Improving navigation and learning in hypertext environments with navigable concept maps

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ABSTRACT

In this paper, we have discussed the design of CoMPASS and the theoretical foundations that it is based on. CoMPASS is a hypertext system that presents students with external, graphical representations in the form of concept maps as well as textual representations both of which change dynamically as students traverse through the domain and make navigational decisions. In a study in which middle school students used CoMPASS, we analyzed students' navigation paths as well as their learning outcomes. A comparison class in which students used the system without the maps for navigation provided us with information about students' use of the maps for navigation and its effect on their learning. We found that students who used the maps version of the system performed significantly better in a concept mapping test as well as an essay test and their navigation was more focused. We have discussed the findings of the study and its implications for designing hypertext systems.

CONTENTS

1 INTRODUCTION

Hypertext environments are now increasingly being used in education. The flexibility and non-linearity of hypertext systems, attributes that seem to hold great promise, have also been viewed as causing confusion and disorientation with users not being able to figure out where they are and where they should go next (Marchionini, 1995). In hypertext and hypermedia systems, learners are encouraged to actively interact with large integrated bodies of information presented in alternative representations and contexts, by browsing through the space selectively (Bolter, 2001). Hypertext therefore allows more learner control providing flexibility to the users to decide what links to follow and in what order (Marchionini, 1995).

In order to cope with the specific constraints of a non-linear presentation, learners of hypertext have to acquire specific strategies such as knowing where they are, deciding where to go next and building a cognitive representation of the network structure. In a traditional text, writers typically present a coherent set of arguments. The words, sentences and paragraphs flow together (local coherence) and the sections follow (global coherence) in a coherent manner. However in a hypertext, it is more difficult for a writer to maintain global or macro-coherence (between sections), because there are numerous sections to which a learner can usually jump. Hypermedia designers have therefore proposed the use of navigational aids to support effective decision-making during navigation, to allow for flexibility and learner control, while at the same time keeping the learner from getting lost. Interface features such as hierarchies, overviews, outlines and maps (Dee-Lucas & Larkin, 1995; Shapiro, 1998), multiple views, focus+context views (Bedersen & Hollan, 1995a; Pirolli, Card & Wege 2001) and contextual navigation aids such as structural and temporal context information (Park & Kim, 2000) have been used to help in navigation. However, hierarchies and overviews have not necessarily lead to better learning (Dee-Lucas & Larkin, 1995; McDonald & Stevenson, 1999) According to

McDonald and Stevenson, navigational aids such as a spatial map may foster “efficient navigation” but “may not be a prerequisite for effective learning.” We believe that if navigational aids can be designed to reflect the conceptual structure of the domain, both navigation and learning can be supported.

The real strength of educational hypertext systems lies in presenting the content in a way that *shows the numerous and multiple interrelationships* between concepts. Consider the organization of a traditional expository text. There is a clear sequencing of ideas into sections and sub-sections, although expert readers are known to traverse the text in a non-linear way. In a printed text, associative relationships define organization that lies beneath the order of the pages and chapters (Bolter, 1991). Associative lines of thought that relate concepts and ideas permeate the text. However, it is extremely difficult to make these explicit in a linear text. As described by Sasot and Suau (2000) one of the most interesting aspects of hypertext systems is that they can express, in a particularly forceful way, the logical relationships that exist between concepts. Hierarchies and outlines make the vertical structure of the text visible, but they do not make the associative links visible to students. We have sought to make these relationships visible by building an interface that reflects the conceptual organization of the content. In the system CoMPASS (Concept Mapped Project-based Activity Scaffolding System), we have integrated the spatial navigational aids in the form of concept maps with the conceptual structure of the domain to support navigation and help learning at the same time. The concept maps help externalize the relationships between concepts so that students can see the interconnections therein, and the maps also aid navigation.

In this paper, we have discussed the design of CoMPASS and the theoretical foundations that it is based on. Then a study in which middle school students used CoMPASS is discussed. We analyzed students' navigation paths as well as their learning outcomes. A comparison class in which students used the system without the maps for navigation provided us with information about students' use of the maps for navigation and its effect on their learning. We have discussed the findings of the study and its implications for designing hypertext systems.

2 DESIGN OF COMPASS

CoMPASS is a hypertext system to help middle school students learn science. CoMPASS presents students with external, graphical representations in the form of concept maps as well as textual representations both of which change dynamically as students traverse through the domain and make navigational decisions. The maps are dynamic, zoom in and out in the form of a fisheye view (Bedersen & Hollan, 1995b; Furnas & Bedersen, 1995) and are constructed dynamically as a function of the strength of the relationships between the concepts, by retrieving the concepts from a database. Students therefore see any particular concept in relation to many other concepts, thereby helping them achieve a richer and a more integrated representation of science knowledge. Although the system contains topics in science, in this paper we have described a study involving one particular topic in Physics, forces and motion.

2.1 Visual Representations

Visual representations (Glinert, 1990) like concept maps help accentuate relevant characteristics of a representation (Hübscher, 1997; Narayanan & Hübscher, 1998) and make higher-order relations more accessible (Tufte, 1990). Concept maps and networks have been found to help in learning from texts and in learning how to write. For example, Mayer, Bove, Bryman, Mars, & Tapangco, (1996) have emphasized the importance of visual and verbal summaries in learning from scientific text. The Writer's Assistant (Sharples, 1994), an environment to support students in writing, offers a "notes network" that allows the writer to set down ideas as notes and link them together into a network of association.

INSERT FIGURE 1 ABOUT HERE

According to Novak & Gowin (1984), concept maps are intended to represent meaningful relationships between concepts. A concept map presents ideas in the form of nodes, which are linked by a word. In its simplest form, a concept map would be just two words connected by a linking word to form a semantic unit. Novak and Gowin believe that concept maps provide a kind of visual map showing some of the pathways we may take to connect meanings providing "a schematic summary" of the knowledge to be learned.

Shavelson, Lang & Lewin (1994) distinguish between hierarchical concept maps and non-hierarchical (network like) concept maps which are *relational,* so that relationships (links) can be non, uni- or bi- directional. Figures 1 and 2 show a set of concepts in the domain of physics: Figure 1 shows a hierarchical map, which can be used to provide structure and sequence. Figure 2 shows a relational concept map. In a hierarchical map, there is a definite parent-child relationship between nodes. However, in relational map, concepts are defined by their relationship to other concepts, in such a way that any number of links may connect two nodes.

INSERT FIGURE 2 ABOUT HERE

This results in subsets of closely related nodes and links providing a richer representation than a hierarchy. A hierarchical map can orient the learner but does not show all the relationships between concepts.

In CoMPASS, we have used visual representations in the form of relational concept maps. However, a problem with representing large concept maps on the screen is that they do not scale up very well (Narayanan & Hübscher, 1998). It is hard to display large maps with many relationships on a single screen, and showing part of the map results in a fragmentation making it hard to retain orientation. Fisheye views (Furnas & Bedersen, 1995) can be used to alleviate this problem. By using fisheye views, the portion of the screen that the user chooses with a mouse-click becomes the focus and can be maximized while the rest of the map is minimized but still visible. For a large domain however, even fisheye views can get confusing. We therefore needed to break down the domain into several sub-topics; for the forces and motion unit the subtopics were the different "types of motion" such as linear or circular motion. Each sub-topic is tied to real-world examples.

2.2 Structure of the Domain

Research on cognition from a constructivist perspective emphasizes the importance of a context to help students learn (Brown, Collins, & Duguid, 1989; Collins, Brown, & Newman, 1989). In a domain such as physics, the concepts and principles are better understood if they are tied to a context. For example, consider a student studying force in the context of a parachuter trying to land in windy weather (air resistance) or a car traveling on a rough road (friction). Maps of the two situations can be found in Figures 2 and 3 respectively. In linear motion when solid objects slide over each other, the major force opposing motion is sliding friction. However, for the 'falling object' (parachute), the acceleration of the falling object is due to the force of gravity between the object and the Earth. The force of friction, which opposes motion, in this case is the air resistance.

INSERT FIGURE 3 ABOUT HERE

We have used examples from the real world for each sub-topic. Each example is indicative of a type of motion, e.g., parachutes as an example of falling objects. For each type of motion, there is core set of concepts that are most relevant to an understanding of it. Once a student chooses the type of motion such as linear motion, projectile motion, the motion of falling objects etc., CoMPASS provides the student with examples and an explanation of that phenomenon (for example 'falling objects'), along with a map of the concepts and principles that can help understand that phenomenon. Students can then choose any concept from this map and a fisheye is displayed.

