents can be organized via navigable structures, such as concept maps. These structures can help students to follow a more coherent navigation pattern in which they choose to read texts that are both related to each other and to the reading goal at hand. However, prior knowledge and reading comprehension ability may impact the ways in which students are able to utilize the structure of the digital text system in order to navigate through the content. Prior knowledge can aid readers in selecting relevant text information and making connections among related units of information but may also have a negative impact on goal-relevant navigation of digital texts. It is not clear whether learners with higher comprehension abilities may be better able to utilize structural affordances of texts and digital texts systems in order to establish text coherence and make connections among related units of information. This is important to investigate given that establishing text coherence and making relevant connections among information sources aids in comprehension and, therefore, learning. This study investigates these ideas in relation to learning from multiple online texts in a closed digital text system. A path analysis was used to test a model of whether navigation behaviors in a system of digital texts mediate the effects of prior knowledge and reading comprehension ability on learning outcomes.

2. Theoretical model and research questions

The review of literature above suggests a lack of understanding of the role of comprehension ability in learners' capabilities to take advantage of the ways in which relationships among digital documents are visualized. In addition, the literature review also supports the idea that prior content knowledge impacts learners' navigation through digital texts. Consequently, the goal of this study is to further investigate the relationships among reading comprehension ability, prior content knowledge, navigation behaviors in a conceptually structured system of digital texts, and learning outcomes. Fig. 1 shows the theoretical model of this study and the variables are described below.

This model will be used to investigate the following research questions:

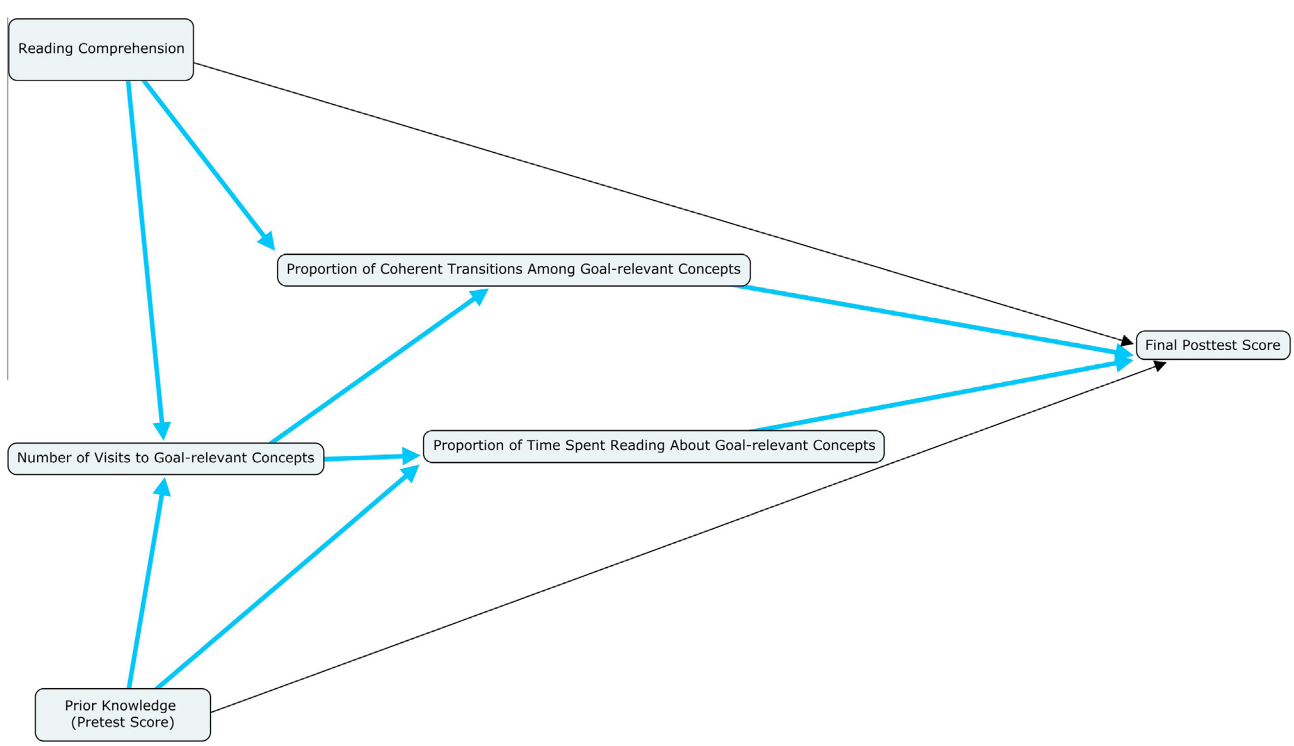

Fig. 1. Theoretical model of the study. This figure illustrates the proposed relationships among the variables in the model. The paths represented by the thicker lines are those that are the focus of this study.

1. Do navigation behaviors in a digital text environment mediate the relationship between prior knowledge and learning outcomes?
2. Do navigation behaviors in a digital text environment mediate the relationship between reading comprehension ability and learning outcomes?

