The Effects of Multidimensional Navigational Aids and Individual Differences on WWW Hypertext Navigation

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(ABSTRACT)

The most common application of hypertext today is found on the World Wide Web, with the numbers of sites and potential users increasing continually. Hypertext systems are characterized by hyperlinks that allow users nonsequential access to the documents contained within them. Because users are not constrained to read through these documents in a linear manner, new problems may arise not found in traditional paper versions.

These problems are generally characterized by a sense of being “lost” within a hypertext system. The user may not know exactly where they are or how to get where they want to be. They have lost many of the visual cues that indicate position found in ordinary texts like books. Navigational aids or overview maps have been suggested as a means to help counteract this problem. These navigational aids can take a standard table-of-contents and extend it dynamically or provide a completely new paradigm of browsing. To that extent, many new varieties of maps (including three-dimensional ones) have been developed but not thoroughly studied. As well, it may be theorized that users of differing cognitive abilities may be helped or hindered by such devices.

An empirical study was performed to investigate the effect of multidimensional maps. Three different navigational aids were examined which varied the way pages are displayed along one, two or three dimensions. Two hypertext systems were also where one was roughly twice the size of the other. The participants were given a search task twice to examine performance on page revisits. Finally, three cognitive tests were given to view the effects of individual differences. These included a spatial ability, verbal ability and visual memory test.

The results indicated that no performance differences existed between the different navigational aids. However, a significant interaction was present between the maps and the type of Web site; smaller Web sites benefited from the 3D navigational aid. It is theorized that an observed effect for hypertext system was due to site complexity as opposed to size. The results from the cognitive ability measures were mixed. People with low verbal ability scores took longer to locate answers. People with high spatial ability scores found more answers and had scores that were less sensitive to the type of navigational aid used. No significant differences were discovered between people of high and low visual memory abilities.

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INTRODUCTION

Background

The growth of the "internet" or "World Wide Web" has been phenomenal; in no more than a few years the number of Web sites has increased from thousands to millions. A recent study estimates the number of publicly accessible Web pages at a minimum of 320 million and growing continually (Lawrence and Giles, 1998). Additionally, companies not only set up public sites but also private internal networks or "intranets." As the growth of data easily available at a user's fingertips increases, so does the complexity required in retrieving the appropriate information. People may actually become lost in a sea of text, graphics and animations. Internet browsers provide tools and features that can assist the user, and, the actual internet sites may provide navigational assistance. However, more research still needs to be conducted to ensure that users can retrieve the information they desire with the least amount of difficulty.

Definitions

Before a more detailed examination of user's problems with hypertext, a brief introduction to the technology is needed. As people read standard text such as a book, they usually do so in a sequential or linear manner going from one page to the next, beginning to end. The essence of hypertext, which separates it from traditional paper documents, is its nonlinear nature. Users are free to explore hypertext in a nonsequential manner jumping from page to page in almost any order. This almost random reading activity may be referred to as browsing implying that the user must actively decide their destination. Figure 1 demonstrates this behavior. Here the user at page one has the opportunity to go to any of the following pages in the hypertext system. And those pages allow movement between them as well (Nielsen, 1995).

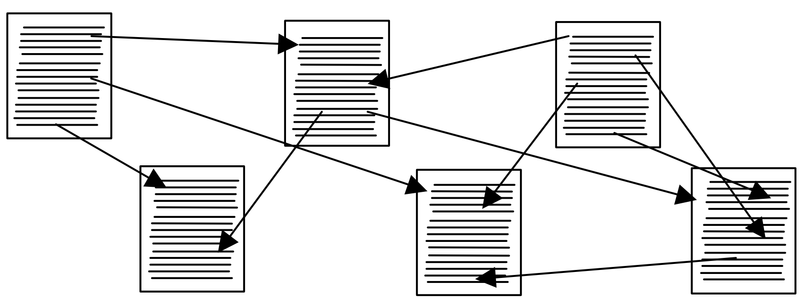

Figure 1: Nodes and Links

The structure of the hypertext document may be thought of as containing two components. Nodes represent the actual pages or pieces of information. Links (or hyperlinks) are the mechanism through which traveling from one point to another may take place. These links are usually (one-way) directed; the destination node may provide no means of transversing backwards to the previous node. In Figure 1, there are 6 nodes and 10 directed links. Each node may have any quantity of links or none at all depending on the author's intentions. At the least, a hypertext system must consist of two nodes with a link between them. The first node will contain a link to a destination node. Usually there is some text or graphic that serves as a linking mechanism whereas the destination is the entire node or page itself (Nielsen, 1995). In some systems, the destination may be a specific part of a node, such as a section of text or an image. Also present may be landmark nodes, prominent nodes in the network that are accessible by many of the others (Nielsen, 1990).

One method to help define hypertext systems is to give some examples of systems that do not qualify. Conklin (1987) presented a few examples:

- Windowing Operating Systems. They do not qualify because there is no underlying database of information.
- File Systems. No simple method of linking between documents is available.
- Database Systems. They lack a "single coherent interface" which supports the features of hypertext.

Perhaps, more importantly, Conklin (1987) provides some characteristics of an idealized hypertext system:

- An underlying database which contains text or graphical nodes. In hypermedia systems, these nodes may also be video or audio based.
- The nodes correspond to windows on a one-to-one basis.
- The windows may be interactively manipulated using standard operations. These include the ability to maximize, minimize, close, move and resize.
- The windows should contain links to other nodes. Once the link is selected, another window is opened displaying the newly requested information.
- The user should be easily able to add new links and nodes.
- The hypertext database can be navigated in three different methods: (1) by following links present on the nodes, (2) by using a search engine to find a keyword or attribute, (3) by using an overview map which displays the network graphically.

The underlying topology in a hypertext document may be constructed in several ways. Figure 2 graphically represents these kinds of alternatives.

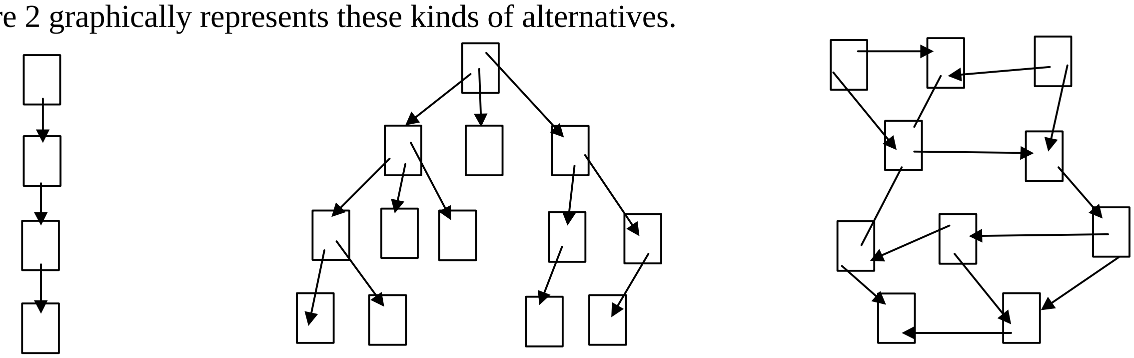

Figure 2. Three different hypertext structures (from left to right: Linear, Hierarchical, Nonlinear)

A linear construction is similar to traditional text in that each node leads to the next in a sequential manner. A hierarchical design appears more tree-like; each node can only be accessed by the nodes above or below. A nonlinear or network construction may appear Web like with links connecting many nodes without a defined structure. Hierarchical and nonlinear structures have been shown to be the most popular designs in hypertext systems (Mohageg, 1992). Because of peoples' experience with ordinary reading, the structure of hypertext should impact the usability of the system.

McDonald and Stevenson (1996) conducted an experiment where the only independent variable was hypertext topology using the three levels described above. A sample hypertext system was developed in HyperCard. It was theorized that linear structures would result in the best performance while non-linear would have the worst. The results supported that hypothesis. Participants spent a progressively longer time completing their search task as the structure became more complex, as well, they opened more cards. When asked to rate their disorientation, the levels were highest in the hierarchical and nonlinear structures.

Batra, Bishu and Donohue (1993) found that users adapt with time to learn to use different topologies easily. Users were even able to adapt when placed in the middle of a hypertext document as opposed to the top. However, they found that hypertorus (a circular non-linear structure) promoted browsing, while a hierarchical topology fosters more efficient navigation behavior. Mohageg (1992) similarly found that users of hierarchical structures performed more efficiently than those using a network structure.

Brief History

Hypertext systems existed long before the internet was rushed into the spotlight. In fact, most experts trace the roots to Vannevar Bush who in 1945 published, "As We May Think." This article proposed a device called memex ("memory extender") which provided users a machine for browsing the growing amount of scientific literature. Using the technology of the time, microfilm and photocells would contain a library of text and other graphical information. His goal was to allow users access to information with "exceeding speed and flexibility." To make it possible he suggested the modern-day idea of hyperlinks: "It affords an immediate step, however, to associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the Memex. The process of tying two item together is the important thing" (Bush, 1945).

As hypertext began its evolutionary growth, several important systems were developed as outlined by Jakob Nielsen (1995):

- Augment/NLS (1962-1976). Developed by Douglas Englebart at the Stanford Research Institute out of a project to augment human capabilities. The NLS had several hypertext features and allowed researchers to store their documents in a manner which allowed cross-references.
- Xanadu (1965). Ted Nelson, who first used the word, "hypertext," had a vision of a system where all the written works of the world would be stored electronically. This would create a global database where any one document has the power to refer to any part of another document.

- Hypertext Editing System (1967). The first working hypertext system developed at Brown University.
- KMS (1983). A "Knowledge Management System" primarily used with very large hierarchical, hypertext systems and others as well. It uses the concept of a frame to represent the nodes.
- Hyperties (1983). A hypertext system developed by Ben Shneiderman that can work in primarily textural-based operating systems like DOS. It allows navigation with a mouse - when the user selects a link, a preview of the next page is displayed.
- NoteCards (1985). Designed at Xerox PARC and built to run on their Lisp machines. It contains four basic components: notecards, a link, FileBoxes, and a browser card. The browser card is of particular interest because it provides an overview diagram of the system. It allows users the ability to see the structure and an alternate method of navigation.
- HyperCard (1987). A graphical programming environment for the Apple Macintosh that allows for easy prototyping of hypertext systems via its language called HyperTalk. The program, like NoteCards, is based around a card metaphor on which users can build buttons that will act as links or can call other programmed routines.

Hypertext Today: the WWW

Perhaps the most visible example of a hypertext application today is the internet or the World Wide Web (WWW). The National Center for Supercomputing Applications (NCSA) Mosaic browser, which was introduced in 1993, popularized the World Wide Web in a previously unseen manner with a growth of 289,000% that same year. Although the Gopher system and newsgroups had slowly been gaining popularity, it was the graphical nature of the WWW which brought it much attention. Users of Mosaic were simply able to type in a URL (Uniform Resource Locator) or mouse-click on a link to be transported to a Web page. As well, a simple graphical user interface let users interact in a much more intuitive manner than the previously available text command line prompts (Nielsen, 1995). Soon Mosaic's popularity waned as a similar program from Netscape Communications Corporation (Netscape Navigator) captured the largest market share. Recently, Mosaic was discontinued by NCSA and Internet Explorer by Microsoft Corporation has become a standard part of most popular PC operating systems.

The mechanisms through which these browsers work may be thought of as two-fold. First a standard communication protocol called HTTP (hypertext transfer protocol) allows information to be transferred between the servers and destination computers. This information is delivered in a standardized format called HTML (hypertext markup language). HTML is simply an ASCII file that contains certain codes dictating the structure of the displayed text and graphics. It also contains information regarding the destination of the links on the page. These links often refer to other sites and their home pages. These may be thought of as the top node in a hierarchy of related pages. Often they contain an overview of the site giving users an idea and a method (linking) to access information within the organizations' Web site (Nielsen, 1995).

Browsing and Searching

Understanding the tasks users perform in hypertext environments is crucial to the design of usable system. Generally, information retrieval is the goal that prompts the use of the system. But how that information is retrieved will differ. One common method is a directed search. Employing a search-engine, a user may type in a series of keywords, Boolean operators, and constraints. A list is returned containing a series of nodes ("hits") that match the request to which the user can link. Another method can be categorized by the term, browsing. This is an exploratory, informal strategy where the user may visit many different nodes in their search for information. It is good technique for exploring new areas and for ill-defined problems, though tends not to be as efficient when conducting searches for specific items (Marchionini and Shneiderman, 1988).

Problems

Hypertext as a medium of information exchange has many advantages. However, there are several drawbacks that inhibit its use. Interestingly, these problems relate to hypertext's chief advantage, its flexibility (Gupta and Gramopadhye, 1995). Conklin (1987) outlined several difficulties that are as true now of the WWW as they were then of general hypertext programs. The two most frequently mentioned problems are: disorientation and cognitive overhead.

The *disorientation problem* may be described as the phenomena of getting lost in hypertext. It may be identified by:

1. A lack of knowledge of where one is within a network of information.
2. A lack of knowledge of how to get to some other place within the network.

This may be contrasted to using linear text documents. A person has a visible cue of how far they are within the document by the quantity of pages before and after their current position. Also, if they need to find additional information on other pages there are only two directions to turn: forward and back. In a hypertext system, these cues and navigational methods are not present. A very large network with hundreds or thousands of nodes (in case of the WWW, millions) creates a serious problem of navigation. The user may easily lose a sense of direction and location (Conklin, 1987). Also supporting this conclusion are Valdez, Chignell and Glenn (1988) who find that an unstructured network of information can increase a sense of disorientation.