2.3 Fisheye Views

In fisheye views, concepts that are spatially close (Furnas, 1986) to the focus appear bigger than those that are on the outer (peripheral) levels. This kind of fisheye and zooming works well with hierarchies (Kumar & Furuta, 1999; Shipman, Marshall, & Lemere, 1999). However, when a concept map is relational, the fisheye view could be organized in such a way that the concepts that are *most related* conceptually to the focus are displayed *close to each other spatially*. In CoMPASS, we have used the relationship strength to determine the spatial proximity of the concepts. Thus the stronger the relationship between the two concepts, the closer they are spatially in the concept map. The relationship strengths were obtained by consulting with experts – Physics professors and researchers by getting a consensus on how they see the relationships between concepts. The maps are dynamically constructed and displayed with the fisheye.

INSERT FIGURE 4 ABOUT HERE

Take for example Figures 4, and 5. In Figure 4 the student has chosen the situation of falling objects and has then selected the concept of ‘Drag’. When a learner chooses a particular concept, that concept becomes the focus (F). In the figure, Drag is the focus. The concepts that are closest to the focus (L1) are the ones that are ‘most related’ to the focal concept in that situation. The next level (L2) consists of concepts that are indirectly related to the focus but directly related to one or more of the L1 concepts. The links in the text correspond to the L1 concepts, which are conceptually closest to the focus. When the students change focus, the map is redrawn based on relationship strengths. In Figure 5, the focus has changed to ‘Gravity’ because the student has chosen this concept. The map has changed to show the closely related concepts. In this way the maps support not only navigation but also *provide conceptual support* for helping student learn science.

2.4 Alternative Views

CoMPASS also supports alternative views of concepts. For example, to start with, a student might be interested in learning about ‘Force’ in the context of objects falling in air. She can change ‘views’ anytime (top right of screen in Figure 5) so that she can study the same phenomenon (Force) in other contexts such as linear motion or even simple machines. Learning in a subject area such as science involves understanding of the rich set of relationships among important concepts (Ruiz Primo & Shavelson, 1996), which may form a web or a network (Anderson, 1993). Successful science learning requires that the curriculum should be viewed as a dynamic set of ideas to be explored rather than a fixed set of ideas to be transmitted (Marx et al., 1991). As described by Spiro, Feltovitch, Jacobson, & Coulson, (1991) in the Cognitive Flexibility theory, revisiting the same material at different times, in rearranged contexts, for different purposes, and from different conceptual perspectives is essential for attaining the goals of advanced knowledge acquisition. The alternative views that CoMPASS offers can help students to study science concepts and phenomena in depth by visiting them in multiple contexts. CoMPASS is implemented in Java and can be accessed using a web browser.

INSERT FIGURE 5 ABOUT HERE

3 METHOD

After the initial pilot studies in which CoMPASS was used in an after-school club, CoMPASS was used in a regular classroom to help students learn science as they were engaged in science projects. Students from two eighth-grade classes participated in the quasi-experimental study, which was conducted in a middle school[1]. The first class, the maps-class used CoMPASS, and the second, index-class used an index version of the system with a list of concepts, instead of the maps for navigation. Both versions of the system had the same text, but they each used a different method for navigation. The teacher and the curriculum were the same for both the classes. The total number of students in the study was 36, eighteen students in each class. The average age of students was 12 years.

Students used the system to learn about ‘Forces and Motion’. At the beginning of the unit, students were required to design roller coasters and raise questions about how roller coasters worked, and by doing so, encounter issues related to forces and motion.

[1] Since the study was conducted within the constraints of the classroom, random assignment of students to the two conditions was not possible.

The unit started with a conceptual design of roller coasters that students would eventually build. After their initial designs, students explored the different concepts that affect the working of roller coasters, built their models and raised questions about the physics of roller coasters. During each of their class periods, students participated in an activity planned by their teacher and were encouraged to ask questions and use CoMPASS to answer their questions. For example, in one of the classes, the teacher discussed how loops in a roller coaster worked. Students then built loops and also explored issues using CoMPASS. Whole class discussions followed after students had done their research with CoMPASS. The entire unit lasted four weeks, but for this study we used three specific days based on the tasks that students engaged in. The teacher used the same activities for both classes. The only difference was the version of the software that was used. Students used the software individually and were in a computer lab adjacent to the classroom for the duration.

We tracked students' use of CoMPASS on three specific days to help make comparisons. On day 1 the question that students were exploring was "How is a pendulum similar to a roller coaster?" On day 2, students had a more open-ended task of exploring "how loops worked" in a roller coaster. The task on day 3 was to use CoMPASS as a resource to find the scientific principles that can be used to explain how different toys that they were assigned work. Some examples of the toys that the students were assigned were: a balloon with a propeller, a basketball, Jacob's ladder, etc. The first goal was more specific in that students were required to explain the similarity between a pendulum and a roller coaster by finding out more information from CoMPASS. The second goal was more open-ended and required students to research the topic in depth.

The third goal was the most open-ended of the three. In each case, there were some concepts that were more goal-related than the others. Students had had at least two hours of experience using CoMPASS before we started collecting data for day 1. Students did not use their textbooks for this unit but used CoMPASS for research. On each of the days, students used CoMPASS for forty-five minutes. The sessions were two days apart from each other, because of the schedules of the two classes.

Our research questions were as follows:

1. Do students use maps or links in the text for navigation?
2. Do concept maps encourage students to focus their navigation on goal relevant concepts?
3. Do concept maps lead to a deeper understanding of the domain because they make the structure of the knowledge space explicit?
4. What are students' attitudes about using maps in CoMPASS?

We used a range of qualitative and quantitative measures to understand student learning with CoMPASS. We used navigation data from the system, in the form of log files. The log files kept track of the source of navigation (i.e. whether students used the maps, links in the text or the index), the number of times that students visited a concept and the time spent on each concept. A test with multiple-choice items and an essay question was used as a pre-post test to study change in students' science knowledge. A concept map post-test was also used and a rubric developed to analyze students' maps, so that we could examine the richness of the conceptual relationships acquired by them. We also used a post-test survey to understand students' perception of the usefulness of the system, especially the maps for navigation. All post-tests were administered immediately after students completed the third task.

4 RESULTS

4.1 Use of Navigation Tools

Our first question was whether students would use the structural navigation tools (i.e. concept maps, and index) more often than the links in the text while navigating CoMPASS. To answer this question we analyzed data from the students' log files, to look at their overall use of navigation tools on both days. Figure 6 shows the percentage use of each of the navigation tools. Percentages were calculated by taking into account the number of times students used the maps, links in the text or the index for navigation and the total number of hits on any of the navigation tools.

INSERT FIGURE 6 ABOUT HERE

It is clear from Figure 6 that students in both the classes used the structural cues (index, the concept map) for navigation. Students in the maps-class used the maps more often than they used the links in the text on all the three days. The average use of links in the text for students in the maps-class was 16.16% while students in the index-class used the links in the text more often (38.75%). Students in the index-class used the links in the text as a primary navigation tool on day 1 (77.68%) but they mostly used the index on day 2 (77.7%) and day 3 (85.46%). Students in the maps-class, on the other hand, used the maps for navigation more often on all the three days. The average of all the three days showed that students in the index-class use the links in the text more often than students in the maps-class (χ^2 (1, N = 200) = 22.82, $p < .001$). A reason for this could be that the maps provided coherence between the concepts that they were learning. However, merely using the maps does not mean that students made coherent transitions between concepts. We analyzed their navigation paths to understand their transitions as described in the next section.

4.2 Focused vs. Random Navigation

Our second research question was whether the maps would encourage students to visit more concepts that were conceptually related to one another, as well as visit concepts that were 'relevant' to their current goal, thereby making their navigation more focused as opposed to random. Relevant concepts for each of the days were determined by the researchers and the teacher based on the goal for that day. We used the data from the log files[2] to analyze student's navigation patterns both qualitatively and quantitatively. We analyzed students' navigation paths to understand how they used the system to fulfill their learning goal for each day. Specifically, for a qualitative analysis of the patterns, we looked into transitions made between concepts the concepts that they

[2] Although there were 18 students in each class, some of the log file data had errors or was not complete and had to be deleted from the study. As such the number of students with complete data was: day 1 – maps-class = 17, index class = 11; day 2 – maps-class = 17, index-class = 17; day 3 – maps-class = 13; index-class = 15.

visited. For a quantitative analysis, we examined the time spent on each concept and the number of goal related concepts visited on each of the days.