3. Methods

3.1. Materials

Eighth grade students used the digital text system CoMPASS (Puntambekar, 2006; Puntambekar et al., 2003) as part of a design-based physics inquiry curriculum on Forces and Motion. As part of the curriculum, students engaged in a design challenge and related investigations using CoMPASS and other activities. The overall goal was for students to design a fun, yet safe, roller coaster for an amusement park. The curriculum design allowed students multiple opportunities to read a variety of digital text sources for background information to complement their hands-on activities for their design challenge. The curriculum took approximately 10 weeks to complete during this study. The role of the teacher in the curriculum was to support and facilitate students' use of the multiple curricular materials (e.g. student notebook, multiple text resources, and design materials) to help learners construct understandings of the physics concepts related to designing a roller coaster. The teacher participated in professional development and had the opportunity to engage with the curriculum materials and ask questions before implementing the curriculum in the classroom.

3.1.1. CoMPASS eTextbook

The CoMPASS eTextbook, which was the focus of this study, supported students in developing a rich understanding of physics concepts and their relationships by providing navigable concept maps designed by physics educators and content experts to mirror the conceptual structure in physics. The CoMPASS system provides two representations: a navigable concept map and text that describes the concepts (see Fig. 2). The concept maps are dynamically constructed and displayed with the fisheye technique (Bedersen & Hollan, 1995; Furnas, 1986). The maps are designed such that the concept that the student selects becomes the center (focal) point of the map and the other concepts move accordingly based on the strength of their relationship to the center concept. Students used CoMPASS in order to learn about forces and motion concepts to help them create their roller coasters. Students navigated CoMPASS individually in four navigation sessions for about 30 min each session at approximately two-week intervals throughout the curriculum. Their goal was to research concepts for the design challenges that were part of designing their roller coasters, which required them to learn about concepts such as *momentum* and *force*. Students each had their own computer and navigated individually on CoMPASS. The teacher introduced the CoMPASS digital text system, but did not actively support students during their navigation sessions, other than to answer occasional questions about the system and content. She told them that CoMPASS was going to be like their textbook for the curriculum and that they were to use the digital texts to find information about physics concepts relevant to their design investigations throughout the curriculum.

3.2. Participants

The data for this study were collected at a Midwestern middle school in two separate school years in ten 8th grade science classrooms ($N = 189$), all taught by the same teacher. Students in this study used the Forces and Motion curriculum described above for approximately 10 weeks to learn about physics concepts to help them design their roller coaster. The teacher had used the Forces and Motion curriculum for one year prior to the beginning of data collection for this study. Navigation log data used for this study were collected while students used CoMPASS for one of the

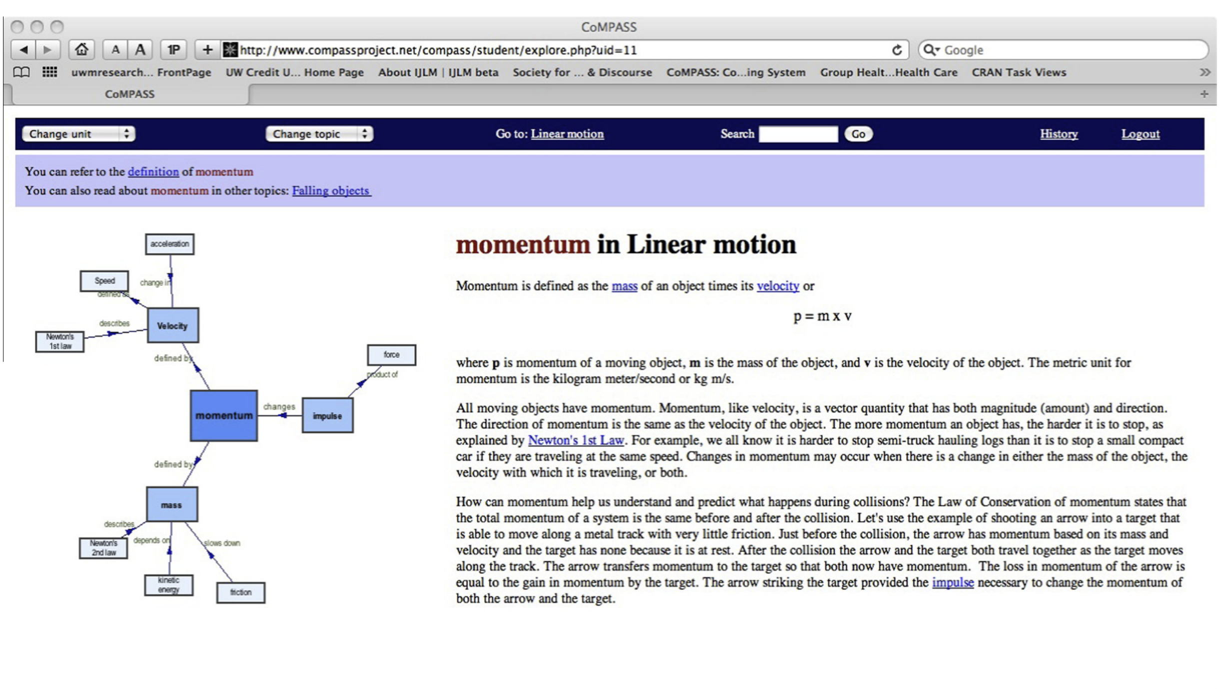

Fig. 2. Screenshot of the CoMPASS eTextbook. This figure shows the navigable concept map and text for the concept of momentum in the topic of linear motion.

first 30-min navigation periods of the curriculum in order to investigate concepts that would help them to design the initial drop portion of their roller coaster.