The *problem of cognitive overhead* in modern hypertext systems and WWW browsers is the user's difficulty of keeping track of the links experienced and available. As a user browses through hypertext learning about a particular topic, they encounter many links to distract them. At each link a mental operation must take place which evaluates whether this link is worthy of transversal. Perhaps even an additional operation takes place evaluating the actual meaning of the link. If a user decides to follow a link, they may become sidetracked forgetting their original topic and how to return to it. They could have two simultaneous, related trails through hyperspace which interest them and must decide how to juggle their time and cognitive resources. This dilemma causes the user to use additional effort and concentration than may ordinarily be required of them when using a traditional document (Conklin, 1987).

Elm and Woods (1985) provide an operational definition of getting lost in a hypertext environment, "[a] degraded user performance, that is, a decrease in the ability to extract the information needed to successfully perform domain tasks, [as opposed to] subjective feelings of being lost." They emphasize that when the user does not have a clear idea of their location or the relationships within a database, their efficiency on the system will decrease. This decrease in performance could be related to disorientation and cognitive overhead. A user may be forced to visit more links/pages or open more cards to find the information which they desire. In contrast they describe good spatial navigation by:

1. The ability to generate specific routes as the task demands require.
2. The ability to transverse or generate new routes as skillfully as familiar ones.
3. Orientation abilities, that is, the development of a concept of "here" in relation to other places.

Foss (1989) provides two additional paradigms which may characterize user's difficulties. The first is the Embedded Digression Problem. A user in a hypertext system may become so entangled in a web of links that they loose track of their place within the document. As the user goes deeper into the document, they begin to loose track of their digressions and thus become lost. Or, they may forget to go back and travel on a path which they had once planned before. The second problem is the Art Museum Phenomena. This is a learning problem where users have trouble developing an understanding of what has been viewed. Due to the nature of browsing itself, users tend to visit a large number of nodes, some of which may contain unfamiliar information. The users may never stop to fully observe or study the node and may later have trouble recalling the information seen or the places they have been. Another problem is what may be described as 'lack of closer.' Here, a user is unsure what portion of a network they have visited or is relevant (Shneiderman, 1987).

The problems mention represent true difficulties for the user. In a study by Nielsen and Lyngbaek (1989), 56% of the users reported being confused about their location in a document using a popular commercial hypertext system. Another series of studies demonstrated that participants were faster and more accurate using either text represented on paper or in a linear manner than on the computer (Edwards and Hardman, 1989; Leventhal et al; Mohageg, 1992).

Solutions/Navigational Help

The users of hypertext systems are provided with assistance to overcome several difficulties. This help may be thought of as coming in two forms. The interface of the browser or hypertext software may provide tools for navigation. The actual hypertext document or Web site may also provide navigational aid.

Browser Software

Applications that are used to view hypertext provide several tools and features which assist the user. World Wide Web client applications or browsers will primarily be discussed because of the recent emphasis placed upon making them usable to the general public. Some of the features serve a dual role, not only describing where a user has been, but allowing them to return.

Most browsers provide a visual cue to represent a link that has been previously visited. As a user encounters a page or node, the previously visited links will either be highlighted, underlined, or a different color than usual (Nielsen, 1995). Another method to help users is the ability to store a series of bookmarks. These bookmarks are generally accessible from the toolbar and provide the user a method to easily obtain the Web pages which interest them most. As opposed to retyping the URL or finding a page with an appropriate link, the user simply selects the destination from a displayed list. These functions may help ease cognitive overhead. The user is not faced with another decision (have I visited this link?) and they have their most popular sites a mouse-click away.

Another popular feature is the availability of history lists. These lists store the recent browsing history of the user and may be accessed through the menu or toolbar. The list visually displays the most recently visited pages at the top in Netscape Navigator. Mosaic places them at the bottom. The user is free to choose (click on) any item within the list to revisit the page. Because of this feature, the list does not necessarily contain all of the most recently visited pages. For example, if the user chooses a page on the list to go back to, all the items that they have visited since will be erased from the list. Thus, they begin rebuilding the list from that point forward (Cockburn and Jones, 1996).

The forward and back buttons work in conjunction with the history lists to provide navigational support. The forward button will take the user to the next item in the list (assuming they are in the middle and not the top). The back button will take the user to the previous page. In essence, the forward and back buttons move the user up and down the history list, but do not move them through a temporal ordering of the pages they have visited (Cockburn and Jones, 1996).

Usage of the back button has been shown to be the most popular form of navigation accounting for 42% of all page requests, discounting link selection (Catledge and Pitkow, 1995). However, Cockburn and Jones (1996) showed that users actually have an incorrect mental model of the functioning of the navigation buttons and history list. Through a usability study, subjects were asked to predict whether a previously visited page could be obtained by using the back button. Because the task required them to recall a page from the history list, the target page could not be revisited. Nonetheless, most subjects assumed it could. This implies a discrepancy between the user's mental model and the designer's system model which may add to the disorientation and cognitive overhead problems already present.

Hypertext Document

The authors of hypertext documents and Web sites may provide the user with additional navigational help not built into the browser. As previously discussed, a home page or a landmark node may assist the user in navigating a large space. Here the user may find an overview of the document or site in the form of a map or an index. This will provide the user with a starting point for navigation and help them to develop the framework of the site.

As the user travels through the site several other features may be of assistance. Every page may provide a link for the user to return to the home page. Also, links may be offered that will navigate to the next or previous pages in a series. The author may display a textural or graphical description of where the user is within the site. A table of contents could remain fixed on the screen by placing it within a frame. The user then has two frames on the screen, one containing the contents and the other displaying the current page. The table of contents would have hyperlinks attached to the descriptions, thus allowing the user navigational support.

Experimental Software

Some software used to ease navigation has not reached the commercial market. Most are in an experimental or definition stage where no formal user evaluations have been reported. One such example is the Navigational View Builder for visualizing hypermedia systems. It takes advantage of the landmark nodes to show context between them and other WWW nodes. Using a structural analysis technique it determines the importance of nodes through the system and their relationships to each other (Mukherjea and Foley, 1995).

Two other browser add-on programs build a graphical navigational tool as the user travels through hypertext. Webmap and WebNet present a 2D graphical map in the form of nodes (circles) and links (connecting lines). As the user transverses through the WWW, a map is built to demonstrate their paths. The user can then see a picture of their route and (with WebNet) other possible links available at their past and present locations. Users are free to click on the map which will return them to a previously visited location. The designers hope that these programs would ease some of the cognitive overhead associated with browsing (Domel, 1994; Cockburn and Jones, 1996).

Quantitative Assessments

Many factors affect users' performance with hypertext. Previous investigations have identified some of these areas empirically. Of particular interest are: (1) overview maps/index, (2) the size of the hypertext document, (3) the individual differences between users. Most studies use measures of efficiency and accuracy to determine the degree of difficulty in interacting with the system.

Overview Maps

Overview maps provide a representation of the hypertext system's structure. They allow the user to see beyond the current node and view a graphical or spatial representation of the entire network of nodes and links. Often the map is dynamic, changing as the user travels through the hypertext. This is necessary because to display the entire system (often thousands of nodes) would be too cluttered; instead perhaps only the closest nodes are displayed. Frank Halasz from Xerox believes all hypertext systems should provide an overview and has done so in his own system, NoteCards (Nielsen, 1995). Because the user now has a "map" of their environment, it may be assumed that some of the traditional problems would be alleviated. The presentation of a global view visually has been suggested to promote quick perception and understanding, allowing the user to easily move between documents (Gershon, 1996). In general, studies tend to support this hypothesis.

Webb and Kramer (1987) examined subjects' ability to find information within a hierarchical menu system. In their task, the time to find an item within the database was recorded. Although they did not use a hypertext system, their results are interesting because of the factors involved. Subjects presented with a spatial map describing the content performed better than those without. They also found that an analogy, which texturally explains the database, yielded the fastest results and assisted them the most in remembering the structure a day later. However, no post-hoc tests were presented which examined if the difference between the spatial map condition and the analogy were statistically significant. But they did suggest from practical observation that as the size of the database increases, the relative usefulness of a spatial map may decrease. An interaction was also discovered; as the amount of nodes the subjects had to search increased, a large difference in time could be seen between those who had no help (map and/or analogy) and those who did.

Another experiment explored navigational tools and the size of the hypertext system. Gupta and Gramopadhye (1995) developed a system in HyperCard to test users' ability to retrieve target information to answer questions. The time (efficiency) and the number of cards (accuracy) visited were recorded and analyzed. They used four different levels in their navigation tools factor: no aid, a map, an index, both a map and index. The map in this situation was in the form of a localized spatial map showing each card as a node in a tree structure. Users could interactively navigate with the map; by clicking on a node, they would be transported there. The navigational aid was only presented on the second trial. Users with the map or index showed the most significant improvement. Surprisingly, users with both aids did not perform as well perhaps indicating that it was too much of a strain on cognitive resources. Their findings related to the size of the system will be presented in the next section.

More information can be portrayed in a overview map than just the titles of the nodes and their relationships to each other. A study by Vora, Helander and Shalin found that labeling the links with a text description increases performance. These labeled links provided context information that semantically related the two nodes they connected. However, in a study by Stanton, Taylor and Tweedie (1992), the use of an overview map resulted in poorer performance, less use of the system, lower perceived control, and poorer development of cognitive maps. These findings seem to contradict much of the literature that implies maps will be of assistance. They claim that a navigational aid must be well designed and even if it is, it may increase cognitive overhead due to being another item the user must learn. They suggest that the nature of the task will determine if maps are appropriate. If learning and development of a cognitive map is important, then overview maps may reduce the need for users to actively construct their own. The small size of their system (42 cards) may be another reason why navigational aids were not as effective. This size may allow the user to easily form a mental model without the need of additional maps which may create too much of a cognitive burden.

Chen and Rada (1996) used a meta-analysis technique to combine the results of several experiments on hypertext. Seven studies showed that graphical map usage influences effectiveness (a medium-to-large combined effect size of r=.38). Effectiveness was a measure of both achievement scores and hypertext coverage. Only the factor, 'complexity of the tasks', had a greater effect size than maps. Three studies showed an effect for efficiency when using maps (a small-to-medium combined effect size of r=.28). The authors suggest that, "graphical maps appear to be necessary for users dealing with large and complex information structures and to be useful to resolve the problems of disorientation and high cognitive overhead."

Size of the Hypertext

The size of hypertext documents appears to play a role in their usability. Batra, et al; (1993) suggest that participants in their experiment did not experience disorientation due to the size of the hypertext they used. Only 40 nodes were used in their study, and they suggest that if users were placed in a middle of a much larger system their performance may decrease. Another study using 42 cards showed no performance increase using a navigational map, perhaps indicating that the usefulness of navigational aids may change with the size of the hypertext (Stanton, et al, 1992)

The previously mentioned study by Grupta and Gramopadhye (1995) examines the effect of size of the hypertext structure on users' performance. Their experiment consisted of four levels of navigational aid, two trials, and two stack sizes. The big stack had 77 cards and the small stack contained 37. Their findings are as follows:

1. The effectiveness of navigational aids is dependent on the size of the stack.
2. The map is more effective in reducing travelling time and is less sensitive to stack size. Perhaps due to the operation of the index (scrolling to find information), it is sensitive to the size of the stack. The index is more effective in reducing the total time for small stacks.
3. The index is equally beneficial in reducing the number of nodes visited for both the small and big stack. However, the map is more beneficial with stacks of smaller sizes in reducing the number of nodes visited.
4. User performance on both speed and accuracy measures degraded when both the index and the map were provided simultaneously. Subjects were inefficient in their usage of the tools.

The authors cite Zozma et al (1992) for an explanation of the varied performance. Their research showed navigational tools occasionally diminish performance when the user has insufficient domain knowledge or experience with the tool to take advantage of its capabilities.

Individual Differences

Individual differences are theorized to play a role in hypertext navigation. Certain people are predisposed to skills that may aid them. Logically, it would appear that a high level of spatial ability would be of assistance due to the graphical structure of hypertext systems. A system or navigational aid should take advantage of users' inherent abilities or try to accommodate for their lack of a particular ability.

A study by Vicente, Hayes and Williges (1987) is one such study that examined the individual differences of users. Although they used a search task within a text based hierarchical file system, the results would certainly be applicable to hypertext. They examined many different predictors for task performance, including: perceptual speed, spatial orientation/scanning/visualization, visual memory, vocabulary, reading rate, comprehension, demographic information, and cognitive style factors. Results showed that psychometric tests of vocabulary and spatial visualization were the best predictors. The spatial factor was the most influential; users with low spatial ability took on average twice as long to perform the task as those with high.

A second study examined the addition of a graphical interface that consisted of a partial map and an analog indicator of the current file. These features were added to help the users by creating a sense of visual momentum. This is a measure of the effort required to assimilate information across a series of displays. Continuous transitions between scenes contain information about one location with respect to the next and are thought to have high visual momentum. The results showed a performance increase for the graphical interface; however the performance difference between the high and low spatial groups remained constant (Vicente and Williges, 1988).

A study of information retrieval using a hypertext based help system also analyzed individual differences. A significant positive correlation was found between visualization ability and search efficiency. As well, users with higher visualization ability returned to the top of the information hierarchy less often, demonstrating that they had developed a superior mental model of the system (Campagnoni and Ehrlich, 1989). Another study examined the effects of age and cognitive ability as predictors of performance in information retrieval. Age has been demonstrated to be an important factor, while general cognitive ability was not. Spatial memory and logical reasoning scores were negatively correlated with response times (Westerman, Davies, Glendon, Stammers and Matthews, 1995).