Analyses of Patterns of Transitions

We wanted to analyze whether students in the maps-class made more transitions between related concepts because the maps provided them with a graphical representation of the most related concepts. We used the log file data and if the student spent less than 10 seconds on a concept, the entry was deleted from the analysis because students could not have read much in 10 seconds. This threshold was decided based on classroom observations. To examine the qualitative differences in students' navigation paths, we used the pathfinder algorithm. Pathfinder is a graph theoretic technique that allows for representing and comparing *dynamic* properties of navigational paths (Schvaneveldt, 1990). Pathfinder yields a network representation that consists of nodes and links. Based on the proximity of nodes visited, Pathfinder analysis also yields the most frequently chosen path. We applied the Pathfinder algorithm to analyze the most frequent transitions and graphically represent them (as illustrated in Figures 7 through 12) by using a distance matrix based on the number of transitions between concepts. The labels on the nodes consist of the concept name followed by [F:G], where F is the number of traversals starting at this node and G is the number of traversals ending at this node. So, drag [5:7] means that the concept "drag" got visited seven times, and the users went to other concepts from it five times. The thicker a line between two concepts, the more traversals happened between those two nodes. Traversals in both directions were added up. A one-sided arrow meant that students went from concept A to concept B and did not go back to concept A. On the other hand, a two-sided arrow meant that students traversed through concepts A and B in both directions, and this signifies navigation back and forth between the two concepts.

On day 1 the question that students were exploring was “How is a pendulum similar to a roller coaster?” The most important concepts that students were required to understand were potential and kinetic energy, and Newton’s laws. An initial discussion in the class helped students to raise ‘issues’ that they needed to explore in order to answer the question. Figure 7 shows that ‘velocity’ was the most frequently visited concept in the case of maps-class, while for the index-class it was ‘force’ that had the most visits (Figure 8). The most frequent transitions in the maps-class were between friction and mass, momentum and velocity and Newton’s three laws. The most frequent transitions in the navigational path of the index class were between gravity and acceleration, gravity and friction, force and gravity and among the three Newton’s laws. Although both classes visited concepts that were not directly related to the goal of the day, students in the maps class had more transitions between the concepts relevant to the goal. On the whole, students in the index-class visited more concepts. Both classes seemed not to focus on the most relevant concepts but seemed to have explored the domain.

INSERT FIGURE 7 AND FIGURE 8 ABOUT HERE; KEEP THEM ON THE SAME OR FACING PAGES

On the day 2 students were asked to find information to understand how loops worked in a roller coaster. Figures 9 and 10 show the navigation paths of all students in maps-class and the index-class respectively. Figure 9 shows that the most frequent transition was between force and acceleration. In addition, ‘force’ was the concept with most visits and acceleration with the second most visits. Other frequent transitions were force→gravity, potential energy→energy and kinetic energy→energy. All these transitions were meaningful in order to understand the scientific principles that explain how loops work in a roller coaster, which was the goal for that day. Therefore, the pathfinder network of maps-class suggests that the concept maps may have helped students make coherent transitions (i.e., visit relevant concepts). Transitions in the graphic also show double sided arrows which meant that students did not navigate in a linear order but went back to reread the text.

On the contrary, Figure 10 shows that students in the index-class made many frequent transitions. However, these were mainly in a linear order and followed the order of the concepts as presented in the index. This suggests that there was not always a coherent transition between the concepts. Also most of the arrows are one-sided suggesting that they followed a linear path dictated by the order the concepts that were listed in the index: acceleration↔energy↔force↔gravity→kinetic energy →mass→Newton’s 1st law→Newton’s 2nd law→Newton’s 3rd law→Newton’s laws→potential energy→speed↔velocity. It seems that students’ navigation was driven by the order in which the concepts were presented.

INSERT FIGURE 9 AND FIGURE 10 ABOUT HERE; KEEP THEM ON THE SAME OR FACING PAGES

These navigation patterns show the qualitative differences in navigation and illustrate that the navigation of students in maps-class was more focused than the navigation of students in the index-class. The fact that students in maps-class used the concept maps as a primary navigation tool might be the reason why they chose to focus on the relevant concepts thereby making coherent transitions. The concept maps might have provided students with conceptual support and therefore, they could focus on the relevant concepts without making many transitions from one concept to another. Also, on day 2, students in the maps-class were more focused in their navigation as compared to day 1, and this might have been because of their experience in using the maps for navigation.

Figures 11 and 12 show the navigation path of all the students in the two classes for day 3. There were three most frequent transitions in Figure 11: momentum→mass, Newton's laws→Newton's 3rd law, and Newton's 1st law→Newton's 2nd law. The three laws were important in order to explain how the toys worked. For the index-class, the transitions among the three laws also appear to be frequent. The arrows that represent these transitions form a triangle in the lower right part of the navigation path of the index-class. It is interesting to note that the three arrows that represent the transitions among the three laws are one-sided. This means that the students went from Newton's 1st law to Newton's 2nd law but not vice versa. However the arrow that represents the same transition in the navigational path of the maps-class is double sided. A reason for the one-sided transition for the index-class might be the fact that Newton's 1st law appeared first followed by Newton's 2nd law in the index.

INSERT FIGURE 11 AND FIGURE 12 ABOUT HERE; KEEP THEM ON THE SAME OR FACING PAGES

Analysis of Goal Related Navigation

Although the pathfinder networks showed us the trends in the navigation patterns, we wanted to further analyze the navigation by examining the quantitative differences using two navigation indices: proportion of goal related concepts visited on each day and the proportion time that students spent on goal-related concepts. We used the log file data for each day and found the proportion of goal related concepts (number of goal related concepts visited divided by the total number of concepts visited). Similarly, we found the proportion of time that students spent on goal related concepts. This helped us understand whether students in the maps class used the system more productively by visiting more goal related concepts and by spending more time on them. As indicated before, 'clicks' during which a student spent less than 10 seconds on a concept were not used in the analysis. Although the log files kept track of the time, it is possible that they were just looking at the screen and not reading the text. However, this was taken care of to a large extent by the teacher and two researchers going around the room to make sure that students were on task.

INSERT FIGURE 13 ABOUT HERE

Figure 13 summarizes the proportion of visits to the goal-related concepts and the proportion time spent on those concepts. Data show that students in the maps class spent a greater proportion of time on goal related concepts on all of the days and also visited a larger proportion of concepts that were relevant to the goal of the day. Independent samples t-tests (two-tailed) were conducted to test whether students in the maps and the index classes differed in the proportion of goal related concepts they visited and the proportion of time that they spent on goal related concepts on each of the three days. The proportion of goal-related concepts that students in the maps-class visited was greater than that of the index-class; however the proportion of goal related concepts decreased as the tasks became more open-ended. This may have been because students explored the domain a bit more when they had to figure out what concepts were relevant. The maps-class however, could get to more goal-related concepts, perhaps because the maps showed them the related concepts. Students in the index-class visited fewer goal related concepts and visited more concepts that were not related to the goal. As the navigation patterns also suggested, they tended to visit concepts in an alphabetical order, regardless of their goals. Although students in the maps-class visited a higher proportion of goal-related concepts, the difference in the ratios of the number of visits for the two groups was not significant on any of the days. However, time spent on the goal related concepts was significantly higher for day 1 ($t(26) = 2.19$; $p = .038$) as well as for day 2 ($t(34) = 2.45$; $p = 0.18$) and day 3 ($t(28) = 2.35$; $p = .026$). This meant that students in the maps-class used CoMPASS more productively by visiting more goal related concepts and also by spending more time on them. Thus the navigation of the maps-class was more focused and relevant to the goal.

4.3 Depth of Knowledge

To analyze the depth of science knowledge acquired by students we conducted a pre-post science knowledge test. We used a pre-post measure[3] consisting of multiple-choice items as well as an essay item. We also used a concept map post-test only measure in which students were asked to draw a conceptual map of their understanding of the forces and motion concepts.