4. Analysis

Path analysis was used to test our initial model of the hypothesized relationships between reading comprehension ability, navigation behaviors, and learning outcomes (see Fig. 1). In this model, reading comprehension ability was predicted to relate to post test scores both directly and indirectly through navigation behaviors. In addition, prior knowledge was predicted to relate to post test scores both directly and indirectly through navigation behaviors. The arrows in the model indicate the hypothesized relationships.

Maximum likelihood was used to estimate the model and the adequacy of model fit was determined by the chi-square test. A significant chi-square implies poor model fit. The criterion for statistical significance was set at $\alpha = .05$. Model fit was also assessed using other fit indexes including the root mean square error of approximation (RMSEA) (<0.05 indicates good model fit) and the Comparative Fit Index (CFI) and the Tucker-Lewis Index (TLI) (>.95 indicates good model fit). Below, we describe the data sources used in our model.

4.1. Endogenous variable

4.1.1. Post test of knowledge of forces and motion concepts

Knowledge of forces and motion concepts was measured using a test that consisted of nine multiple-choice questions. See the Appendix A for the Forces and Motion test. The goal of the questions was to assess students' knowledge of how forces and motion concepts apply in a variety of situations, which requires making connections among concepts and knowing how concepts affect one another. This test was used as a measure of students' learning from the CoMPASS eTextbook because it was designed in such a way that if students formed an integrated understanding and interpretation of the information presented in the CoMPASS texts, they should have been able to use this knowledge to answer the conceptual questions that made up the test.

4.2. Exogenous variables

4.2.1. Pre test of prior physics knowledge of forces and motion concepts

Prior knowledge was measured using the same test as the post test of forces and motion content. See the Appendix A for the Forces and Motion test. This measure was used as an index of students' prior knowledge before they conducted research for their challenge with the CoMPASS digital text system.

4.2.2. Reading comprehension scores on a standardized test

Students took the comprehension portion of the Gates-MacGinitie Reading Test (G-MRT) for grades 7–9, which involves reading short passages and answering multiple-choice questions. Scores could range from 0 to 48. The comprehension test was used to measure students' comprehension ability before interacting with the digital texts in the CoMPASS system.

4.3. Mediating variables

4.3.1. Visits to goal-relevant concepts

The first variable of interest was the number of times students visited goal-relevant concepts, or the concepts that they needed to understand for the initial drop portion of their hands-on investigations, while conducting research with CoMPASS for the roller coaster design. Any concepts that students spent less than 5 s on were eliminated from the analysis, as this time or less would not be sufficient to take in information from the text. This variable was used as an index of navigation because presumably students with more prior knowledge would have a better idea of what concepts they needed to visit and read about for their challenge. Additionally, the prediction was that students with better reading comprehension abilities would be better able to navigate to goal relevant-concepts by effectively using the structure of the CoMPASS system.

4.3.2. Proportion of time spent reading about goal-relevant concepts

The second variable of interest was the proportion of total navigation time that students spent reading about goal-relevant concepts, or the concepts that they needed to understand for the initial drop portion of their hands-on investigations, while conducting research with CoMPASS for the roller coaster design. Any concepts that students spent less than 5 s on were eliminated from the analysis, as this time or less would not be sufficient to take in information from the text. This variable was calculated by taking the total time that students spent on goal-relevant concepts divided by the total time spent navigating on CoMPASS. This variable was used as a measure of how long the students spent reading about the goal-relevant concepts that they visited, as it was important that students not only visited appropriate concepts but also took time to read the content related to goal-relevant concepts rather than concepts that would not help them with their challenge.

4.3.3. Proportion of coherent transitions among goal-relevant concepts

The third variable of interest was the proportion of coherent transitions among goal-relevant concepts. Coherent transitions were defined as those among concepts related to the focal concepts at the first level of relation to the current concept being read about in the CoMPASS eTextbook. For example, in Fig. 2 above, transitions between momentum and velocity, impulse or mass would be considered coherent transitions. Therefore, coherent transitions among concepts were used as a measure of students' abilities to use the structure of the system to select concepts that were most relevant to the text currently being read. This key variable was used as an indicator of students' reading processes related to maintaining text coherence in order to make connections among the concepts in the texts and better comprehend conceptual relationships. This variable was calculated by taking the number of coherent transitions among goal-relevant concepts divided by the total number of transitions made among concepts during the time spent navigating on CoMPASS.

5. Results

The descriptive statistics for all variables can be found in Table 1.

5.1. Model Interpretation

The chi-square test statistic for the initial model was not significant $\chi^2(4) = 3.387$, $p = .495$. Further, the RMSEA = .000, the CFI = 1.000, and the TLI = 1.046, with all indexes indicating good model fit. In addition, based on the values of the modification indexes (MI), no additional paths were added to the model. Given that multiple indices indicated good model fit, and therefore predictive validity, this model was interpreted. For model estimates of direct, indirect and specific indirect effects see Tables 2 and 3.

Table 1
Descriptive statistics for variables in the model, $N = 189$.

Model variables	Min	Max	Mean	SD
Reading Comprehension	7	48	35.71	8.329
FM Pre Test	0	7	2.98	1.298
FM Post Test	0	9	4.70	1.743
Number of Concept Visits	2	118	22.49	16.164
Proportion Time on Concepts	35	95	77.76	11.200
Proportion of Coherent Transitions	0	53	14.89	9.968

Table 2
MLR estimates of prior knowledge, reading comprehension ability, navigation behaviors, and learning outcomes model.