Chen and Rada's (1996) meta-analysis study also examined the effect of the users' spatial ability when interacting with hypertext systems. Out of the three studies used, all showed that spatial ability in general increased the efficiency of interacting with hypertext. The combined effect size (r =0.45) was the largest of all the factors investigated, second only to the "complexity of the task." These results become particularly interesting when the prospect of three-dimensional overview maps is discussed.

Overview maps have been shown to ease cognitive overhead, however a new question arises when considering 3D maps: Will users who have low spatial ability suffer because of the extra cognitive work they would need to use such a map? Also, from a basic research standpoint, any investigation of individual differences could further the field of HCI by providing predicative power for future design decisions involving cognitive abilities of users (Dillon and Watson, 1996).

Multidimensional Maps

Emerging technologies have made 3D graphics available on standard personal computers. The ability to visualize a data space in three-dimensions provides a more true picture of the structure and a more efficient method of display. It has been argued that two-dimensional overview maps are inappropriate for hypertext navigation. The user sees a representation of a world that is 2D, however the underlying nodal network may be conceptually 3D (Stanton, Taylor, and Tweedie, 1992). Edwards and Hardman (1989) also agree stating that one-dimensional indexes may be inappropriate because the hypertext information is spatially based lending itself more towards a multidimensional map. They suggest that methods used in making the physical world memorable and navigable could be applied in a hypertext system to prevent the disorientation. Therefore, a review of some proposed experiments and software applications is presented.

Proposed Experiments

Several experimental designs and considerations have been published. To date, no follow up literature has demonstrated any results from the following author's ideas.

Rundus (1990) developed a platform for the study of user interfaces in two hypertext systems. The first had small data objects that could be used to represent a help system and the second was a larger, more heterogeneous collection of data objects. Two main areas of research were to be studied. The first involved the creation of a 3D interactive graphical interface. Several of the issues, which he had begun to consider, were:

1. How should a data object be graphically represented? In other words, what should its size, shape, and color be to convey information about the underlying object or node?
2. What content information is most important?
3. How should the relationships between the objects be represented?
4. What are the desirable reduced versions of objects which would be present in the distance or background?

The second area of research was exploring a method for providing a preview of the information to be found at particular nodes which the user may choose to follow. He hoped that these areas would support the user in browsing information that lacked structure.

Smith and Wilson (1993) developed a system to examine information retrieval in hypertext. They used HyperCard and Virtus Walkthrough as the 'engines', and data about their university department as an information base. They wished to compare two versus three-dimensional representations of information and the effect of spatial versus schematic representations. A spatial representation may be characterized by a placing of the nodes within space so that the distance and direction between them is meaningful. Schematic representations provide no such meanings. In their work, a graphical map was presented which showed the data structure on the same screen as the card with the hypertext. No empirical studies were conducted; however the following experimental factors/treatments can be credited to them:

1. 2D/Schematic: A graphical hierarchical structure in two dimensions where the nodes are squares and the links connecting them are the lines. A Web-like output resulted which is visually complex.
2. 2D/Spatial: A 2D floor plan is used. The floor plan represents their building through which information could be accessed by visiting the various rooms.
3. 3D/Schematic: A 3D representation was constructed showing the data structure's (hypertext's) hierarchy. Three-dimensional cubes represented the nodes. However, the tangled

links were removed.
4. 3D/Spatial: A virtual environment was constructed from the floor plan which users could navigate (walk) through to find information.

They claim the nature of the domain will dictate the type of interface necessary to aid navigation. For simple information systems, a 2D tool could suffice; however, as the information becomes more complex, a third dimension is necessary to allow full exploration and use of the system. They also predict that the adding of a third dimension will initially make navigation more difficult, but will improve consequent task performance and allow the user to explore the space more fully.

Software Applications

Various software applications have been developed to take advantage of three-dimensional graphical representations of information structures. SemNet was one of the first that used 3D to explore large knowledge bases (Fairchild, Poltrock, and Furnas, 1988). However, recently Xerox Palo Alto Research Center has been in the forefront of using 3D technologies for data visualization. Several of their ideas will be discussed first.

To view large information spaces, several tools have been developed. One of these, called Cone Trees, was developed at Xerox PARC. Although not created for hypertext systems, its usefulness as a graphical overview map should be considered. Cone Trees displays a hierarchical file structure as a three-dimensional cone. This format was used to maximize screen space and enable visualization of the entire structure. When the user selects a node, the cone is dynamically rotated so that the node may be viewed within its relationship to the neighboring hierarchy. It was hoped that the visual momentum contained within interactive animation would shift some of the user's cognitive load to the perceptual system. By showing the movement, a user could assimilate the relationship between the substructures without actively thinking about it (Robertson, Mackinlay and Card, 1991; Robertson, Card, and Mackinlay, 1993). If the cone were to simply jump into position, the user would not be easily be able to see how one location is related to another and become easily "lost."

Another possible software solution developed at Xerox PARC is the WebBook and the Web Forager. Once again, these programs use a 3D metaphor except they help with the organization of World Wide Web pages. The WebBook binds related HTML pages together into a book-like form allowing users to actually flip through them in an animated fashion. Here, the 3D graphics and interactive animation are used to provide the users with an idea of the relationships between the pages. It also allows a document lens to present a fisheye view of the collection. The entire concept seems to extend the Web browser's bookmark metaphor into allowing those marked pages to be grouped together in a visually book-like form. The Web Forager can group together the books and make searches more efficient. A collection of books or pages can be seen across a three-dimensional landscape where their size or nearness may represent relevance to the user's task or search. Although no empirical evaluations have been reported, it may be hypothesized that the added third dimension and new book metaphor may help the user to create a better understanding of the WWW (Card, Robertson, and York, 1996).

Silicon Graphic's FSN (File System Navigator) is another approach to visualizing a file structure in three dimensions. Files and directors are represented as 3D bars and platforms, respectively. Line paths connect them and may be used similar to a hyperlink. A file may be opened by clicking on its bar whose dimension and color indicate the size and age of the file. Users are then able to fly through the space to visit various directory sites. A similar interface to FSN, as shown in Figure 3, is the Harmony Information Landscape. This view is presented from the Harmony application which provides several different methods of information visualization including a local view of where the user is in a file system. Andrews (1995) believes it is a powerful tool to fight against the lost in hyperspace phenomena.

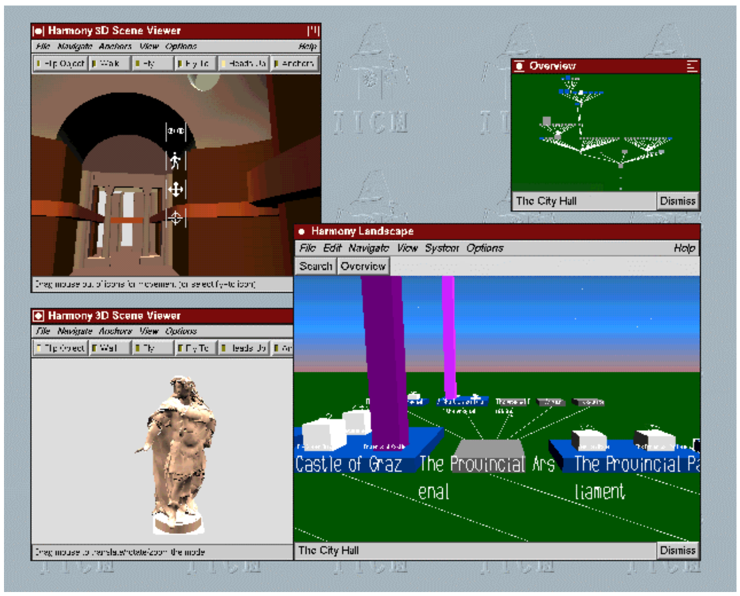

Figure 3. Harmony Information Landscape (Andrews, Kappe, and Maurer, 1995)

Apple Computer has also developed an application for navigating World Wide Web sites, known as "HotSauce". Pages are distributed in three dimensions as shown in Figure 4. The user can travel through the layout with the use of the mouse and keyboard, and clicking on a node will result in the page being displayed in the internet browser. Various topic nodes (the ovals) help organize the information, but are not linked to any actual pages. HotSauce can function as a stand-alone application or as a browser plug-in allowing it to be incorporated within a hypertext document. An animated movie of this application is shown in Appendix 8.

VRML (Virtual Reality Modeling Language) allows a Web author to model their site in three dimensions. Based on Silicon Graphic's Inventor, VRML files are ASCII documents transmitted through the internet. A special browser plug-in is needed to view and explore the three-dimensional environments. The author has the option of assigning links to any object within the virtual world. When a user selects a link they can be transported to another position within the world, another VRML file, or even back to a 2D hypertext site. Applications can be found in architecture, education, engineering, advertisement, entertainment, and any other category that can be modeled in 3D (Mohageg, Myers, Marrin, Kent, Mott, and Isaacs, 1996).

Because VRML is the standard for transmitting 3D information across the World Wide Web, its use as a navigational tool is being explored. One common use is to construct a three-dimensional room or city where the various objects contain links to other locations or documents (Intervista White Paper, 1997). A 3D bookmark generator (Bookmarks Exploring Dabbler) has also been developed. It reads a bookmark list from an internet browser such as Netscape, then constructs a representation of them in VRML using spheres to represent the nodes. The color and shape of the sphere represent the type of link destination (HTTP, FTP, Gopher, Telnet). The brightness and size of the sphere demonstrate the age of the link or when it was last accessed (Rezzonico and Thalmann, 1997).

Figure 4. Apple's HotSauce

Hughes (1995) discusses a combination HTML/VRML browser. It would consist of: two main display areas, one for the hypertext document and the other a 3D representation. It may also contain other navigational tools and messaging windows. The two different mediums would work in conjunction with each other; as a user navigates through space in one of the modes, the other responds accordingly with new information. These ideas have implications for the design of a navigation aid. An internet browser window can be split into sections by the use of a frame. Within the frames can be the hypertext document and a map. This map may be arranged in such a manner so as to be able to view the Web structure in a similar manner as a cone tree. The user would then be free to choose their navigational method - either the map, or the hypertext itself.

Many ingenious two-dimensional maps have also been developed. Of particular interest is the Hyperbolic Tree Browser as developed by Xerox PARC and implemented in Microsoft's Site Analyst product. The interface is displayed below in Figure 5 and in Appendix 8.

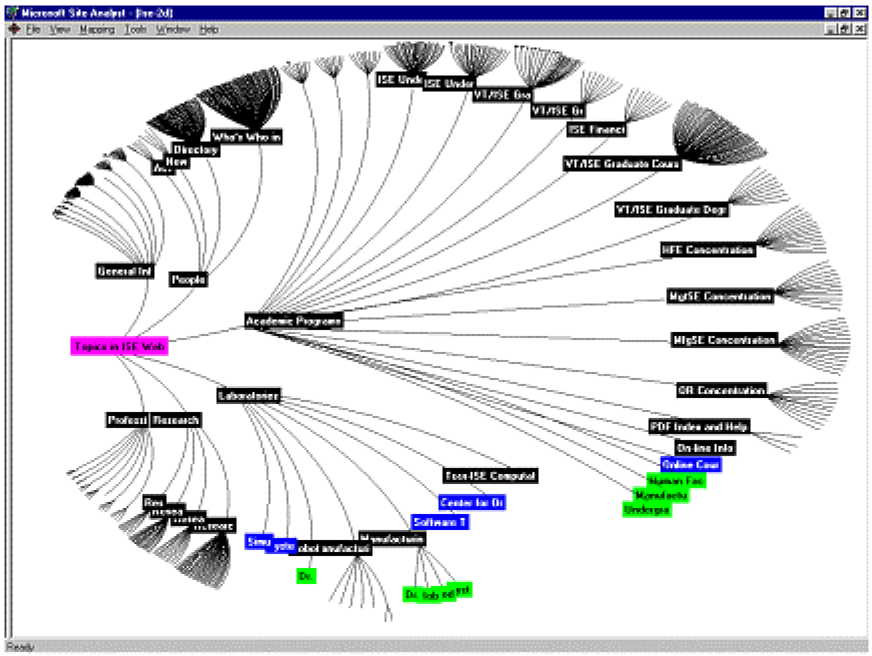

Figure 5. Microsoft's Site Analyst, A Hyberbolic-Type View

This is considered a "Focus+Context" view of an information space. In particular, the user can see the areas around their current position in great detail/focus. The more distant nodes are seen smaller, but the overall structure/context of the information is retained (Lamping, Roe, Pirolli, 1995).

Virtual libraries have been proposed as one application area of all these above technologies. In a system such as this, the individual books or journals may represent the nodes. Rogers, Cunningham and Holmes (1994) developed an interface for retrieving a file/document from a large collection similar to that of a library. It uses a 3D flying metaphor and was implemented in FSN. Assuming that the structure is somewhat hierarchical, for an elevated standpoint, the user can see the highest levels of the hierarchy. They are then able to zoom/fly down to more closely examine the next level. Here, buildings represent the documents/files. Characteristics (color, size…) about the buildings represent properties of the item such as its age or size. The authors performed no empirical evaluations to determine the usability of the system. They did suggest, however, that implementing a system such as this in virtual reality might enhance a user’s ability to interact with the system. It has also been suggested that systems such as Cone Trees or a Hyberbolic view could be used to visualize search results or queries. And that by moving the information sets across various visualization techniques, different attributes could become more apparent thus leading to a better understanding of the material (Rao, Pedersen, Hearst, Mackinlay, Card, Masinter, Halvorsen, and Robertson, 1995).