The pre-post science knowledge test consisted of two parts: 16 questions that assessed factual information in a multiple-choice format and an open-ended essay question (see Figure 14). Students' response to the open-ended essay question was scored based on the depth of their science understanding. A complete answer that showed connections between concepts was given a score of 2 points. An answer in which students had mentioned concepts but only had a partial explanation and showed no connections was given a score of 1, and an incorrect response was given a score of 0. A total score for students' responses in the multiple-choice (facts) part as well as their responses in the essay question was obtained (Figure 15).

INSERT FIGURE 14 ABOUT HERE

A two-tailed independent samples t-test was conducted to test the difference between the two classes on the facts test. We found that there were no significant

[3] Based on a test developed in the Learning by Design™ project at Georgia Tech.

differences between the two classes in the pretest as well as the post-test. An analysis of covariance (ANCOVA) was used to adjust for differences in pretest scores for the essay question. The results showed that there was a significant difference between the two classes in the essay test scores, F (1, 33) = 3.95, p = 0.05. Follow-up t-tests (two-tailed) on differences between pre-post-test were conducted to evaluate whether the two variations of the CoMPASS system had an effect on students' understanding of the science assessed by the essay question. Results of the t-test revealed a significant difference between the two classes, $t_{(34)} = 2.47$, $p = .02$, effect size=.82[4]. The improvement in the post-test scores for the essay question of students in the maps class (M = .17, SD = .71) was higher than the improvement in the post-test scores of students in the index class (M = -.33, SD = .49). In fact students in the index-class performed worse in the post-test essay question than in the pretest. A reason for this may have been that the index presentation which was linear may have been detrimental to learning. The difference in the pre-post test scores between the two classes represents a large effect size (d = .82).

INSERT FIGURE 15 ABOUT HERE

We also analyzed the concept maps that students created at the end of the unit based on a rubric we developed. We examined two aspects of the maps: the explanation provided for the concepts and the explanation provided for the connections among the

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

concepts. Student responses were scored on a scale of 0-3 based on the depth of science understanding that they showed. A score of 0 meant that the explanation was incorrect while a score of 3 was demonstrative of a complete and clear explanation for the concept or connection. The coding rubric is described in Figure 16. Two raters coded students' responses in the pre-post test and the maps and compared ratings to get 'percent agreement'. The inter-rater reliability was between 85-90%.

INSERT FIGURE 16 ABOUT HERE

The number of concepts that the students included in their concept maps ranged from 9-11, and each was scored based on the three-point scale. Similarly, each connection was scored based on the rubric. A total score for the concept explanations and the connections was obtained. We found that on the whole, students in maps-class had better explanations for the concepts as well as the connections. Their maps were richer and they used more formulas as well as better and deeper descriptions for the concepts and the connections in their maps. Figure 17 summarizes the descriptive statistics of the total score obtained on the maps test by students in each of the classes.

A t-test was conducted to evaluate whether the students in the maps-class scored significantly higher than students in the index-class on the concept maps task. The results of the test indicated a significant difference in the total score for the connections between the two classes, $\underline{t}_{(30)} = 2.28$, $\underline{p} = .03$. No significant difference was found for the explanation of concepts between maps-class and the index-class.

INSERT FIGURE 17 ABOUT HERE

Results on the concept map correspond with the results on the pre-post test in that students in maps-class did better when they were tested on the depth of their science knowledge while the two classes did not differ in their factual knowledge. This was true of the multiple-choice items in the pre-post test, and on the explanation of concepts on the concept maps test. The two classes did not differ in their responses to ‘fact’ questions. However, maps-class did better on the essay test, and also did better in the way they connected concepts and explained those connections in the concept map test.

4.4 Influence of Maps on Navigation and Learning

Although the results of the essay and the concept mapping test indicate that the students in the maps-class showed a richer understanding of the relationships, we further analyzed the data to understand the relationships between the three variables – prior knowledge, navigation indices and the learning outcomes. For this analysis, we computed correlation coefficients among the variables. We computed Pearson’s r (two-tailed) between the pretest scores and the navigation indices, i.e., the proportion of hits on goal-related concepts and the proportion time spent on goal-related concepts. As shown in Figure 18, there was no significant correlation between the pretest scores, both multiple choice and essay questions, and the two navigation indices. This showed that navigation was not correlated with prior knowledge and that students’ navigation decisions may have been influenced by the version of the system that they used.

INSERT FIGURE 18 ABOUT HERE

To understand whether there was a relationship between the navigation indices and the post-test measures, we once again used Pearson's r (two-tailed). We found that there was no significant correlation between the navigation indices and the multiple-choice as well as the essay part of the post-test. This indicated that the knowledge gain in the essay part of the post-test may not have been influenced by the type of navigation used. In the case of the index-class, the essay scores in the post test were lower than in the pretest, indicating that the index-navigation have had an unfavorable effect on learning. However, there was a significant positive correlation between the scores on the concept mapping test (concept scores and the connection scores), and the proportion time spent on goal related concepts as well as the proportion of goal-related concepts visited for both the classes, as shown in Figure 18.

Results therefore suggest that the conceptual knowledge as measured by the concept mapping test seems to have been influenced by the type of navigation.

4.5 Students Attitudes About the Maps

We used a survey to understand students' attitudes about the maps and whether they were helpful. Students in the maps-class completed the survey after the third day of using CoMPASS. The survey had twenty-two Likert type items and four open-ended questions that asked students about their impressions of CoMPASS. We have summarized the responses for the items that are most relevant to the use of concept maps for navigation and understanding. As can be seen from Figure 19, in general, students were very positive about the concept maps and did not have any difficulty using them not only for navigation but also to understand the relationships between concepts, which was the intent of the maps. However, there were many students who were neutral about whether the maps helped them to understand the science concepts better (40.5%) or the strength of the relationships among them (45.2%). The majority of the students, though, reported that they liked being able to control the order in which they could read the text by selecting the concepts (76.2%). In addition, 69% of the students indicated that they would not prefer to have just the textual representation in CoMPASS.

INSERT FIGURE 19 ABOUT HERE

To understand whether students who had positive attitudes about the maps did better on the post-test, we computed correlations (two-tailed, Pearson's r) between the mean scores on items that were related to rating the usefulness of the maps and the post test scores. We found a positive correlation (Pearson's $\underline{r}$ = .611; p=.02) between the attitude scores on items listed in Figure 19 and the connection scores on the concept maps post-test. This showed there was a significant positive relationship between the perceived usefulness of maps and performance on the concept map test. We also found that there was a significant positive correlation between the essay test scores and the attitude score (Pearson's r = .588; p=.03).

Representative comments of students in maps-class for the open-ended questions that were included in the post attitude survey are summarized in Figure 20 and demonstrate that students not only liked the maps for navigation but also found them useful.

INSERT FIGURE 20 ABOUT HERE

5 DISCUSSION

In this paper we reported the design of CoMPASS, a system that uses navigable conceptual maps to help students learn from hypertext. We used CoMPASS in middle school classes where students used it as a resource as they engaged in science activities. The main aim of the study was to understand whether the maps helped students in their navigation and whether navigating via the conceptual map helped students to acquire a richer understanding of the science knowledge.

Researchers have investigated the use of navigation aids to help students learn from hypertext and their relationship with learning outcomes (e.g., Shapiro, 1998; McDonald & Stevenson, 1999; Park & Kim, 2000). We explored the use of maps as a means of navigation and examined not only the learning outcomes but also students' navigation paths, in the real-world context of learning in a classroom. In our study we found that not only did students use the navigation aids provided in each version of the system (index or maps), but their navigation patterns were influenced by the kind of structural aid that was provided in the system. Students in the maps-class, who used the maps for navigation showed more relevant transitions between concepts, based on the learning goals that they had on any particular day.

Analysis of students' navigation paths suggested that the maps encouraged students to visit more concepts that were conceptually related to one another as well as to visit concepts that were relevant to their learning goal, thereby making their navigation more focused as opposed to random. Students in maps-class who used the maps as a primary navigation tool visited fewer concepts, spent more time on the concepts that were relevant to their goals, and made coherent transitions. This suggested that the concept maps might have provided students with conceptual support and, therefore, they could focus on relevant concepts without making a lot of transitions from one concept to another. On the other hand, students in the index-class made a lot of transitions between concepts but they spent less time on each concept. The pathfinder networks that illustrate their navigational paths indicated that the transitions between concepts were not always coherent. For example, the navigation path of students in the index-class on day 2 suggested that the transitions were mainly in a linear order and followed the order of the concepts as presented in the index. Given that there was no significant difference in the prior knowledge as measured by the pretest, and there was no significant correlation between the navigation indices and the pretest scores for both the classes, our results suggested that the type of navigational aid might have affected students' navigation decisions.