	Estimate	S.E.	Est./S.E.	Two-tailed *P*-value	StdYX
FM POST TEST ON					
PROPORTION TIME	0.023	0.010	2.285	0.022	0.149
PROPORTION COHERENT	0.002	0.011	0.216	0.829	0.014
READING COMPREHENSION	0.079	0.014	5.503	0.000	0.374
FM PRE TEST	0.143	0.092	1.558	0.119	0.106
PROPORTION COHERENT ON					
READING COMPREHENSION	0.050	0.087	0.571	0.568	0.041
CONCEPT VISITS	0.096	0.045	2.154	0.031	0.156
PROPORTION TIME ON					
CONCEPT VISITS	−0.144	0.05	−2.903	0.004	−0.208
FM PRE TEST	−0.319	0.617	−0.517	0.605	−0.037
CONCEPT VISITS ON					
FM PRE TEST	−0.918	0.934	−0.982	0.326	−0.074
READING COMPREHENSION	−0.211	0.146	−1.448	0.147	−0.109

Table 3
Total and indirect effects for prior knowledge, reading comprehension ability, navigation behaviors, and learning outcomes model.

	Estimate	S.E.	Est./S.E.	Two-tailed *P*-value	StdYX
Effects from READING COMPREHENSION to FM POST TEST					
Total	0.079	0.014	5.545	0.000	0.378
Total indirect	0.001	0.001	1.092	0.275	0.004
Specific indirect					
FM POST TEST					
PROPORTION COHERENT					
READING COMPREHENSION	0.000	0.001	0.202	0.840	0.001
FM POST TEST					
PROPORTION TIME					
CONCEPT VISITS					
READING COMPREHENSION	0.001	0.001	1.127	0.260	0.003
FM POST TEST					
PROPORTION COHERENT					
CONCEPT VISITS					
READING COMPREHENSION	0.000	0.000	−0.213	0.832	0.000
Direct					
FM POST TEST					
READING COMPREHENSION	0.079	0.014	5.503	0.000	0.374
Effects from FM PRE TEST to FM POST TEST					
Total	0.138	0.093	1.488	0.137	0.103
Total indirect	−0.005	0.015	−0.310	0.757	−0.003
Specific indirect					
FM POST TEST					
PROPORTION TIME					
FM PRE TEST	−0.007	0.015	−0.504	0.614	−0.006
FM POST TEST					
PROPORTION TIME					
CONCEPT VISITS					
FM PRE TEST	0.003	0.004	0.862	0.389	0.002
FM POST TEST					
PROPORTION COHERENT					
CONCEPT VISITS					
FM PRE TEST	0.000	0.001	−0.210	0.834	0.000
Direct					
FM POST TEST					
FM PRE TEST	0.143	0.092	1.558	0.119	0.106