Navigational Aid Selection

Many factors are important to consider when choosing a navigational aid to use in an empirical study that aims to examine the differences between various levels of map multidimensionality. The feasibility of several different alternatives is investigated below.

The most complex aid (3D map) is discussed first. Two applications easily provide three-dimensional graphical navigation maps for personal computers, Apple's HotSauce and the VRML modeling language. Table 1 presents a list of advantages and disadvantages associated with each.

Table 1: Advantages and disadvantages of using different 3D navigational aids

Method	Advantages	Disadvantages
HotSauce	1. Runs on both PC and Macintosh platforms	1. Not absolutely three dimensional and interactive - the user cannot freely roam
	2. Text is very legible	2. Cannot be placed in a browser frame
	3. Maintains a straight/upright perspective and viewpoint	3. Cannot be used in other environments – such as the CAVE
	4. Simple code to develop (MCF: Meta-Content Format)	4. Motion can become jerky deep within the system
		5. No longer supported by Apple
VRML	1. Provides true 3D experience	1. VRML coding difficult to develop
	2. Runs of both PC and Macintosh platforms	2. Large virtual environments are memory intensive
	3. Can be placed in a frame	3. Text is fuzzy and illegible
	4. Most popular 3D scripting language for the WWW	4. Easy to get disorientated/lost
	5. All nodes are active	
	6. Complete control over color/shapes/sizes of the layout	

The HotSauce application is chosen as the 3D visualization method, as shown previously in Figure 4. Two reasons primarily motivate this decision. First, the coding is much simpler to develop as the program was intended for just this type of visualization. Second, the text descriptions on the various nodes are much more clearly visible than with VRML which has yet developed the ability to use TrueType fonts. Once again, this interface will allow the user to travel through the environment as they begin at the highest level and look down through the structure. Each node is labeled with a hypertext link or the title of the destination page. They are then free to either zoom in on a sub-node or click on the node to reveal the associated hypertext document. Because the navigation motion is smooth between levels, it is hoped that visual momentum will help the user understand the structure (Wickens, 1992).

The next aid is a two-dimensional overview map, which can be accomplished through several different methods. The entire hypertext structure could be drawn and presented to the user as an image-map in a similar (but much larger) representation as Figure 1. Or, the nodes could be placed in an HTML table. When the user selects a link from the table, another row is added via a CGI script showing the pages in the next sub-level. Finally, a new application from Microsoft, Site Analyst, could be used. The map presents the entire structure in a hyperbolic fisheye view as described previously. Table 2 describes some of the advantages and disadvantages of each representation.

Table 2: Advantages and disadvantages of different 2D graphical maps.

Method	Advantages	Disadvantages
Site Analyst	1. User can dynamically manipulate map	1. Cannot be put in HTML frame
	2. Actions in browser update map accordingly	2. Color coded nodes may be distracting
	3. Makes efficient use of screen space	3. Only works on Windows95
	4. Animation allows for visual momentum	
HTML Table	1. Can be displayed in frame	1. Does not display all the nodes at once
	2. Less clutter/easy to read	2. Development difficult
	3. Few computer memory problems	
Image-map	1. Displays all the nodes at once	1. Very large and cluttered – Significant scrolling required to examine different portions
	2. Can be displayed in a frame	2. Memory problem due to large image
		3. Development very difficult
		4. Static image display

Microsoft Site Analyst is chosen as the 2D graphical navigation map. Although primarily a tool to help Web masters visualize their site and any associated problems, it provides a unique navigational interface. The hyperbolic fisheye view is characterized by an efficient usage of screen space while still providing a sense of orientation within the structure. Only the closest nodes to one's current position are drawn in detail, as shown in Figure 5. The user may freely manipulate the map to reveal different sections by dragging various nodes. Clicking on a node places it in focus and renders the nearby nodes, while double-clicking will load the respective page in the browser window.

Finally, a one-dimensional index is examined. It is commonly used in hypertext navigation and is often present on a home page where an overview of the site is given. Or the information may be placed in a frame for constant reference. The index may be developed by placing the text in a standard HTML page, or the index capabilities of Site Analyst or HotSauce could be employed. Table 3 presents some of the advantages and disadvantages. Because the Site Analyst interface is already being used for the 2D map, it is chosen here as well. The index takes an outline form with each sub-level indented. The user is free to click on any text that will load the appropriate page. Plus/minus symbols in front of the text indicate that the particular branch may be expanded to reveal more pages in a sub-level. This index is shown in Figure 6 and Appendix 8, where it is seen open several levels deep within the hypertext hierarchy.

Table 3. Advantages and disadvantages of different (1D) index-type navigational aids.

Method	**Advantages**	**Disadvantages**
Site Analyst	1. Good interface mechanism (allows dynamic growth)	1. Oddly color-coded levels
	2. Actions in browser update index	2. Only works on Windows95
	3. All items in list are active	
	4. Integrates with other Site Analyst view (2D as discussed in Table 2)	
HotSauce	1. Provides additional navigation features ("Go to top of list")	1. Cannot be placed in a frame
	2. Integrates with HotSauce (3D as discussed in Table 1)	
	3. Good interface mechanism (allows dynamic growth)	2. Cannot click on topic items (inactive)
Standard HTML	1. Can be placed in a frame or in a separate window	1. Not dynamic (static – stays the same)
	2. Easily editable	2. The length would be unmanageably long.
	3. Provides for more designer control over color coding of levels	
	4. Runs on both platforms	

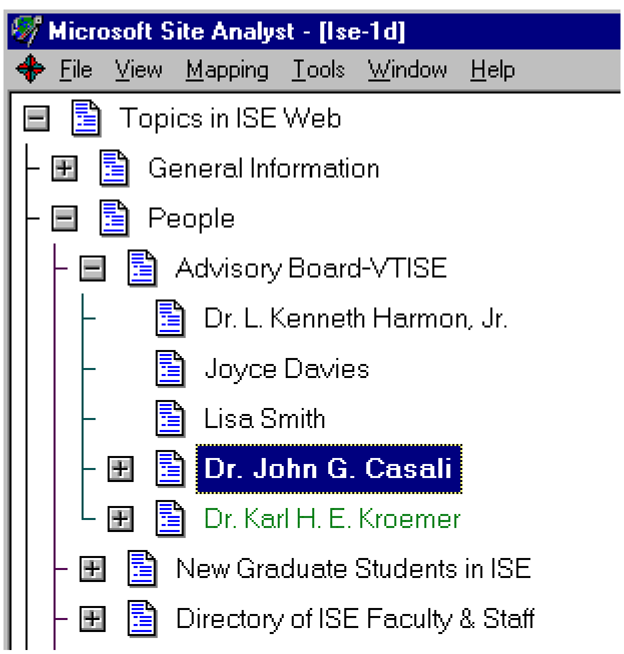

Figure 6. Portion of the One-Dimensional Navigational Aid: Microsoft Analyst ("Tree-View")

It should be noted that all of the navigational aids chosen in this study can be classified under Shneiderman's (1998) Data Type by Task Taxonomy for information retrieval and visualization, due to their hierarchical nature and presentation of nodes. When dealing with hypertext systems, the maps also allow the user to "overview first, zoom and filter, then [get] details on demand." This is seen by the fact that they all start with an overview or high-level depiction of the system. Then, the user can zoom in on a particular area or section, thus filtering out unnecessary items. Finally, they can select a particular node to get the details, or in this case, the actual Web pages.

Problem Statement

A literature review revealed the need for additional research into multidimensional navigational aids and their usefulness. "Few authors provide empirical evidence assessing the effectiveness of the [navigational] tools or comparing them. Research is needed that explores the roles of different tools, how well users can follow [the navigational tools], and which ones minimize user disorientation" (Zimmerman, Tipton, Bilsing, and Green, 1993). This research attempts to examine these issues.

The authors of hypertext systems or World Wide Web sites must provide an environment that will allow users to complete their tasks in the most efficient and accurate manner. Users of hypertext systems characteristically have problems of disorientation and cognitive overhead that reduce their performance. Overview maps have been shown to aid in navigation. However, there are many different forms of maps and new three-dimensional varieties that have not been extensively studied.

Hypertext systems frequently vary in size. The choice of navigational aid may depend on the type or size of the hypertext system being used. Previous research has shown performance differences in differently sized and structured hypertext systems, but provides no comparison with the effect of overview map.

Individual differences also affect how well a person can use a hypertext system. Performance differences have been shown to exist between people of differing cognitive capabilities such as spatial or verbal ability. What is unknown is if these differences may interact with the type of navigational aid or Web system.

Research Goals

The goals for this research are to:

1. Examine the effects of different overview maps that differ in their degree of dimensionality.
2. Examine if the hypertext system interacts with the type of overview map presented.
3. Determine if users' individual differences (spatial & verbal ability, visual memory) will predispose them to improved performance on a particular navigational aid.
4. Add to a series of hypertext guidelines by providing a set of partial set of conditions under which to apply certain overview maps.

Research Hypotheses

For the purpose of brevity, “performance” in this section refers to the amount of time and number of pages that a participant must access to complete a search task, as well as the total number of answers located. The research hypotheses for this study are:

1. A significant difference in performance exists between the various multidimensional navigational aids.
2. Post-hoc analysis will show that users are characterized by lower performance when finding information as the interface as more dimensions (1D, 2D to 3D).
3. A significant difference exists in performance when finding information in the large hypertext condition as compared with the small - with the small associated with better performance.
4. Subjects with higher spatial and verbal ability will outperform users with lower ability.
5. The better the subjects’ visual memory, the better their performance when relocating search items.
6. A significant interaction exists between the hypertext system and the type of navigational aid. As the size increases, navigational aids which better organize information (ones with more dimensionality), will result in better performance.
7. A significant interaction exists between subjects’ spatial ability and the type of navigational aid. A higher spatial ability will assist a subject when using a more complex navigation aid.

METHODOLOGY

Subjects

Twelve participants were recruited from Virginia Polytechnic Institute and State University and the surrounding Blacksburg community. They ranged in age between 19 and 63 years old with a median age of 20.5. Because of the nature of the task, any participant having experience with either the Industrial and Systems Engineering (ISE) Department or the Human Factors Engineering Center (HFEC) and their WWW sites was prevented from participating. This eliminated people who may have already begun to develop a cognitive map of the task environment. As such, Industrial Engineering majors were excluded from participating. A Bausch & Lomb Vision Tester was used to determine that the subjects were not near sighted or colorblind. Due to the task demands, only subjects with (corrected) 20/25 visual acuity were allowed to participate. Each subject was paid five dollars per hour to participate.

Experimental Design

A 3x2x2 within subject experimental design was used with three different factors: 1. Navigational aid (1D, 2D, and 3D) 2. Hypertext system (ISE and HFEC) 3. Trial (first and second). To eliminate the effect of learning, the presentation order of the navigational aids was completely counterbalanced as shown in Table 4. As well, half of the subjects always used the ISE site first; the other half always used the HFEC site first. Subjects were randomly assigned to a particular treatment combination upon arrival.

Table 4. Presentation Order of Treatments across Sessions

Subject Number	Age	Gender	WWW site used first	Map used in Day 1	Map used in Day 2	Map used in Day 3
1	19	F	ISE	1D	2D	3D
2	22	M	ISE	1D	3D	2D
3	21	M	ISE	2D	1D	3D
4	19	M	ISE	2D	3D	1D
5	63	M	ISE	3D	1D	2D
6	33	M	ISE	3D	2D	1D
7	19	M	HFEC	1D	2D	3D
8	19	M	HFEC	1D	3D	2D
9	51	F	HFEC	2D	1D	3D
10	20	F	HFEC	2D	3D	1D
11	33	M	HFEC	3D	1D	2D
12	20	F	HFEC	3D	2D	1D

Task Environment

Participants used a Gateway 2000, 200mHz Pentium PC with Windows95 and 32 megabytes of RAM. A 17-inch CRT display operating at 1280x1024 resolution displays the interface. The screen area was divided into three sections, as shown in Figure 7.

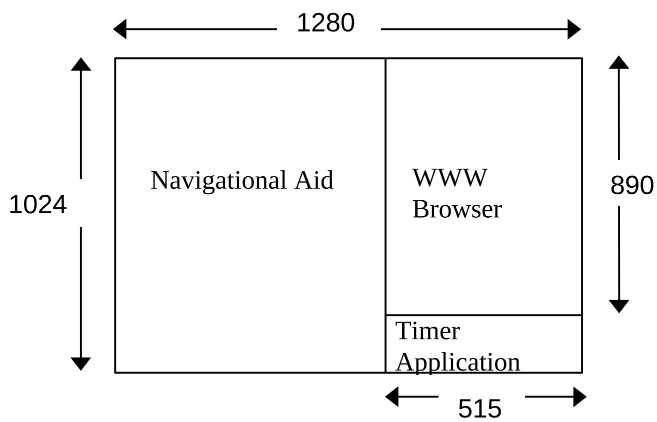

Figure 7. Configuration of Screen Layout.
(Pixel Measurements Displayed.)

This layout is very similar to that discussed by Hughes (1995) and many common internet sites today. Placing a navigational aid in the left portion of the window is a frequently used method to assist browsing and searching. Netscape Navigator, a standard internet browser, was placed in the top-right portion of the screen to display the hypertext document. When users click on an active section of the navigation aid, which contains a link, the browser window will respond accordingly and be updated with the newly requested page. The bottom-right portion of the window contains a timer application. This application, written in Microsoft Access and shown in Figure 8, presents the particular item that the subject must search for and will log their time by pressing buttons within the interface.