An important aspect of navigation aids that was emphasized by Shapiro (2000) is that support in the form of interactive overviews can overshadow the learning goal. This was supported in our study in that the index group largely followed the structural aids provided in the index no matter what their goal was. Even though the goals were increasingly open-ended on the three days, the structure of the index drove the navigation of the index-class. However, the maps-class clearly focused their navigation based on their goal for each of the days. An important strength of hypertext is that it enables “authors to describe relationships that are difficult to express in sequential prose” (Bernstein, 1991). One of the challenges of designing effective hypertext systems is that learners need support while at the same time they need enough flexibility so that they can explore the information space (Hübscher & Puntambekar, 2001). As Bernstein (1991) described, “effective hypertext writing depends on the tension between regimentation and richness, between predictability and excitement.” Navigation support should therefore be designed to help students with their conceptual understanding and the maps in CoMPASS did just that. By providing students with conceptual maps for navigation, we did not overly restrict navigation; instead the maps provided students with conceptual structure. Consequently, we found that the conceptual representation in CoMPASS did not overshadow the goals of students in the maps-class, but instead supported them by showing the relationships between concepts. Our results lead us to believe that by integrating the spatial navigational aids with the conceptual structure of the domain, learners can be better supported to learn from hypertext systems, so that they will find information relevant to their goals. The concept maps in CoMPASS guided the students through the nonlinear sequences of the text providing conceptual support by ‘externalizing’ the associative/logical relationships between the science concepts.

Although students’ navigation patterns suggested that the maps helped them focus their navigation, did students in maps-class really learn better as well? Jonassen (1989) has argued that the “most significant problem in learning from hypertext is the integration of information in the learner’s knowledge structure.” Research has shown that that concept mapping is a powerful and psychometrically sound method for assessing conceptual change (Ruiz Primo & Shavelson, 1996). Creating concept maps engages students in a thoughtful way and encourages them to reflect on relationships among concepts and complexity of ideas (Novak & Gowin, 1984). According to Jonassen & Wang (1993) students show some of their best thinking when they try to represent something graphically, and thinking is a necessary condition for learning. In a study by Nicoll, Francisco & Nakhleh (2001) the relationship between using concept maps throughout an undergraduate Chemistry course and the connections that students could make at the end of the course was studied. It was found that the group that was exposed to the maps differed significantly from the no-maps comparison group in the total number of nodes, links and in the useful links in post-interviews. Our results suggested that while there was no difference on the test that measured factual knowledge of Physics, students in the maps-class did better on the essay question that required them to make connections between concepts. They also did better on the concept map post-test in that the connections that they made between concepts showed that they had gained a richer understanding of the subject. Their maps were richer and they also used more formulas. We found that there was a significant positive relationship between the navigation indices and the scores on concepts and connections. This suggested that the knowledge representation in the system, as reflected in conceptual maps, may have helped students gain a deeper understanding of the relationships between conceptual units. However, navigation indices were not significantly correlated with the facts and essay portions of the multiple-choice test. It is possible that the type of navigation did not affect knowledge gains as measured by facts part of the post-test. Although the essay question was designed to measure a deeper level of understanding, it is possible that one essay question was not enough to measure this. A reason for this may also have been that the essay question did not adequately measure students' understanding of the relationships.

Students' responses on the attitude survey also showed that they found the maps helpful for finding information relevant to their goals. The concept maps served as a visual support to help students make coherent transitions between concepts. The connections in the map and the fisheye representation of the concepts indicated other relevant information to what they were reading at a particular time, and students seemed to have a positive attitude towards these.

In a hypertext system, learners constantly have to make decisions about where to go next. Designers of hypertext systems constrain this choice to help the users select appropriate nodes, by deciding which hyperlinks are available to the learner at any particular time, by ordering and prioritizing topics or by providing structural aids. Our results suggest that by designing an interface that reflects the underlying structure of the domain, we can not only support navigation, but also support learning.

6 CONCLUSION

In this paper we described CoMPASS, a system that uses external representations in the form of dynamic concept maps to help students learn from hypertext. We used CoMPASS in middle school classes to understand its use and effectiveness in support students in a real world setting. We analyzed students' navigation patterns and found that the maps did help students in staying focused on their goals, as compared with an index version of the system. However, we need to further explore the nature of the task or goals that students have and its interplay with navigation patterns. In our study, the tasks ranged from less to more open-ended and it seemed that students made coherent transitions in all of the tasks. This study was conducted in classrooms and we are planning on conducting controlled experimental studies so that we can better support the findings about the type of navigation, its effect of the decisions that students make and the learning outcomes. Also, in future studies, we are looking not only at the class navigation but also navigation patterns of groups of students. We are also collecting audio data of students' interactions with the system so that we can examine what 'triggering events' lead to the kinds of navigation patterns that students follow. Further, although results of the learning outcomes are encouraging, the results are by no means conclusive, because of the small sample sizes, and longitudinal studies that explore the use of concept maps will be helpful to understand students' developing conceptual knowledge.

7 NOTES

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9 FOOTNOTES

1) Since the study was conducted within the constraints of the classroom, random assignment of students to the two conditions was not possible.

2) Although there were 18 students in each class, some of the log file data had errors or was not complete and had to be deleted from the study. As such the number of students with complete data was: day 1 – maps-class = 17, index class = 11; day 2 – maps-class = 17, index-class = 17; day 3 – maps-class = 13; index-class = 15.

3) Based on a test developed in the Learning by Design™ project at Georgia Tech.