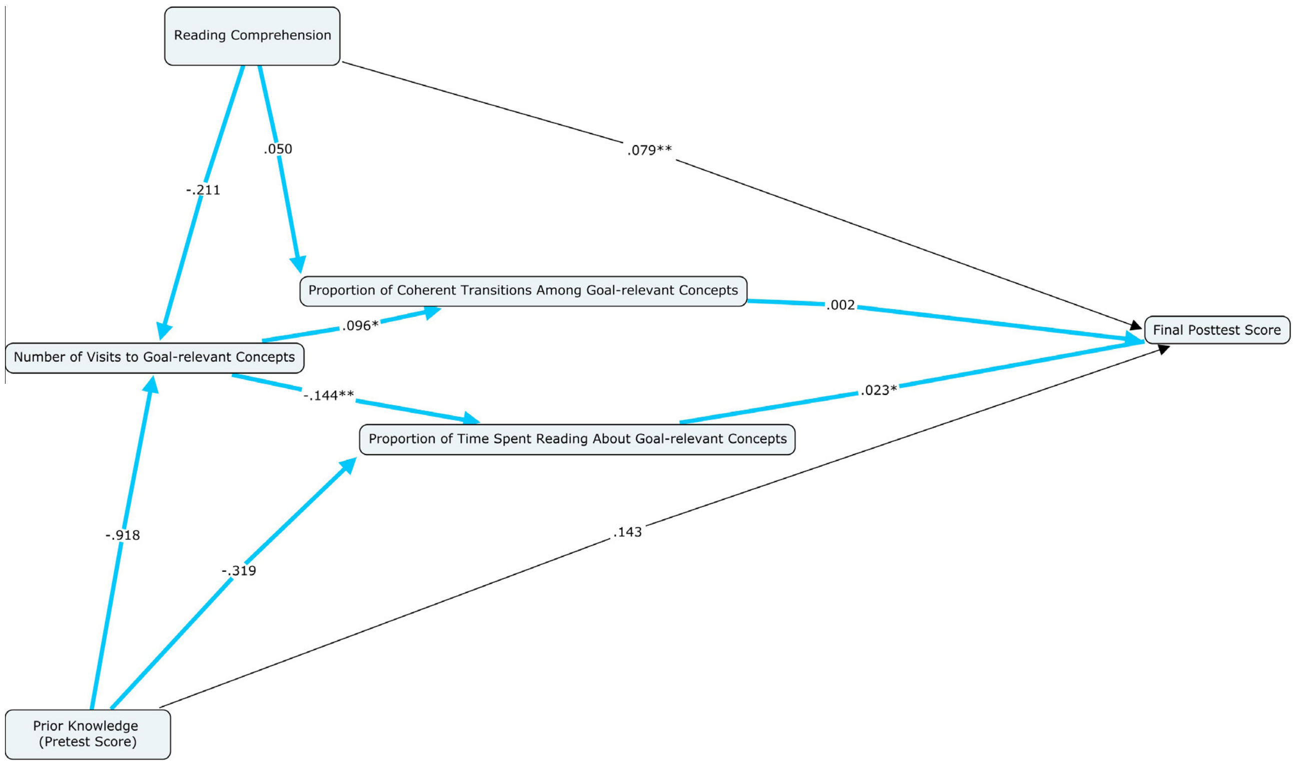

Fig. 3. Results of the path analysis for the model, * $p < .05$, ** $p < .01$.

The outcomes of the model, presented in Tables 2 and 3, suggest the following. The direct effect from pre test to post test score is not significant. Further, none of the indirect effects between pre test score and post test score with navigation behaviors as mediators are significant. The direct effect from reading comprehension ability to post test score is significant with a positive relationship between reading comprehension ability and post test score. According to the model, for every one-unit increase in reading comprehension score, there is an approximately 0.079 point increase in post test score. However, the indirect effects between comprehension ability and post test score with navigation behaviors as mediators are not significant.

There is a significant positive relationship between the proportion of time spent on goal-related concepts and scores on the forces and motion post test. For every one-unit increase in the proportion of time on goal-focused concepts, there is an approximately 0.023 point increase in post test score. The relationship between the number of goal-related concepts visited and the number of coherent transitions is also significant and positive, with students who visited more goal-related concepts making more coherent transitions. Finally, the relationship between the number of goal-related concepts visited and the proportion of time spent reading about goal relevant concepts is significant but negative. Thus, students who visited more goal-related concepts spent a lower proportion of their total navigation time reading about goal-relevant concepts. See Fig. 3 for a summary and significance values of the relationships in the model.

6. Discussion

The aim of this study was to further investigate the relationships of prior content knowledge and reading comprehension ability to navigation behaviors within a system of digital texts. There was a particular focus on the transitions that learners made among documents and whether learners navigated in such a way as to facilitate their understanding of the relationships among the concepts presented in these informational texts. Another goal was to provide insight into whether navigation behaviors were related to learning outcomes, as suggested by previous studies, and whether navigation behaviors mediated the relationships between prior knowledge and learning outcomes and reading comprehension ability and learning outcomes. The results shine some light on these issues, although not necessarily in the way expected by the previous review of studies.

6.1. Research question 1: Prior knowledge, navigation, and learning

The first research question was focused on whether navigation behaviors in a digital text environment mediated the relationship between prior knowledge and learning outcomes. Clearly, prior knowledge is important for comprehending texts (e.g., Kintsch, 1988), and numerous studies have demonstrated that prior knowledge has implications for learning from digital texts (e.g., Alexander et al., 1994; Amadieu et al., 2010; Lawless et al., 2007). However, the way in which prior knowledge interacts with digital text system structure to influence the comprehension in these environments is as yet unclear, particularly for higher prior knowledge learners (e.g., Chen & Macredie, 2010; Lawless et al., 2002; Potelle & Rouet, 2003; Salmerón et al., 2005). The results of this study attempt to elucidate the impact of prior domain knowledge on navigation behaviors in a digital text environment and on learning outcomes. In opposition to previous work that found that prior knowledge affected navigation behaviors, the results show no significant relationships between prior knowledge and navigation behaviors (goal-relevant concept visits and reading time, and coherent transitions) or learning outcomes (post test score).

There are various potential interpretations of the lack of relationships between prior knowledge, navigation, and learning outcomes. One is that students with all levels of prior knowledge possibly learned equally well from the CoMPASS digital text system and curriculum given the flexibility of the system and the explicitness of the relationships. The system may have been structured well enough that students with both low and high prior domain knowledge were able to effectively utilize the structure of the system to learn the content. Additionally, perhaps the multiple-choice test was not sensitive enough to tease out the differences in prior conceptual knowledge that would have influenced students' navigation choices and patterns. Finally, looking at the final mean for the post test we see that students still had room for improvement, which means that there was a need to further support students' understandings of conceptual relationships regardless of the prior domain knowledge they began with. There may not have been a significant relationship between the pre and post tests because students' scores on the post test did not change considerably from the pre test. Consequently, the influence of prior domain knowledge on students' navigation behaviors in CoMPASS is not yet clear.