Figure 8. Question and Timer Application (shown with example question)

The search task question initially appears in a dialog box centered on the screen (but disappears after the participant begins searching) but remains in the Question and Timer Application. When the subject has located the answer to the question, they press the “Found Item” button which stops the timer the elapsed time is recorded into a database once the subject enters the correct search answer. The “Pause” button will pause the timer if a distraction is encountered. Appendix 2 contains a description of the interaction process in the form of instructions.

The room in which the study took place also contained a video camera that captured the computer monitor’s display. This setup, as well as the desk where all participants completed the cognitive tests, is shown in Figure 9. The camera was carefully focused so as not to capture a significant portion of the participant’s face. The CRT screen image was being primarily recorded. The signal from the camera was transmitted into an area outside of the experimentation room. From the removed vantage, the experimenter could observe the study as it progressed without having to distract the subject by their presence in the same room.

Figure 9. Picture of Experimental Setup from Camera's Vantage

Navigational Aid

Three different navigational aids make up the first independent variable. This factor seeks to examine the effect of map dimension on various search tasks. A one, two and three-dimensional navigational aid form the various levels of the factor. Figures 10, 11, and 12 present the navigational aids for each of the two different hypertext systems. Appendix 7 also contains larger versions of the same pictures. Each navigational aid was previously discussed in the Introduction section of this paper. These images represent screen snap-shops that also include the Navigator browser and the Question and Timer Application.

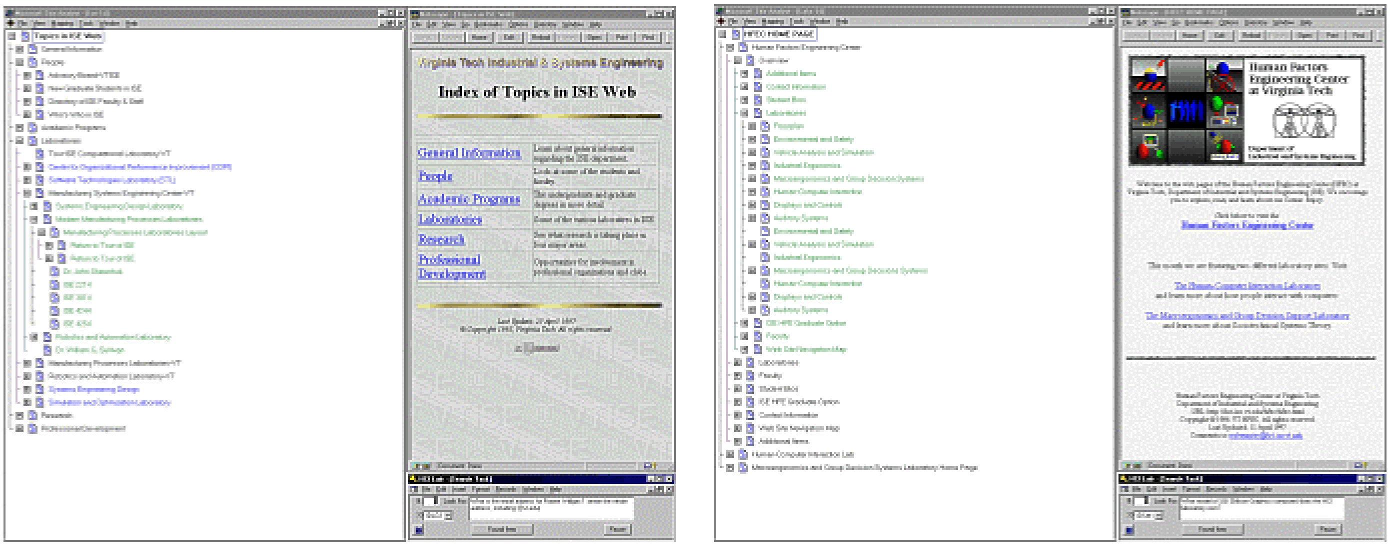

Figure 10. The One-Dimensional Navigational Aid: Microsoft Site Analyst in "Tree View" (Open several levels.)
(The image on the left and right display the ISE and the HFEC Web sites, respectively.)

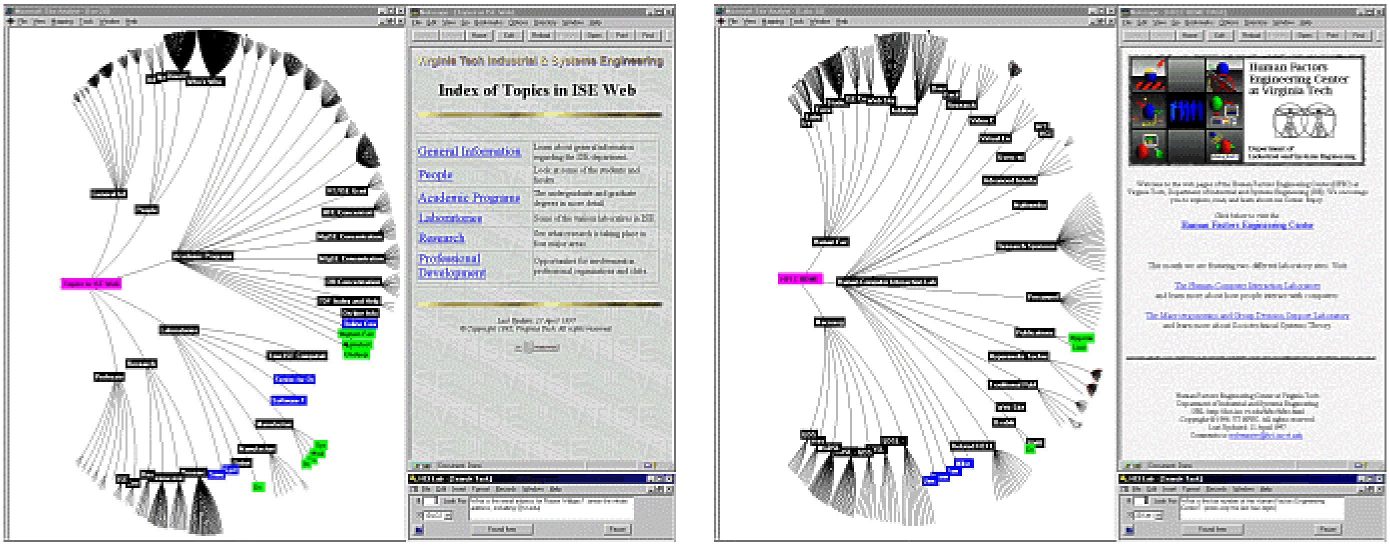

Figure 11. The Two-Dimensional Navigational Aid: Microsoft Site Analyst in "Cyberbolic View"
(The image on the left and right display the ISE and the HFEC Web sites, respectively.)

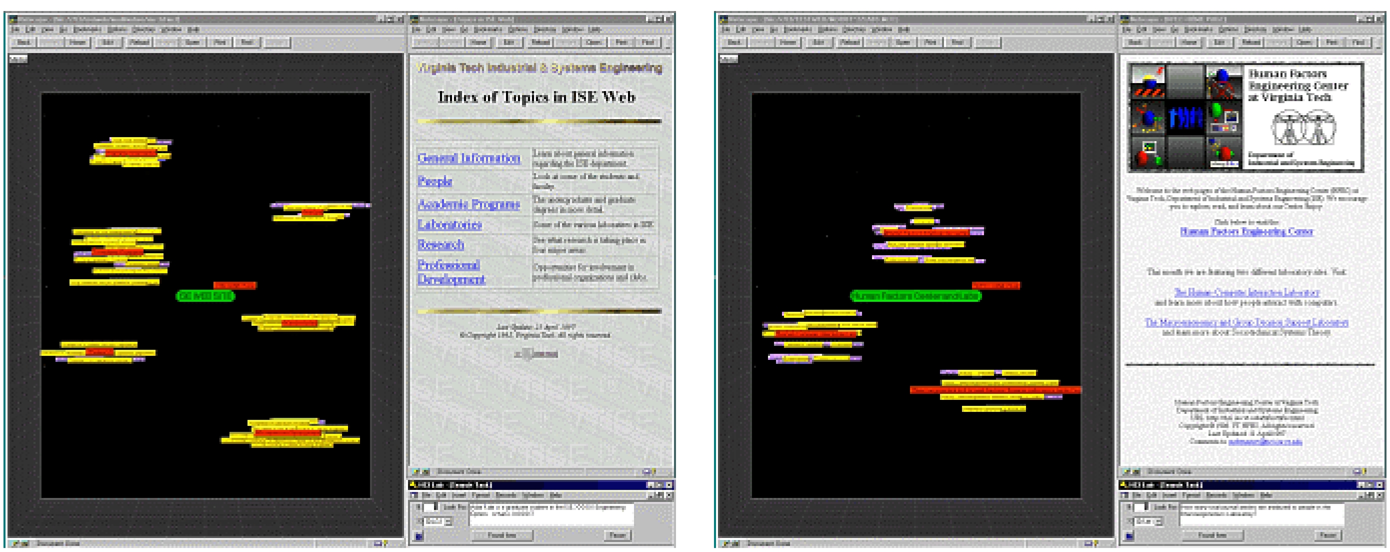

Figure 12. The Three-Dimensional Navigational Aid: Apple's HotSauce
(The image on the left and right display the ISE and the HFEC Web sites, respectively.)

Microsoft Site Analyst was used to help create each of the three graphical maps within the navigational aids. First, its automated Web spider would crawl through the hypertext system finding each page. It developed the structure of the system by examining how the pages link from one to the other.   After this process is complete, Site Analyst generated the 1D and 2D maps used in the study. At this point, the one-dimensional map was expanded to display all branches and the hierarchical view exported to standard HTML. A program was written to convert this HTML file into the Meta-Content Format (MCF) file necessary for use with the 3D HotSauce application. By doing so, it was ensured that all three maps contained exactly the same pages and in the same structure. Each node within the 3D map was then manually placed into position.

Hypertext System or Web Sites Used

Two different hypertext systems, the Industrial and Systems Engineering (ISE) Department and the Human Factors Engineering Center (HFEC) Web sites, were chosen for evaluation in the second factor. The former site was modified to create six grouping containing the major content areas of the site. The latter site was also modified to include the complete sites of the Virginia Tech Human-Computer Interaction Laboratory and the Macroergonomics and Group Decision Systems Laboratory. Links on the HFEC home page accessed these labs. All the sites can essentially be described as hierarchical which is the most common topology for hypertext systems. Each site was saved locally on the laboratory computer preventing problems resulting from changes to the site from outside sources or internet-access difficulties. It should again be noted that *these are not the exact same sites publicly available on the WWW.*

The two hypertext systems were chosen because they differed in content and organization, but especially due to the differences in size as outlined in Table 5.

Table 5. Overview of the ISE and HFEC Web systems.

Hypertext System	**Number of unique HTML pages.**	**Number of nodes displayed in maps.**
ISE Web site	260	1880
HFEC Web site	110	879

It can be observed that the ISE site has over twice as many unique individual Web pages as the HFEC site. The navigational aids displayed a anchor for every link exiting an HTML page up to a limiting point. The final branch/anchor may have links exiting it, but are not displayed in the navigational aid – this prevents the recursive nature of Web sites from creating a map that is infinitely large. Therefore, the complexity of the overview maps was really determined by the number of hyperlinks as they related on a one-to-one basis to the anchors displayed on the screen.

Cognitive Tests

Three cognitive tests were administered to the participants for use in a post-hoc blocking statistical procedure to examine the effects of individual differences. All exams were taken from the “Kit of Factor-Referenced Cognitive Tests” by Ekstrom, French, Harman and Dermen (1976). The first test, “Building Memory – MV-2,” required participants to remember the position of items on a street map for later recall. It was used to examine the level of visual memory for objects. The second test, “Extended Range Vocabulary Test – V-3,” required participants to determine synonyms for various words. This test examined the subject’s verbal ability and was chosen because it contains a range of items from easy to hard and is appropriate for the age group in question. The final test, “Paper Folding Test – VZ-2,” required subjects to visualize in their mind how a piece of paper may look after it has been folded and hole-punched. A sample question is shown in Figure 13. This test assessed the spatial ability of the subject and was used successfully before by Vicente (1987) in an examination of individual differences in file searching.

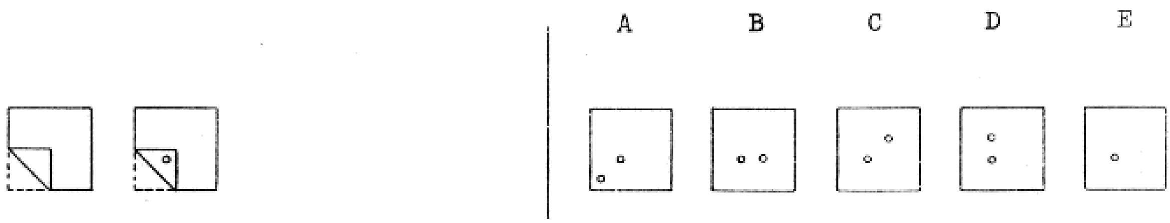

Figure 13. Example Question from the VZ-2. (Correct answer is “A”)

Procedure

The experiment was conducted in three sessions spread across three different days. Each day the participant used a different navigational aid as shown in Table 4. Only the first session included the cognitive tests and was longer than the others. Participants took on average 1.75 hours to complete the first session and 1.25 hours for the other two.