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

10 FIGURE CAPTIONS

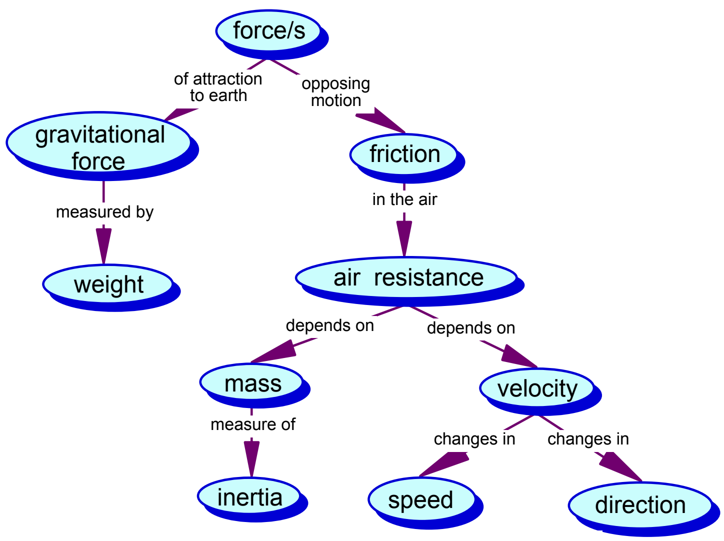


Figure 1: Hierarchical map

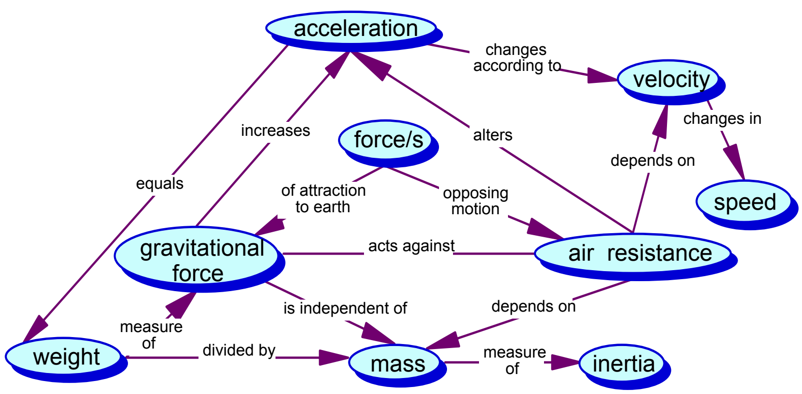


Figure 2: Relational map

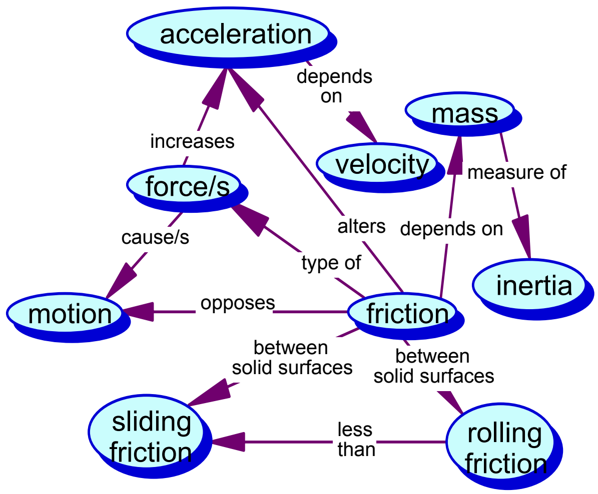


Figure 3: Map showing friction

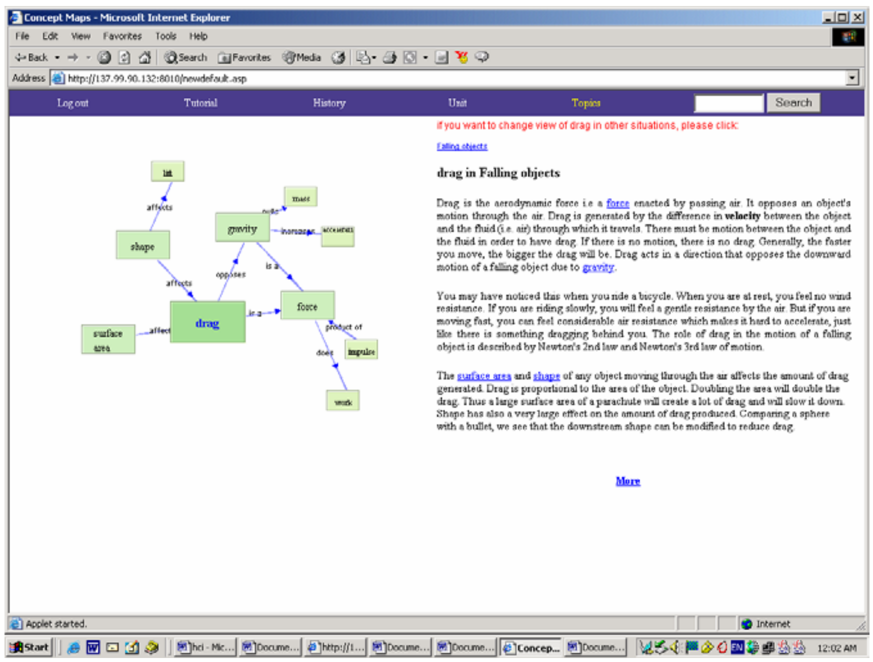


Figure 4: Fisheye showing ‘drag’ as focus

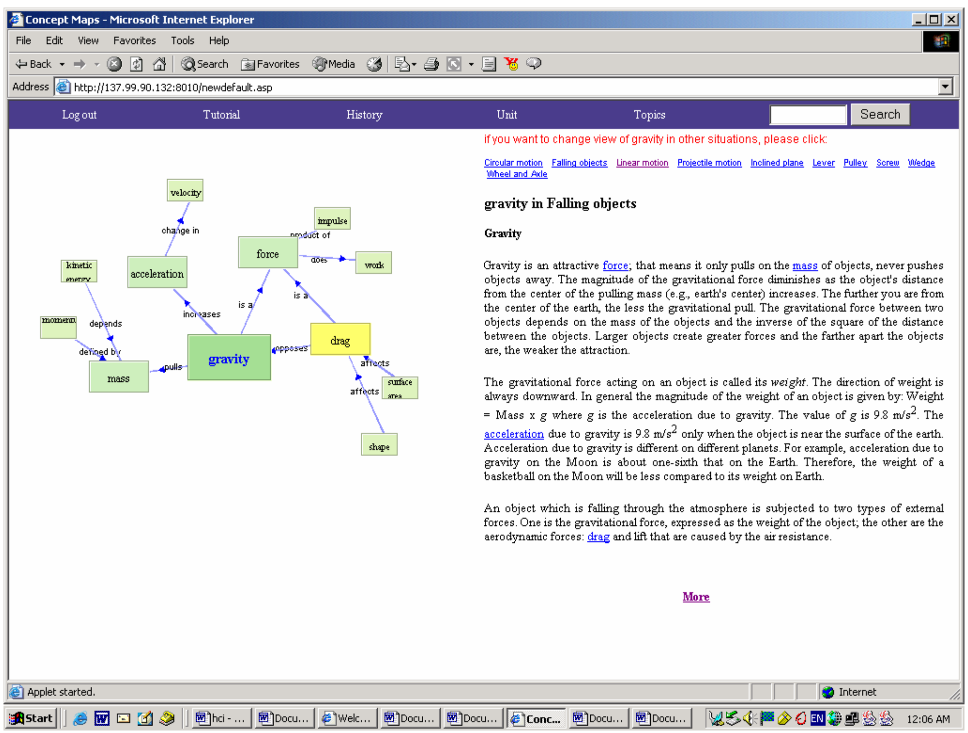


Figure 5: Fisheye showing 'gravity' as focus

	Maps-class				Index-class			
Tools	*Day1*	*Day2*	*Day3*	*Average*	*Day1*	*Day2*	*Day3*	*Average*
Concept maps	86.58	76.19	96.55	83.83				
Index					22.31	77.70	85.46	61.24
Text	13.41	23.80	3.44	16.16	77.68	22.29	14.53	38.75