6.2. Research question 2: Comprehension ability, navigation, and learning

The second research question was focused on whether navigation behaviors in a digital text environment mediated the relationship between reading comprehension ability and learning outcomes. Unlike previous studies (e.g., Coiro, 2011; Sullivan & Puntambekar, 2009), this study did not find significant relationships between comprehension ability, navigation behaviors, and learning outcomes, and thus, aligns with the previous research that has not found a significant relationship between reading ability, navigation, and learning (e.g., Naumann et al., 2007; Sullivan et al., 2011). Nevertheless, there is a significant relationship in the model between comprehension ability and learning outcomes. Put another way, the findings of this study best support an independent model suggesting that reading comprehension skills support comprehension of information from digital texts but are separate from navigation strategies, which also have an impact on comprehension of digital texts independent of reading ability (e.g., Leu et al., 2011). This finding is not surprising given the conflicting nature of the research results investigating the relationship between comprehension ability and learning with digital text environments, and the growing body of work explicating the differences in the types of strategies required when reading digital versus printed texts (Afflerbach & Cho, 2009, 2010). In sum, the lack of relationships between navigation behaviors in CoMPASS and learning outcomes further supports the distinction between reading strategies related to comprehension ability and navigation strategies. Reading comprehension ability seemed to help students to comprehend the information in the text but did not show a significant relationship with navigation behaviors. This finding is in conflict with the work of Salmerón and García (2011) that found that better text comprehenders also navigated a digital text environment in a more cohesive manner.

6.3. Navigation behaviors and learning

Possibly the most noteworthy results of this model are the significant relationships between navigation behaviors and learning outcomes. The number of visits to goal-relevant concepts was positively related to the proportion of coherent transitions made among these concepts, but the proportion of coherent transition was not significantly related to learning outcomes. The more goal-relevant concepts students visited, the more opportunities they had to make coherent transitions, but making these coherent transitions was not related to learning outcomes. This finding does not align with the studies reviewed above that found that the visual affordances of digital text systems, which make relationships among pages of texts salient, support learners to make meaningful, coherent transitions and in turn improve their understanding of the domain (e.g., Cuddihy & Spyridakis, 2012; de Jong & van der Hulst, 2002; Gerjets et al., 2009; Rouet et al., 2005; Shaw, 2010). Students visited approximately 22 goal-relevant concepts during their navigation time. However, the proportion of coherent transitions among these concepts was only approximately 15%, even though with the number of concepts that students were able to visit during their navigation time, they had ample opportunities to use the concept maps to guide their navigation. This low proportion of coherent transitions might not be enough to see any positive effects in terms of learning outcomes. This finding supports previous studies' findings that adolescent students do not always focus on using the structure of the digital text system to make meaningful, coherent transitions and understand the relationships among sources and concepts (Bopardikar et al., 2010; Sullivan, 2010). The navigable concept maps in CoMPASS were designed specifically to make the relationships between physics concepts visually salient and easily perceptible, and yet students in this study did not take advantage of this structure to make coherent transitions among strongly related science concepts. This is an issue given that research has found that using a coherence navigation strategy can lead to better understanding of conceptual relations and a more coherent representation of the information presented in the digital text environment (Salmerón et al., 2005, 2006). Forming a coherent understanding of the relationships among the physics concepts was essential for students' challenges and the design of their roller coasters.

Interestingly, the number of visits to goal-relevant concepts was significantly related to the proportion of time spent reading about goal-relevant concepts, but this relationship was negative. So, the more visits students made to goal-relevant concepts, the lower the proportion of time they spent reading about concepts related to the goal of their design challenge. But, the reason for this negative relationship may be that students who clicked on more goal-relevant concepts also visited more non-relevant concepts, and thus spent a smaller proportion of their reading time focused on the concepts that were most important for their challenge. However, our model does show that this pattern of navigation does not seem to be related to prior knowledge or reading ability, given that that relationships between these two variables and navigation behaviors were not significant. Finally, the proportion of time spent reading about goal-relevant concepts was significantly positively related to learning outcomes. In other words, students who navigated to goal-relevant concepts and spent more of their navigation time reading about these concepts did better on the post test. Thus, navigation behavior in CoMPASS impacted learning outcomes by influencing students' amount of exposure to relevant concepts within the digital text system.

6.4. Study limitations

The components of the model were chosen for both theoretical and practical reasons. Reading comprehension ability and prior knowledge are two factors that have empirically been demonstrated in previous studies to be related to navigation behaviors in digital text environments and they are both pieces of information that are easily accessible to a classroom teacher. The score on the post test was used as a measure of students' abilities to comprehend and apply the information. The navigation behaviors in the model were chosen because they can be used as a proxy for the types of reading behaviors we were interested in seeing if students exhibited. These behaviors included the ability to focus their navigation selections on relevant concepts, to spend time reading about relevant concepts, and to make coherent transitions among concepts that would allow readers to make intertext connections and facilitate conceptual understanding. A shortcoming of these measures is that we do not have think aloud data of any of the students to indicate the reading process they were actually engaging in. However, video of the classrooms during navigation times indicated that students were generally on task while reading in the CoMPASS system. Finally, there are certainly other aspects of the curriculum that would have influenced scores on the post test. However, if students comprehended the information from the CoMPASS eTextbook at a deep enough level for application, they would have been able to answer the questions on the post test. The low overall post test scores indicate that students could have used support for not only their comprehension of the texts in CoMPASS but also their learning from the other aspects of the curriculum.