Participants who volunteered were first screened to ensure that they are neither Industrial and Systems Engineering students nor had knowledge of the particular WWW sites used. Participants arrived and were asked to fill out the informed consent form as found in Appendix 1. A vision acuity and color blindness test was then conducted to ensure they meet the criteria set forth.

The three cognitive tests were administered only during the first session. They were taken in the following order: (1) Building Memory, (2) Extended Range Vocabulary Test, and (3) Paper Folding Test. The experimenter would first ensure that the subject had no questions about the exam, but would then leave the room while the testing was taking place.

Once these preliminary investigations had finished, training for the actual experimental task would begin. Participants were given a copy of the “General Instructions” and the experimenter read them aloud. These as well as all other instructions are contained in Appendix 2. The general instructions explained the overall rules of the study that included the following:

- Participants were not to visit the study’s Web sites outside of the experimental setting until after they are finished with the third session.
- Participants would be required to search for the answers to questions within the Web sites. They must locate the actual page that contains the answer even if they remembered it from their first trial.

- Participants were not to click on any links within the browser window to open Web pages. This ensured that everyone used only the navigational aid to transverse through the sites.
- Participants were to inform the experimenter if they could not find an answer.

They were also cautioned on several issues. Because internal links (links which just point to a location further down the same page and not an external one) were not displayed in the navigational aid, participants were encouraged to use the browser scroll bar frequently. This would allow them to access information further down the same page.

Subjects were then exposed to training on the particular type of navigation aid used for that day and the Question and Timer Application (also found in Appendix 2). For each of these, an instruction sheet was provided highlighting the major features and functions of the application. The experimenter would review each of these with the participant to make sure they understood all of the issues. As well, the experimenter would demonstrate these concepts using the computer. The participants were again instructed to use only the navigational aid as a method of navigation, bypassing clicking links provided on the hypertext documents. Subjects were given as much time as they felt necessary to learn the interface and were allowed to use it following the experimenter's presentation. During this part of the training period, they were given three search tasks requiring them to find answers in a sample tutorial Web site. Anyone who exhibited difficulty was given additional assistance and training. No-one was allowed to move to the actual experimental task until both themselves and the experimenter felt comfortable with their abilities with the navigational aid. To further ensure that all subjects were on equal standing, a sheet of "Additional Tips" (also in Appendix 2) was reviewed which reiterated several of the rules and hints for the study.

Experimental Task

Subjects were presented the actual experimental platform, either the ISE or HFEC WWW site (depending on which they used first). They were given six search tasks which required them to find a particular piece of information within the hypertext system. All of the search tasks/questions are presented in Appendix 3. However, they generally follow the style, "What model of SGI computer does the HCI laboratory own?" – which required the subject to look for the answer "Indigo Extreme." The subject would follow these steps below within the experimental task:

1) Read the search task as displayed on the screen. It was presented in the form of a question to which they must find an answer. It is displayed in a dialog box in the center of the screen and in the Question and Timer Application.
2) After reading the question, pressing "OK" on the dialog box would make it disappear from the screen and start the timer.
3) The navigational tool would be used to open pages within the hypertext system until the answer is located.

4) Upon finding the page with the information, the “Found Item” button would be pressed on the Question and Timer Application recording the search time in the database.

5) The answer would be typed in the blank which would appear.

6) If your answer was correct, they were presented with the next search task.

7) If your answer was incorrect, they must resume the search (re-starts the timer).

After completing all six search tasks, participants were asked to fill out the “After-Task” survey which is contained in Appendix 4. This survey used Likert-type questions to gauge the subjects’ reaction to the search tasks most recently completed in terms of the usability and usefulness of the navigational aid. Next, the alternate Web site (ISE or HFEC) was presented and the above process repeated for six new questions on this Web site.

Following this process, the second trial would begin. Here, participants would repeat the exact same procedure as above. The search tasks and questions remained identical to the first trial. The only difference is that the participants have already located the answers approximately fifteen minutes prior. It is this before and after examination that is represented in the third independent variable.

On the second trial, the first question of the six was not included. Participants would be required to find that answer using the browser by itself without the assistance of any navigational aid. Also during this period at the end of the session, subjects were asked to estimate the sizes of the Web sites and provide some oral feedback regarding their experiences and strategies. They were told to make an educated guess regarding how many unique pages were in the Web site and not to count situations where more than one anchor pointed to the same HTML page as more than one individual page.

Each of the following sessions/days would follow a similar format. However, as previously stated, the participants were not required to complete the cognitive tests again. The “General Instructions” and the instructions to the Question and Timer Application were not presented again if the subject demonstrated that they remembered the information contained within. Going through the tutorial again with the new navigational aid but still following the same experimental protocol that was previously taught evidenced this knowledge. The experimental task questions were different for each navigational aid, and thus for each day. On the third and final day, participants were asked to fill out a “Final Survey.” This survey required them to rank order their preference in navigational aids and provides some qualitative feedback about the various devices. Also on the last day, participants were paid for their services.

As previously alluded to, each experimental session was videotaped. This was used as a backup recording for the experimenter and was erased for each new subject and session. During the experimental task, the experimenter manually recorded the number of pages that the subject needed to visit to find the answer to a question. If the experimenter had become distracted during the process, the videotape could be reviewed to collect the missing information or confirm questionable occurrences.

It should be noted that question difficulty was carefully balanced across all levels of navigational aid. The reason for this is to prevent any internal validity conflicts. If all the easy questions were used with the most complex navigational aid, and all the hard questions placed with the least complex navigational aid, then any statistical effect may be obscured. Results from pre-testing were used to assist in this purpose. First, questions were randomly distributed across various areas of the hypertext system and at given levels. Each treatment had four questions that could be found three levels deep and two that could be found four levels deep within the hypertext. After pretesting, the total numbers of pages needed to locate the answer were added together for each section and across subject. Questions were then shuffled such that each treatment combination had questions of equal levels of difficulty.

Dependent Variables

The dependent measures were primarily focused on assessing the level of orientation that the subject has achieved within the hypertext system. Time measures were taken, however to prevent any biases; other measures were taken which provided additional information. The number of visited pages needed to find the answer to a search task was recorded as well as the total number of search items located. The differences between the first and second trial were used to provide valuable information regarding the degree to which a cognitive map has been developed.

When performing the analysis, the first search task in the first trial (which was skipped in the second) will be discarded. It is felt that the participants may still be exhibiting a learning effect during this search task. The average amount of time and number of pages required to locate an answer was averaged for each experimental treatment but only for the items actually located. No record was kept of how many times participants typed in answers incorrectly. This was due to the fact that primarily spelling mistakes were made in typing which provide no useful information about the navigational aid.

Survey questions were developed for several different uses and all employed Likert-type scales for responses (all surveys are contained within Appendix 4). First, the preliminary survey was used to gauge participants' backgrounds; in particular, their computer experiences. It was thought that these items may correlate with other variables such as cognitive abilities. The 'After Task' survey gauged the subject's reaction to the most recently used navigational aid and Web site. Here, a variety of questions were chosen that related to the usability of the navigational aid. Both surveys contained a question regarding levels of disorientation experienced. This technique was previously found to be an appropriate measure of subjective levels of feeling 'lost' (Edwards and Hardman, 1989).

Summary of Methodology

A brief review of this section is listed below:

- Twelve subjects participated.
- A 3x2x2 within subject design was used with the following factors:
    - Navigational Aid (1D, 2D, and 3D)

- Hypertext System or Web Site (HFEC, ISE)
  - Trial (Before/First, After/Second)
- Three cognitive tests were administered to examine individual differences.
  - VM – Visual Memory
  - V3 – Verbal Ability (Vocabulary)
  - VZ-2 – Spatial Ability
- The experimental task required finding answers to questions within the hypertext system.
- Three dependent measures were taken:
  - Average time to complete all of the search tasks for a particular treatment combination.
  - Average number of pages visited when completing the search tasks.
  - Total number of items found or search tasks completed.
- Several surveys were administered to examine for the subjects' background and reaction to the various navigational aids.

RESULTS

The results from this study will be discussed in three separate phases. First, the primary analysis will be presented for each of the dependent measures used. Second, a post-hoc investigation of individual differences will be done for all three of the cognitive tests performed. Finally, results from the various surveys will be outlined.

Primary Analysis

All analysis were carried out at an alpha (α) level of .05 for both the primary and post-hoc investigations. If a p-value is less than α, then the null-hypothesis is rejected; the probability of incorrectly finding a statistically significant result is minimal. A priori analyses also display the Geisser-Greenhouse (G-Gp) and Huynh-Feldt (H-Fp) correction to the means. Table 6 presents the results from the dependent variable regarding the average amount of time required by the participants to locate the answer to the search tasks.

Table 6. ANOVA Summary Table for Average Time to Locate Answers

Source	**DF**	**SS**	**MS**	**F**	**p**	**G-Gp**	**H-Fp**
Between							
Subject (S)	11	211835.20	19257.70				
Within							
Navigation Aid (A)	2	1341.10	670.60	0.190	0.827	0.746	0.767
A x S	22	76861.90	3493.70				
Web Site (W)	1	41349.00	41349.00	11.500	0.006	0.006	0.006 **
W x S	11	39551.90	3595.60				
Trial (T)	1	170195.20	170195.20	164.560	0.000	0.000	0.000 ***
T x S	11	11376.50	1034.20				
A x W	2	20806.00	10403.00	3.980	0.033	0.036	0.033 *
A x W x S	22	57504.50	2613.80				
A x T	2	1795.60	897.80	0.540	0.587	0.543	0.563
A x T x S	22	36243.50	1647.40				
W x T	1	7946.70	7946.70	4.460	0.058	0.058	0.058
W x T x S	11	19596.50	1781.50				
A x W x T	2	6311.90	3156.00	1.890	0.175	0.177	0.175
A x W x T x S	22	36787.20	1672.10				
Total	143	739502.70	269714.30				

Denotation: * p<.05, ** p<.01, *** p<.001

DF: Degrees of Freedom, SS: Sum of Squares, MS: Mean Square, F: F-Ration, p: p-value

At an α=.05 significance level, there is sufficient evidence (p=.006) to reject the null hypothesis that there is no difference in the average time required to find the answers for the two hypertext systems or Web sites. The mean times and standard deviations for the Web site factor are presented in Table 7. It took over 40% longer to find information in the HFEC site as opposed to the ISE site.

At an α=.05 significance level, there is sufficient evidence (p=.000) to reject the null hypothesis that there is no difference in the average time required to find the answers between the before and after trials. The mean times and standard deviations for the trial factor are presented in Table 7. Participants were able to find answers almost twice as fast during the second trial.

Table 7. Listing of Means and Standard Deviations ($\bar{x}$, s) for the Web Site and Trial Factors

	Web Site Factor		**Trial Factor**	
Dependent Variable	**HFEC**	**ISE**	**Before/First**	**After/Second**
Search Time (sec)	110.80, 54.69	76.91, 72.72	128.24, 70.58	59.48, 55.11
Number of Pages	4.084, 2.490	2.715, 1.462	4.155, 2.217	2.644, 1.899
Total Items Found	4.4861, .5812	4.9167, .3658	4.722, .5097	4.681, .5522

Note: Pairs are not significantly different in all analyses. Refer to text for details.

A significant interaction (p=.033) existed between the navigational aid and Web site factors. Figure 14 plots this effect. A Newman-Keuls analysis on the treatment pairs at an α of .05 yielded several results. No significant differences were found between the different navigational aids within the ISE Web site. However, within the HFEC site, the three-dimensional navigational aid provided significantly shorter search times than the one or two-dimensional maps.

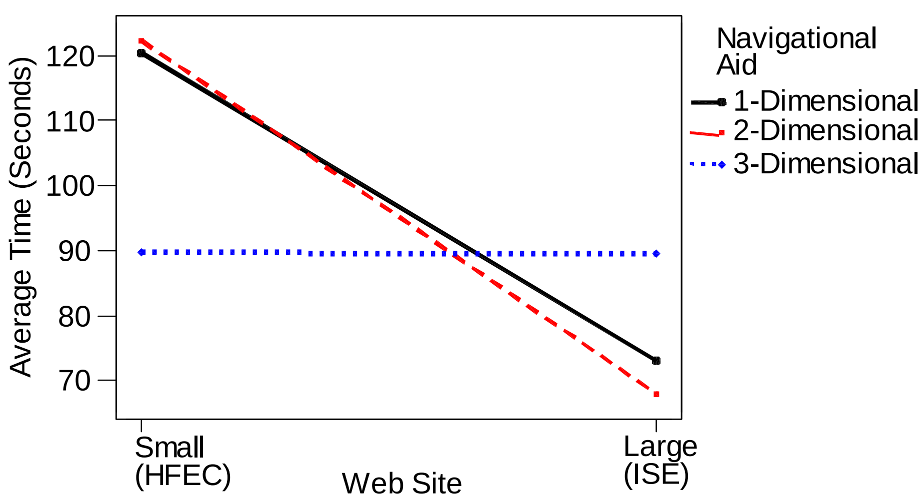

Figure 14. Interaction of Navigational Aid and Web Site for Search Time

Table 8 presents the results from the dependent variable which consisted of the average number pages subjects visited to locate the answer.