Figure 6: Percent use of navigation tools by the two classes

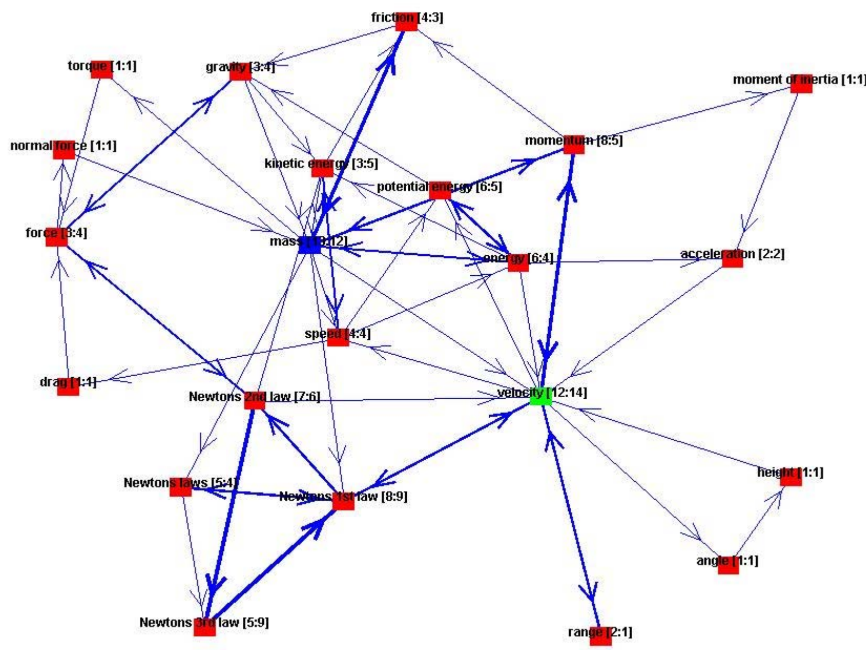


Figure 7: Navigation paths of the maps-class for day 1

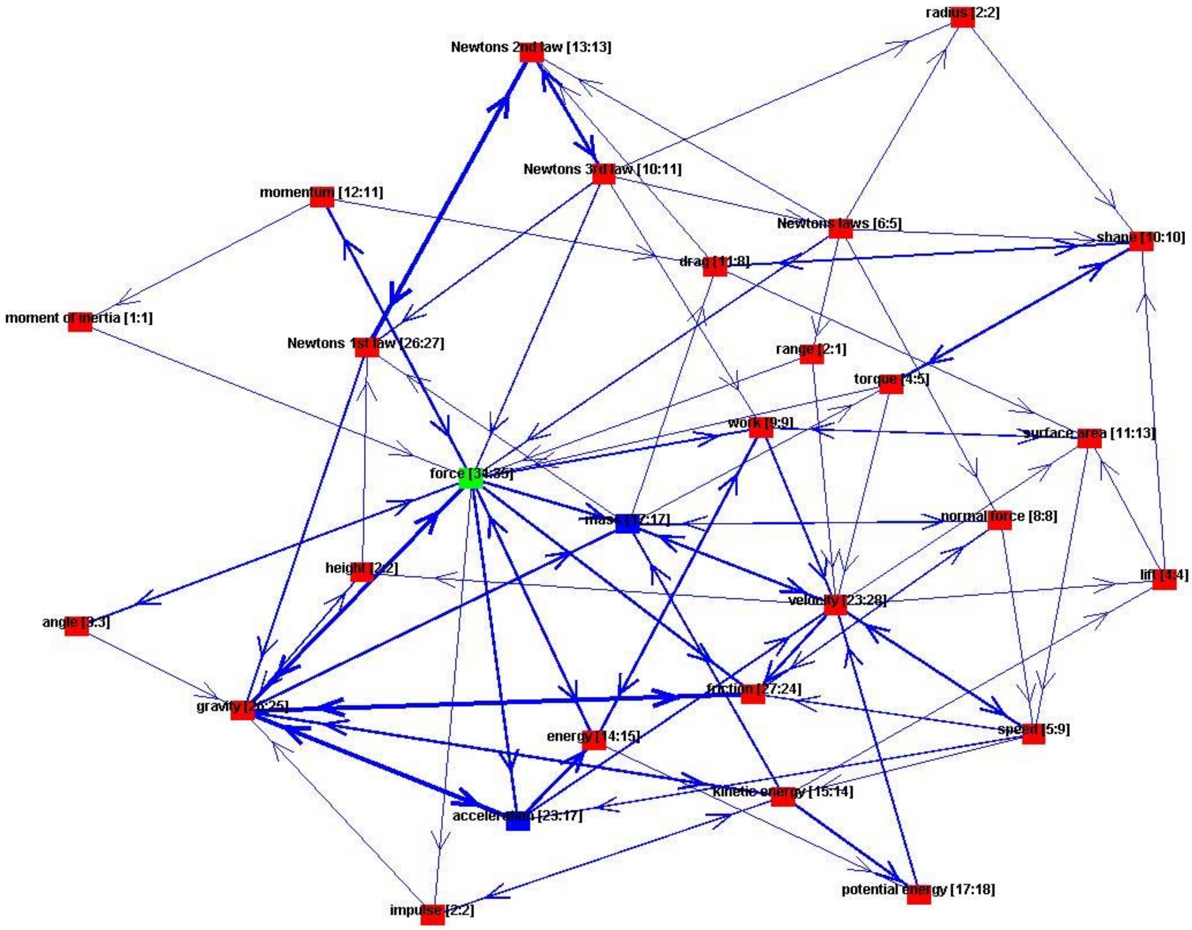


Figure 8: Navigation paths of the index-class for day 1

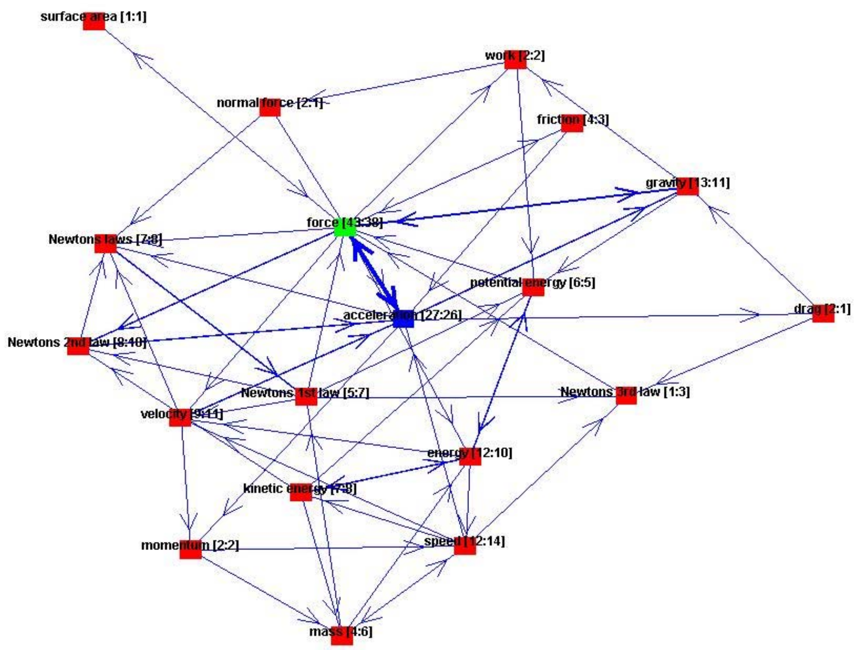


Figure 9: Navigation paths of the maps-class for day 2

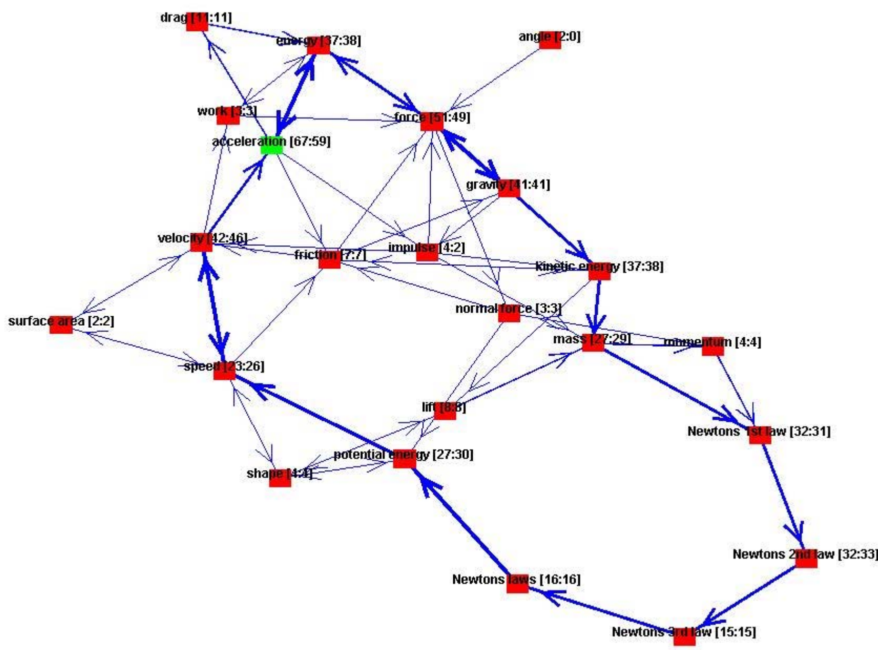


Figure 10: Navigation paths of the index-class for day 2

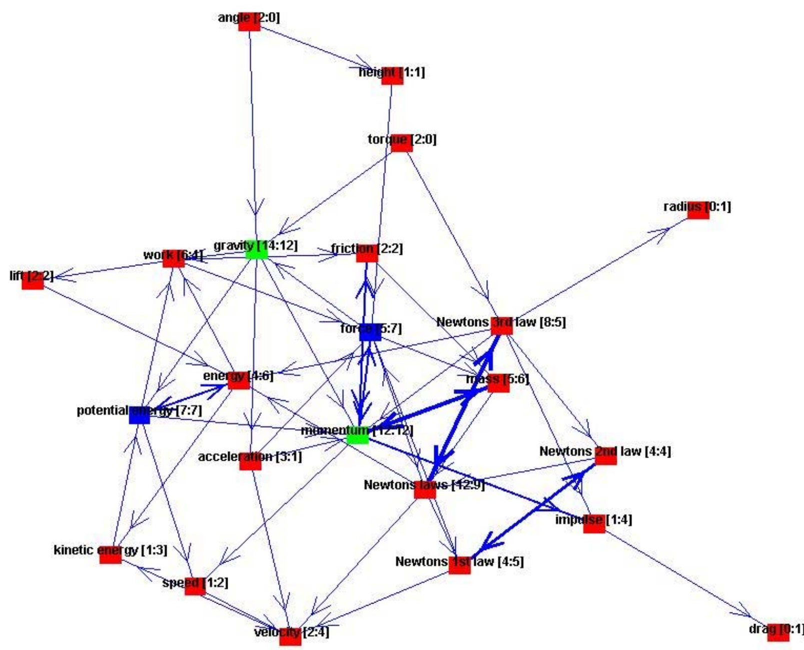


Figure 11: Navigation paths of the maps-class for day 3

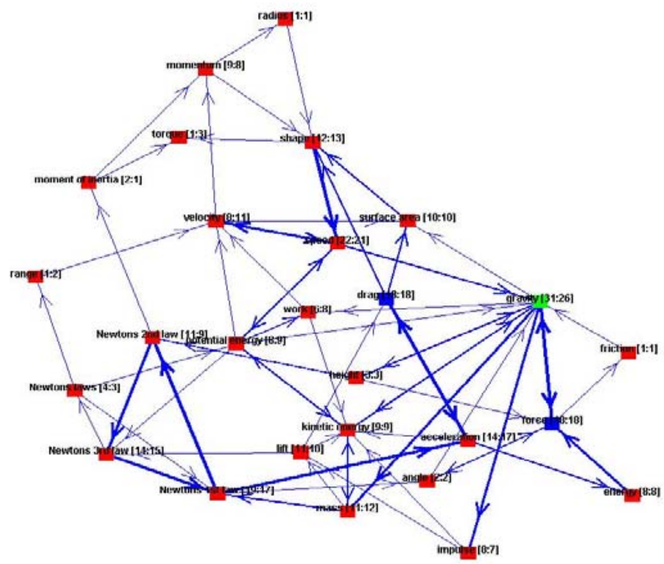
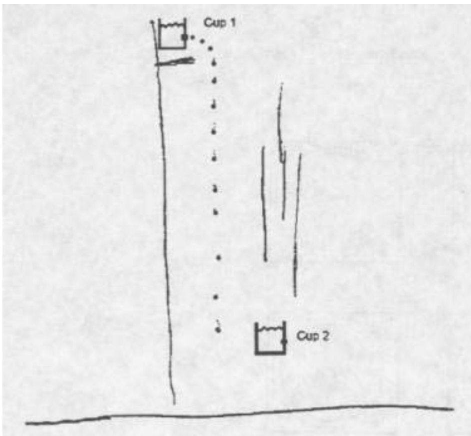


Figure 12: Navigation paths of the index-class for day 3

Day	Dependent measure	Class	N	Mean	SD
1	Proportion time on goal related concepts	maps-class	17	.96	.076
	Proportion time on goal related concepts	index-class	11	.85	.18
	Proportion visits to goal-related concepts	maps-class	17	.90	.14
	Proportion visits to goal-related concepts	index-class	11	.79	.18
2	Proportion time on goal related concepts	maps-class	17	.85	.18
	Proportion time on goal related concepts	index-class	17	.70	.18
	Proportion visits to goal-related concepts	maps-class	17	.91	.15
	Proportion visits to goal-related concepts	index-class	17	.77	.25
3	Proportion time on goal related concepts	maps-class	13	.76	.22
	Proportion time on goal related concepts	index-class	15	.53	.28
	Proportion visits to goal-related concepts	maps-class	13	.64	.24
	Proportion visits to goal-related concepts	index-class	15	.50	.26

Figure 13: Navigation indices for the three days



A class conducts the following experiment: Two identical cups are each partly filled with an equal amount of water. The cups are taken to the top of a 5-meter high wall. Then each cup has a hole poked in the side, near the bottom (the holes are the same size and in the same location on each cup). The holes on each cup are held closed while the cups are poised over the ground. Cup One is held in place, with the hole uncovered, while Cup Two is dropped to the ground. It does not bust. Each container is videotaped and the tapes are reviewed by the class later. The class is able to see that during the time that Cup Two is traveling toward the ground, it does not lose any water, but during the same period, Cup One, held above, does lose water (see diagram below). Explain why this is so.

Figure 14: Pre-post essay test

	Maps-class			Index-class		
	Pretest	Posttest	Mean difference (post-pre)	Pretest	Posttest	Mean difference (post-pre)
		Essay			**Essay**	
Mean	.11	.27	0.17	.39	.06	-0.33
SD	.47	.46	0.71	.61	.24	0.49
N	18					
		Facts			**Facts**	
Mean	3.22	6.22	3.00	3.94	7.39	3.44
SD	1.44	2.62	1.24	1.55	2.45	0.92
N	18					

Figure 15: Mean learning gains in the Pre-Post Science Knowledge Test

Component	Score	Example
Explanation of Concepts	0 points for an incorrect or not valid explanation (misconception) of the concept	"acceleration is the force that causes something to go"
	1 point for partial explanation of the concept	"friction slows you down, reduces speed"
	2 points for a formula used in the explanation of concept	"momentum: mass times velocity"
	3 points for a complete and clear explanation of the concept	"kinetic energy is the energy of motion"
Explanation of Connections	0 points for an incorrect or not valid explanation (misconception) in the description of the connection	a connection between conservation of momentum and gravity that has as a descriptor: "the reason why conservation of momentum is not conserved forever"
	1 point for partial explanation of the connection	a connection between velocity and kinetic energy that has as a descriptor: "all moving objects have"