6.5. Implications for instruction and future research

The results of this study highlight some key areas for instruction and further research. First, the effect of prior knowledge is complex when reading in hyperlinked digital text environments. Prior domain knowledge may not help students to make good navigation decisions or visit goal-relevant information. Therefore, teachers may be able to aid students in reading digital texts regardless of prior knowledge by reiterating to students the importance of taking time to read information, even if it's something students think they already know, and think about relationships among texts. This suggestion is underscored by the finding that students who spent more time reading about goal-relevant concepts did better on the post test. Another issue is that students might have had difficulty distinguishing between relevant and non-relevant concepts, even if they already had some prior domain knowledge. This of course would have affected their ability to select concepts that were the most focused on the goal and to make coherent transitions among those concepts. Thus, helping learners to activate relevant prior knowledge and to reflect on how they will focus their navigation before engaging in the reading process appears to be an essential part of helping learners to engage with digital text systems.

Secondly, the results of this study as well as the work of others (Afflerbach & Cho, 2009, 2010; Leu et al., 2011; Salmerón & García, 2011) suggest that there is an important distinction between strategies that support text comprehension ability and navigation strategies. The next step, for both research and instruction is to explore how to effectively teach and support these strategies and develop text comprehension and navigation skills given the changing nature of literacy when reading with digital texts. Understanding the role of the teacher in this process is imperative and will be the focus of future work. In this study, the teacher played a minimal role, other than introducing the features of CoMPASS and talking about students' goal as being to find information related to their questions about concepts that would help them in their design challenges. Perhaps a different form of facilitation would have led to different navigation behaviors and learning outcomes.

Recognizing the role of the teacher to help students employ navigation and reading strategies will be important not just for science but for other domains as well. In other fields, such as math and history, there are also important relationships that need to be understood among concepts, events, or various types of documents. Although different than the domain of science, the importance of the structure of the digital text environment to aid in the formation of intertextual connections applies to many domains and topics. In particular, an improved understanding of the role of coherence navigation for facilitating knowledge construction in multiple domains and contexts can help to better support learners reading processes in digital environments.

To conclude, this study's attempt to understand how the individual learner characteristics of prior domain knowledge and comprehension ability impact students' ability to take advantage of the navigation affordances of a digital text environment lead to some insights but left other questions unanswered. Undoubtedly, both comprehension and navigation strategies play distinct roles in learning with hyperlinked digital texts. However, the results of this study did not elucidate the way that comprehension ability and prior knowledge relate to the capacity to take advantage of the visualized navigational structure of a digital text system. Rather, the results confirmed previous findings that students of all ability levels struggle to take advantage of navigational affordances to understand conceptual relationships (Sullivan et al., 2011). Better understanding ways to train or support students in taking advantage of digital text structures and their navigational affordances will be an essential component of helping students to comprehend and learn from information presented in digital text environments. We know that recognizing and utilizing the structure of text environments is important for learning given the success that structural training interventions have had in text comprehension research on learning with printed texts (Linderholm et al., 2000; Meyer et al., 1980; Meyer et al., 2002). Further research that includes think aloud protocols and interviews with students to better understand the ways in which they try to make connections among digital texts and how different representations support or hinder this process is required. Expanding this work will allow us to design interventions for training in how to more effectively use the structure of the digital text environment to improve comprehension. In the meantime, the findings of this study underscore the necessity of making the overt support of students' integration of multiple text sources, particularly when working with digital text environments and in complex domains such as science, an explicit part of teaching and learning with texts.

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Appendix A. Forces and Motion test

Instructions

1. Answer the questions by selecting the option that you think is the most appropriate.

2. Some questions require you to type your answer in the space provided. Click in the text box and start writing.

3. When you finish with all questions, click the "Submit" button.

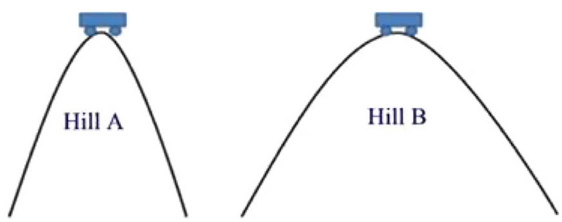
4. If you want to clear *all* the answers that you provided and start again, click on the "Reset" button.

5. You must answer *all* the questions before you click the "Submit" button.

Good luck! Keep cool.

Questions:

1. Two roller coaster cars have the same mass. They each sit at the top of different hills of the same height, as shown below. One car rolls down Hill A, and another car rolls down Hill B.



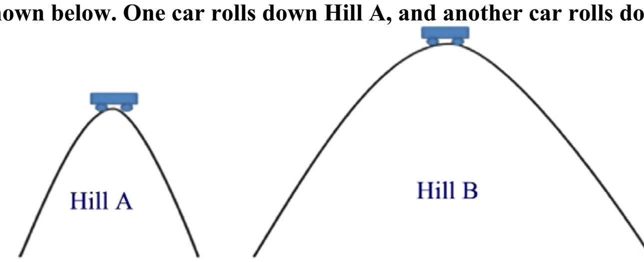
1a. How does the *velocity* of the car at the bottom of Hill A compare to the *velocity* of the car at the bottom of Hill B? (Ignore the effects of friction and air resistance).

- The car at the bottom of Hill A has a greater velocity than the car at the bottom of Hill B
- The car at the bottom of Hill B has a greater velocity than the car at the bottom of Hill A
- Both the cars have the same velocity
- Neither of the cars have any velocity at the bottom
- None of the above.

1b. How does the *kinetic energy* of the car at the bottom of Hill A compare to the *kinetic energy* of the car at the bottom of Hill B? (Ignore the effects of friction and air resistance).