Table 8. ANOVA Summary Table for Average Pages Visited

Source	DF	SS	MS	F	p	G-Gp	H-Fp
Between							
Subject (S)	11	131.50	11.95				
Within							
Navigation Aid (A)	2	0.34	0.17	0.030	0.968	0.949	0.965
A x S	22	118.07	5.37				
Web Site (W)	1	67.49	67.49	23.350	0.001	0.001	0.001 **
W x S	11	31.80	2.89				
Trial (T)	1	82.23	82.23	25.450	0.000	0.000	0.000 ***
T x S	11	35.53	3.23				
A x W	2	11.69	5.85	2.010	0.158	0.162	0.158
A x W x S	22	63.90	2.90				
A x T	2	9.50	4.75	2.870	0.078	0.085	0.078
A x T x S	22	36.42	1.66				
W x T	1	10.16	10.16	4.710	0.053	0.053	0.053
W x T x S	11	23.71	2.16				
A x W x T	2	3.55	1.77	1.160	0.331	0.330	0.331
A x W x T x S	22	33.57	1.53				
Total	143	659.47	204.11				

At an α=.05 significance level, there is sufficient evidence (p=.001) to reject the null hypothesis that there is no difference in the average pages required to find the answers for the two hypertext systems or Web sites. Table 7 also displays the mean and standard deviations for the amount of pages required between the levels of the Web site factor. To locate the answers, the HFEC site required approximately 50% more page visits than the ISE site.

At an α=.05 significance level, there is sufficient evidence (p=.000) to reject the null hypothesis that there is no difference in the average number of pages required to find the answers between the before and after trials. The second trial resulted in much improved performance as shown by the means in Table 7. No other significant effects were discovered.

Table 9 presents the results from the dependent variable that consisted of the total number of answers found to the search tasks.

Table 9. ANOVA Summary Table for Total Items Found

Source	DF	SS	MS	F	p	G-Gp	H-Fp
Between							
Subject (S)	11	14.08	1.28				
Within							
Navigation Aid (A)	2	1.01	0.51	1.920	0.171	0.188	0.186
A x S	22	5.82	0.26				
Web Site (W)	1	6.67	6.67	11.760	0.006	0.006	0.006 **
W x S	11	6.24	0.57				
Trial (T)	1	0.06	0.06	3.670	0.082	0.082	0.082
T x S	11	0.19	0.02				
A x W	2	0.18	0.09	0.430	0.658	0.582	0.598
A x W x S	22	4.65	0.21				
A x T	2	0.04	0.02	1.000	0.384	0.363	0.370
A x T x S	22	0.46	0.02				
W x T	1	0.06	0.06	3.670	0.082	0.082	0.082
W x T x S	11	0.19	0.02				
A x W x T	2	0.04	0.02	1.000	0.384	0.363	0.370
A x W x T x S	22	0.46	0.02				
Total	143	40.16	9.84				

At an α=.05 significance level, there is sufficient evidence (p=.006) to reject the null hypothesis that there is no difference in the total number of answers found for the two hypertext systems or Web sites. Table 7 displays the means and standard deviations for the Web site factor while considering the total number of items found. No other significant differences were observed.

Investigation of Individual Differences

The three cognitive tests which participants undertook provided a method to examine the effects of individual differences on the performance measures. A post-hoc blocking procedure is used where a fourth factor is created which represents the cognitive ability. On the basis of their test scores, subjects are categorized into one of the levels of this new factor. The ANOVA is performed again, this time as a mixed-factor design to account for the new factor.

Visual Memory

Subjects were assigned to groups by looking at naturally occurring breakpoints within their scores on the MV-2 test. Therefore, three groups were created which consisted of the following visual memory abilities: Low (scores: 12.75, 14.5, 15.25), Middle (scores: 16.5, 16.5, 16.5, 16.5), and High (scores: 19, 19, 20.25, 20.25, 22.75). The average score was 17.5 out of 24. Please note that this is the only set of analyses which the treatment cell sizes are unequal in statistical procedures. This was due to the clustering of scores found in the middle group. Table 10 presents a new analysis for average time, which now contains the new three-level visual memory factor.

Table 10. ANOVA Summary Table for Average Time to Locate Answers (Including Memory Factor)

Source	DF	SS	MS	F	p
Between					
Visual Memory (M)	2	30108.30	15054.10	0.750	0.502
S/M	9	181726.90	20191.90		
Within					
Navigation Aid (A)	2	1328.90	664.50	0.180	0.835
A x M	4	11378.30	2844.60	0.780	0.552
A X S/M	18	65483.70	3638.00		
Web Site (W)	1	41002.30	41002.30	9.650	0.013 **
W x M	2	1297.20	648.60	0.150	0.861
W x S/M	9	38254.60	4250.50		
Trial (T)	1	168595.20	168595.20	3.750	0.000 ***
T x M	2	1507.60	753.80	0.690	0.527
T x S/M	9	9868.90	1096.50		
A x W	2	17191.30	8595.60	4.970	0.019 *
A x W x M	4	26354.20	6588.60	3.810	0.021 *
A x W x S/M	18	31150.20	1730.60		
A x T	2	652.70	326.30	0.220	0.805
A x T x M	4	9452.80	2363.20	1.590	0.221
A x T x S/M	18	26790.70	1488.40		
W x T	1	5379.40	5379.40	3.600	0.090
W x T x M	2	6133.60	3066.80	2.050	0.185
W x T x S/M	9	13462.90	1495.90		
A x W x T	2	6758.30	3379.20	2.680	0.096
A x W x T x M	4	14091.40	3522.80	2.790	0.058
A x W x T x S/M	18	22695.80	1260.90		
Total	143	730665.20	297937.70		

Again, significant differences were observed within the Web site main effect (p=.013) and the trial main effect (p=.000) whose respective means are displayed in Table 7. A navigational aid by Web site interaction (p=.019) was also significant and another Newman-Keuls analysis on the treatment pairs was performed at an α of .05. No differences were observed between the one and two-dimensional navigational aids. However, the three-dimensional navigational aid provided quicker search times when using the HFEC site, but slower search times when using the ISE site. Additionally, a significant (p=.021) three-way interaction was observed between navigational aid, Web site, and visual memory. An adjusted

Bonferroni t Test was used to examine for significant unconfounded comparisons in this interaction at an α of .05. The resulting significantly different paired comparisons are shown in Appendix 6 for this interaction. Due to the infrequency which third and higher order interactions are significant in behavioral research, this result may be considered a statistical artifact. However, no other effects involving visual memory were observed.

Table 11 presents a new analysis for average number of pages which now contains the new three level visual memory factor.

Table 11. ANOVA Summary Table for Average Number of Pages to Locate Answers (Including Memory Factor)

Source	**DF**	**SS**	**MS**	**F**	**p**
Between					
Visual Memory (M)	2	38.06	19.03	1.830	0.215
S/M	9	93.44	10.38		
Within					
Navigation Aid (A)	2	0.22	0.11	0.020	0.981
A x M	4	13.79	3.45	0.600	0.671
A X S/M	18	104.28	5.79		
Web Site (W)	1	69.46	69.46	1.090	0.001 **
W x M	2	2.16	1.08	0.330	0.729
W x S/M	9	29.64	3.29		
Trial (T)	1	79.30	79.30	0.470	0.001 **
T x M	2	0.67	0.34	0.090	0.917
T x S/M	9	34.86	3.87		
A x W	2	9.47	4.73	2.120	0.149
A x W x M	4	23.79	5.95	2.670	0.066
A x W x S/M	18	40.11	2.23		
A x T	2	8.65	4.33	2.400	0.119
A x T x M	4	4.04	1.01	0.560	0.694
A x T x S/M	18	32.39	1.80		
W x T	1	7.54	7.54	3.770	0.084
W x T x M	2	5.73	2.86	1.430	0.288
W x T x S/M	9	17.99	2.00		
A x W x T	2	5.58	2.79	2.760	0.090
A x W x T x M	4	15.41	3.85	3.820	0.020 **
A x W x T x S/M	18	18.16	1.01		
Total	143	654.72	236.20		

Web site and trial were again significant main effects (p=.001 for both), with their means shown in Table 7. However, a four-way interaction also was significant (p=.020) involving all of the factors. Again, an adjusted Bonferroni t Test was used to examine for significant unconfounded comparisons in this interaction at an α of .05. The resulting significantly different paired comparisons are shown in Appendix 6 for this four-way interaction. Again, this result is not discussed further because it is likely a not statistically relevant.

Table 12 presents an analysis of the number of answers found. Again, Web site and trial are significant (means shown in Table 7) but no effect concerning visual memory was.

Table 12. ANOVA Summary Table for Total Items Found (Including Memory Factor)

Source	DF	SS	MS	F	p
Between					
Visual Memory (M)	2	3.70	1.85	1.610	0.253
S/M	9	10.37	1.15		
Within					
Navigation Aid (A)	2	1.11	0.56	1.770	0.199
A x M	4	0.18	0.04	0.140	0.965
A X S/M	18	5.64	0.31		
Web Site (W)	1	6.75	6.75	0.650	0.010 *
W x M	2	0.54	0.27	0.420	0.667
W x S/M	9	5.71	0.63		
Trial (T)	1	0.08	0.08	5.880	0.038 *
T x M	2	0.07	0.03	2.400	0.146
T x S/M	9	0.12	0.01		
A x W	2	0.17	0.09	0.430	0.656
A x W x M	4	1.01	0.25	1.250	0.327
A x W x S/M	18	3.64	0.20		
A x T	2	0.05	0.02	1.010	0.382
A x T x M	4	0.05	0.01	0.520	0.724
A x T x S/M	18	0.41	0.02		
W x T	1	0.08	0.08	5.880	0.038 *
W x T x M	2	0.07	0.03	2.400	0.146
W x T x S/M	9	0.12	0.01		
A x W x T	2	0.05	0.02	1.010	0.382
A x W x T x M	4	0.05	0.01	0.520	0.724
A x W x T x S/M	18	0.41	0.02		
Total	143	40.37	12.48		

A significant (p=.038) Web site by trial interaction was also discovered and is displayed in Figure 15. A Newman-Keuls analysis on the treatment pairs was performed at an α of .05 to investigate this effect. Participants found significantly fewer items in the HFEC web site during the second trial than the first. However, no significant differences were discovered between trials for the larger, ISE site.

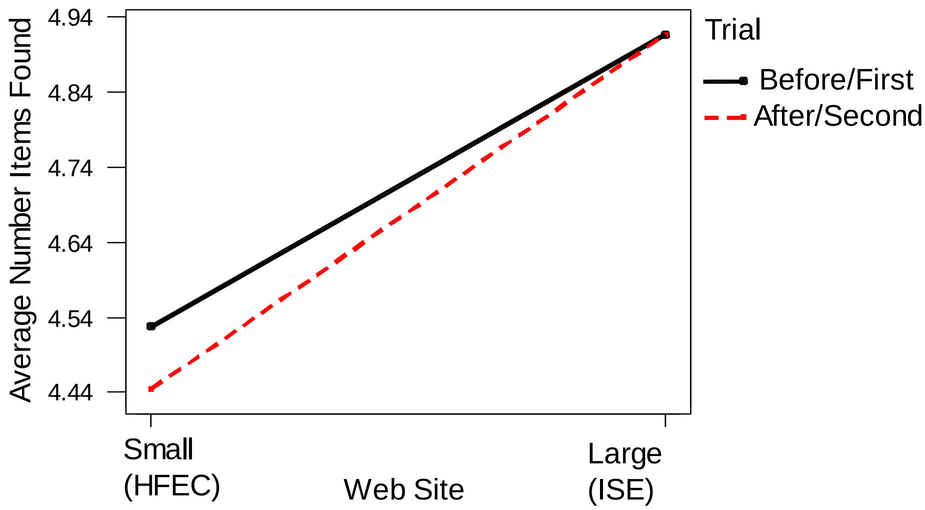

Figure 15. Interaction of Web Site and Trial for Total Items Found

Verbal Ability

These subjects were assigned to groups by using their V-3 scores and separating them into three equal-sized groups. Three groups consisted of the following verbal abilities: Low (scores: 9.25, 14.25, 15.5, 15), Middle (scores: 18.5, 20.5, 20.5, 30.5), and High (scores: 31.25, 38.5, 40.5, 41.75). The average score was 24.6 out of 48. Table 12 presents a new analysis for average time which now contains the new three-level verbal ability factor.

At an α=.05 significance level, there is sufficient evidence (p=.040) to reject the null hypothesis that there is no difference in the average time required to find the answers for people of different verbal abilities. People in the low verbal ability group spent on average 132.1 seconds (87.7 second st. dev.), people in the middle group spent 69.26 seconds (50.24 second st. dev.), and people in the high group spent 80.24 seconds (56.67 second st. dev.) as shown in Figure 16. However, a Newman-Keuls analysis at α=.05 showed that significant differences only existed between the low and the other two groups. No significant differences existed between the middle and high groups. A significant (p=.028) interaction between navigational aid and Web site was also found. Newman-Keuls analysis again showed no differences between the one and two-dimensional navigational aids. However, the three-dimensional navigational aid provided significantly ($p<.05$) quicker search times when using the small/HFEC site, but slower search times when using the large/ISE site and the two-dimensional navigational aid.