	2 points for a formula used to explain the connection	a connection between momentum and mass has as a descriptor: "M x V"
	3 points for a correct and clear description of the connection	the connection between acceleration and velocity has as a descriptor: "acceleration is the change in velocity"

Figure 16: Concept Maps Scoring Rubric

	Maps-class			Index-class		
	N	Mean	SD	N	Mean	SD
Concepts	15	21.8	5.62	17	20.18	7.29
Connections	15	19.1	5.81	17	14.35	6.02

Figure 17: Student responses on the concept-mapping test

Index-class						
	Pretest facts	Pretest essay	Concept score	Descriptor score	Post-test fact	Post-test essay
Proportion time on goal related concepts	0.075	0.251	.841**	.635**	0.072	0.314
Proportion visits to goal-related concepts	0.18	0.23	.574*	.561*	0.18	0.35
Index-class						
	Pretest facts	Pretest essay	Concept score	Descriptor score	Post-test fact	Post-test essay
Proportion time on goal related concepts	0.08	0.25	.746**	.646*	0.26	0.33
Proportion visits to goal-related concepts	0.18	0.23	.572*	.561*	0.28	.03

**. Correlation is significant at .01 level (two-tailed); *. Correlation is significant at .05 level (two-tailed)

Figure 18: Correlations between navigation indices and pre and post-test measures

Statement	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
Concept maps helped to understand the science concepts better	2.4	7.1	40.5	42.9	7. 1
Prefer text only – no maps	21.4	47.6	21.4	9.5	--
Concept maps helped find information easily	--	9.5	35.7	45.2	9. 5
Liked being able to control the order in which the text could be read by selecting the concepts	--	2.4	21.4	66.7	9. 5
Maps helped understand the strength of the relationships among concepts	--	4.8	45.2	47.6	2.4
Concept maps helped understand relationships among the concepts that were not known before	--	7.1	38.1	45.2	9. 5
Navigating via the maps was better than navigating via the text	--	4.8	38.1	47.6	9. 5

Figure 19: Percentages of responses for items in the Post Attitudes Survey

What did you like best in the CoMPASS system?
It was really easy to find the concepts b/c they were on the maps and you didn't have to go searching through pages of writing to find out what a concept was.
That you didn't have to read many pages to find the information I was looking for. I could just click on the icon in the web.
It was easy to find information.
It was a good source to find necessary information that may have been harder to find in a regular on-line search engine.
I liked the concept maps and the connections that were written along the lines.
I liked the concept map links the best because it showed the relationships between concepts.
The concept maps helped me very much in understanding relationships between concepts and helped me find what I was looking for easily.

Do you feel that the concept maps helped you to navigate the text? Explain why.
Sure why not? Some text used terms I could not understand but with the concept maps it clarified them.
Yes because sometimes on the text a connection would be said and it was helpful to look over to the concept maps and see that connection.
Yes the concept maps were very helpful because they helped me understand relationships between concepts.
Yes, because it helped to see more clearly on what other things are related to that text.
Yes because if I was looking for something that was related to the topic I was researching then those concept maps really came in handy.
Yes, I knew where everything was without having to read through the text to find it.
Yes because all you had to do was click on what you wanted and then they'd take you to where you wanted to go.

Figure 20: Representative responses for the open ended questions in the Post Attitudes Survey