- The car at the bottom of Hill A has a greater kinetic energy than the car at the bottom of Hill B
- The car at the bottom of Hill B has a greater kinetic energy than the car at the bottom of Hill A
- Both the cars have the same kinetic energy
- Neither of the cars have any kinetic energy at the bottom
- None of the above.

2. Two roller coaster cars have the same mass. They each sit at the top of hills of different heights, as shown below. One car rolls down Hill A, and another car rolls down Hill B.



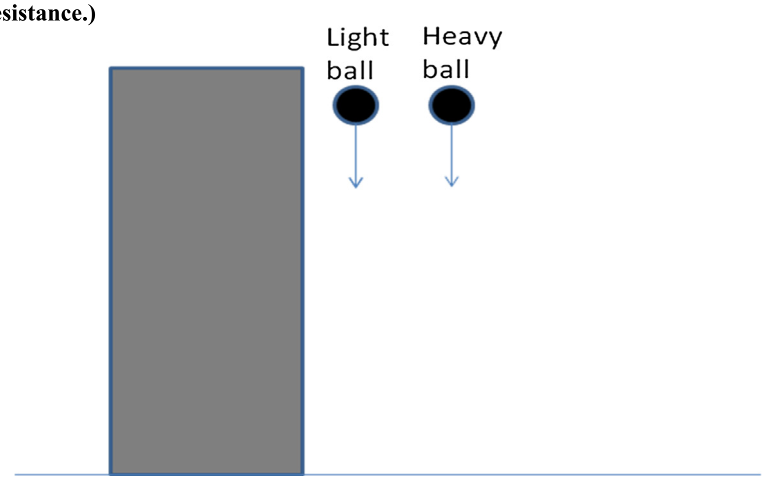
2a. How does the *velocity* of the car at the bottom of Hill A compare to the *velocity* of the car at the bottom of Hill B? (Ignore the effects of friction and air resistance).

- The car at the bottom of Hill A has a greater velocity than the car at the bottom of Hill B
- The car at the bottom of Hill B has a greater velocity than the car at the bottom of Hill A
- Both the cars have the same velocity
- Neither of the cars have any velocity at the bottom
- None of the above.

2b. How does the *kinetic energy* of the car at the bottom of Hill A compare to the *kinetic energy* of the car at the bottom of Hill B? (Ignore the effects of friction and air resistance).

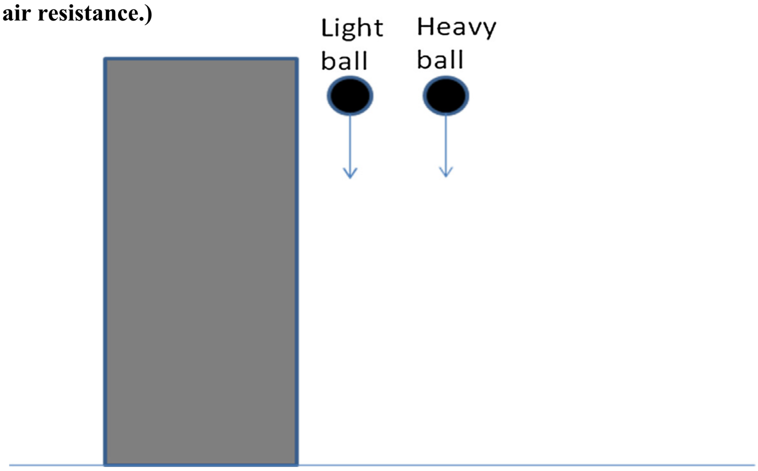
- The car at bottom of Hill A has a greater kinetic energy than the car at the bottom of Hill B
- The car at bottom of Hill B has a greater kinetic energy than the car at the bottom of Hill A
- Both the cars have the same kinetic energy
- Neither of the cars have any kinetic energy at the bottom
- None of the above

3. Two balls, one heavier than the other, are dropped to the ground from the roof of a building. Just before hitting the ground, how do their *velocities* compare? (Ignore the effect of air resistance.)



- The heavier ball has a greater velocity than the lighter ball
- The lighter ball has a greater velocity than the heavier ball
- Both balls have the same velocity
- Neither ball has any velocity
- None of the above

4. Two balls, one heavier than the other, are dropped to the ground from the roof of a building. Just before hitting the ground, how do their *kinetic energies* compare? (Ignore the effect of air resistance.)



- The heavier ball has a greater kinetic energy than the lighter ball
- The lighter ball has a greater kinetic energy than the heavier ball
- Both balls have the same kinetic energy
- Neither ball has any kinetic energy
- None of the above

5. A bowling ball is accelerating due to the force exerted by a person. Which law of motion *best* applies to this situation?

- Newton`s First Law
- Newton`s Second Law
- Newton`s Third Law
- All of the above
- None of the above

6. A book is sitting on the dashboard of a car that is stopped at a traffic light. As the car starts to move forward, the book slides off the dashboard onto the floor. Which law of motion *best* applies to this situation?

- Newton`s First Law
- Newton`s Second Law
- Newton`s Third Law
- All of the above
- None of the above

7. While driving your car, your tires push on the road and the road pushes on your tires. Which law of motion *best* applies to this situation?

- Newton`s First Law
- Newton`s Second Law
- Newton`s Third Law
- All of the above
- None of the above

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