Table 13. ANOVA Summary Table for Average Time to Locate Answers (Including Verbal Factor)

Source	DF	SS	MS	F	p
Between					
Verbal Ability (V)	2	108025.30	54012.70	4.680	0.040 *
S/V	9	103809.80	11534.40		
Within					
Navigation Aid (A)	2	1341.10	670.60	0.170	0.845
A x V	4	5616.50	1404.10	0.350	0.837
A X S/V	18	71245.40	3958.10		
Web Site (W)	1	41349.00	41349.00	9.710	0.012 **
W x V	2	1217.00	608.50	0.140	0.869
W x S/V	9	38334.90	4259.40		
Trial (T)	1	170195.20	170195.20	2.160	0.000 ***
T x V	2	601.60	300.80	0.250	0.783
T x S/V	9	10774.80	1197.20		
A x W	2	20806.00	10403.00	4.400	0.028 *
A x W x V	4	14940.20	3735.00	1.580	0.223
A x W x S/V	18	42564.30	2364.70		
A x T	2	1795.60	897.80	0.530	0.596
A x T x V	4	5867.90	1467.00	0.870	0.501
A x T x S/V	18	30375.60	1687.50		
W x T	1	7946.70	7946.70	4.320	0.067
W x T x V	2	3048.00	1524.00	0.830	0.467
W x T x S/V	9	16548.50	1838.70		
A x W x T	2	6311.90	3156.00	2.100	0.152
A x W x T x V	4	9715.20	2428.80	1.610	0.214
A x W x T x S/V	18	27072.00	1504.00		
Total	143	739502.50	328443.20		

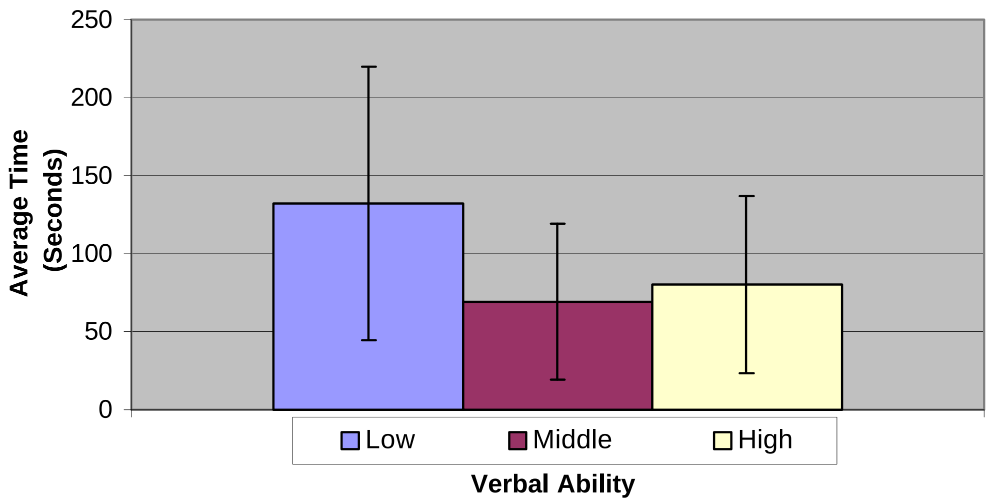

Figure 16. Average Time to Locate Answers for Different Verbal Ability Groups

Table 14 presents another analysis with the verbal factor for the average number of pages needed to locate an answer.

Table 14. ANOVA Summary Table for Average Number of Pages to Locate Answers (Including Verbal Factor)

Source	DF	SS	MS	F	p
Between					
Verbal Ability (V)	2	43.19	21.59	2.200	0.167
S/V	9	88.31	9.81		
Within					
Navigation Aid (A)	2	0.34	0.17	0.030	0.973
A x V	4	5.31	1.33	0.210	0.928
A X S/V	18	112.75	6.26		
Web Site (W)	1	67.49	67.49	9.280	0.002 **
W x V	2	0.29	0.15	0.040	0.960
W x S/V	9	31.51	3.50		
Trial (T)	1	82.23	82.23	7.760	0.001 **
T x V	2	8.87	4.44	1.500	0.274
T x S/V	9	26.66	2.96		
A x W	2	11.69	5.85	1.840	0.188
A x W x V	4	6.69	1.67	0.530	0.718
A x W x S/V	18	57.21	3.18		
A x T	2	9.50	4.75	2.850	0.084
A x T x V	4	6.37	1.59	0.950	0.456
A x T x S/V	18	30.05	1.67		
W x T	1	10.16	10.16	4.590	0.061
W x T x V	2	3.81	1.90	0.860	0.455
W x T x S/V	9	19.91	2.21		
A x W x T	2	3.55	1.77	1.370	0.278
A x W x T x V	4	10.34	2.58	2.000	0.137
A x W x T x S/V	18	23.23	1.29		
Total	143	659.47	238.57		

Neither the analysis in Table 14 or the one following in Table 15 regarding total answers found display the same significant effect for verbal ability as was previously demonstrated. They do however, display the same significant effect for Web site differences and the former displays an effect for the trial factor. These means are illustrated in Table 7.

Table 15. ANOVA Summary Table for Items Found (Including Verbal Factor)

Source	DF	SS	MS	F	p
Between					
Verbal Ability (V)	2	2.06	1.03	0.770	0.491
S/V	9	12.02	1.34		
Within					
Navigation Aid (A)	2	1.01	0.51	1.900	0.178
A x V	4	1.03	0.26	0.970	0.450
A X S/V	18	4.79	0.27		
Web Site (W)	1	6.67	6.67	0.880	0.009 **
W x V	2	0.72	0.36	0.590	0.575
W x S/V	9	5.52	0.61		
Trial (T)	1	0.06	0.06	3.000	0.117
T x V	2	0.00	0.00	0.000	1.000
T x S/V	9	0.19	0.02		
A x W	2	0.18	0.09	0.380	0.690
A x W x V	4	0.36	0.09	0.380	0.821
A x W x S/V	18	4.29	0.24		
A x T	2	0.04	0.02	1.000	0.387
A x T x V	4	0.08	0.02	1.000	0.433
A x T x S/V	18	0.38	0.02		
W x T	1	0.06	0.06	3.000	0.117
W x T x V	2	0.00	0.00	0.000	1.000
W x T x S/V	9	0.19	0.02		
A x W x T	2	0.04	0.02	1.000	0.387
A x W x T x V	4	0.08	0.02	1.000	0.433
A x W x T x S/V	18	0.38	0.02		
Total	143	40.16	11.75		

Spatial Ability

These subjects were assigned to groups by using their VZ-2 scores and separating them into two equal sized groups. Two groups consisted of the following verbal abilities: Low (scores: 2, 6.5, 10.75, 12.75, 14.75, 15), and High (scores: 15.5, 16.75, 17, 17.75, 18.75, 19). The average score was 13.9 out of 20. Table 16 presents a new analysis for average time which now contains the new two-level spatial ability factor.

Table 16. ANOVA Summary Table for Average Time to Locate Answers (Including Spatial Factor)

Source	DF	SS	MS	F	p
Between					
Spatial Ability (Z)	1	18229.50	18229.50	0.940	0.355
S/Z	10	193605.70	19360.60		
Within					
Navigation Aid (A)	2	1341.10	670.60	0.180	0.837
A x Z	2	1929.80	964.90	0.260	0.775
A X S/Z	20	74932.20	3746.60		
Web Site (W)	1	41349.00	41349.00	0.480	0.009 **
W x Z	1	99.10	99.10	0.030	0.877
W x S/Z	10	39452.80	3945.30		
Trial (T)	1	170195.20	170195.20	7.900	0.000 ***
T x Z	1	598.10	598.10	0.550	0.473
T x S/Z	10	10778.40	1077.80		
A x W	2	20806.00	10403.00	3.630	0.045 *
A x W x Z	2	229.30	114.60	0.040	0.961
A x W x S/Z	20	57275.20	2863.80		
A x T	2	1795.60	897.80	0.570	0.575
A x T x Z	2	4734.00	2367.00	1.500	0.247
A x T x S/Z	20	31509.50	1575.50		
W x T	1	7946.70	7946.70	5.140	0.047 *
W x T x Z	1	4132.00	4132.00	2.670	0.133
W x T x S/z	10	15464.50	1546.50		
A x W x T	2	6311.90	3156.00	2.120	0.146
A x W x T x Z	2	6985.70	3492.80	2.340	0.122
A x W x T x S/Z	20	29801.50	1490.10		
Total	143	739502.80	300222.50		

The above analysis does not display any significant effects involving the spatial ability factor. It does however, display the same significant effect for Web site and trial differences that are listed in Table 7. A significant interaction was discovered for the average time between the navigational aid and Web site factors. A Newman-Keuls analysis on the treatment pairs at an α of .05 yielded several results. No significant differences were found between the different navigational aids within the ISE Web site. However, within the smaller HFEC site, the three-dimensional navigational aid provided significantly shorter search times than the one or two-dimensional maps. A significant interaction was also discovered for average time between the Web site and trial factors as graphed in Figure 17. Newman-Keuls analysis on this interaction demonstrated that all treatment pairs are significantly different from each other except the difference between the ISE and HFEC site within the after trial.

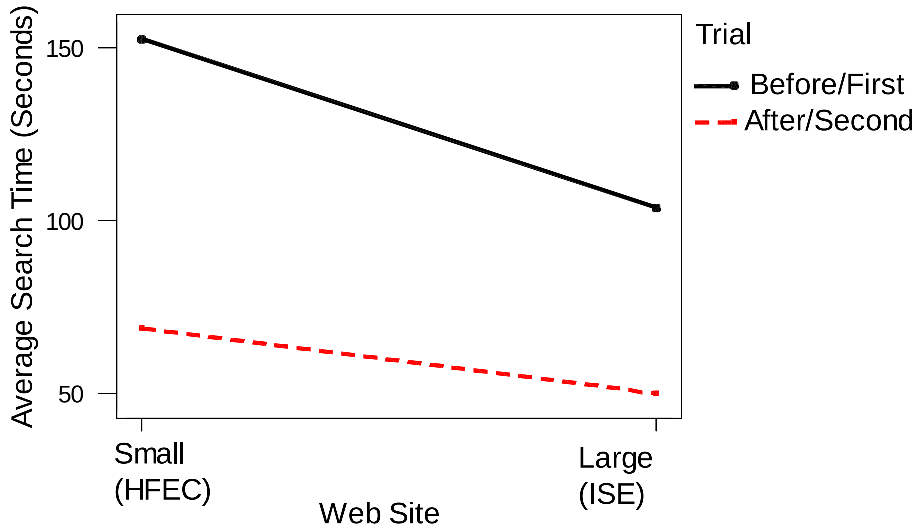

Figure 17. Significant Interaction Between Web Site and Trial for Search Time

Table 17 contains the analysis of the number of pages required to find the search target. Like before, no significant differences were observed which included the spatial ability factor. Also, like before, the Web site (p=.001) and trial (p=.001) factors provided significant differences. These means are displayed in Table 7.

Table 17. ANOVA Summary Table for Average Number of Pages to Locate Answers (Including Spatial Factor)

Source	DF	SS	MS	F	p
Between					
Spatial Ability (Z)	1	3.66	3.66	0.290	0.604
S/Z	10	127.84	12.78		
Within					
Navigation Aid (A)	2	0.34	0.17	0.030	0.971
A x Z	2	0.55	0.27	0.050	0.955
A X S/Z	20	117.52	5.88		
Web Site (W)	1	67.49	67.49	3.440	0.001 **
W x Z	1	3.00	3.00	1.040	0.332
W x S/Z	10	28.80	2.88		
Trial (T)	1	82.23	82.23	4.820	0.001 **
T x Z	1	2.40	2.40	0.720	0.415
T x S/Z	10	33.14	3.31		
A x W	2	11.69	5.85	1.920	0.172
A x W x Z	2	3.05	1.53	0.500	0.613
A x W x S/Z	20	60.85	3.04		
A x T	2	9.50	4.75	3.400	0.053
A x T x Z	2	8.49	4.25	3.040	0.070
A x T x S/Z	20	27.93	1.40		
W x T	1	10.16	10.16	4.990	0.050
W x T x Z	1	3.35	3.35	1.640	0.229
W x T x S/z	10	20.37	2.04		
A x W x T	2	3.55	1.77	1.250	0.308
A x W x T x Z	2	5.17	2.58	1.820	0.188
A x W x T x S/Z	20	28.40	1.42		
Total	143	659.47	226.20		

The last analysis involving spatial ability provides some significant effects. The ANOVA shown in Table 18 examines the dependent variable involving the total number of items found. At an α=.05 significance level, there is sufficient evidence (p=.039) to reject the null hypothesis that there is no difference in the number of answers located for people of different spatial ability. People in the low spatial ability group found on average 4.5139 answers (.6278 st. dev.) and people in the high group found 4.889 answers on average (.3165 st. dev.). Figure 18 charts these differences.

Table 18. ANOVA Summary Table for Items Found (Including Spatial Factor)

Source	DF	SS	MS	F	p
Between					
Spatial Ability (Z)	1	5.06	5.06	5.620	0.039 *
S/Z	10	9.01	0.90		
Within					
Navigation Aid (A)	2	1.01	0.51	2.520	0.106
A x Z	2	1.79	0.90	4.450	0.025 *
A X S/Z	20	4.03	0.20		
Web Site (W)	1	6.67	6.67	4.260	0.004 **
W x Z	1	1.56	1.56	3.340	0.098
W x S/Z	10	4.68	0.47		
Trial (T)	1	0.06	0.06	5.000	0.049 *
T x Z	1	0.06	0.06	5.000	0.049 *
T x S/Z	10	0.13	0.01		
A x W	2	0.18	0.09	0.410	0.667
A x W x Z	2	0.29	0.15	0.670	0.523
A x W x S/Z	20	4.36	0.22		
A x T	2	0.04	0.02	1.000	0.386
A x T x Z	2	0.04	0.02	1.000	0.386
A x T x S/Z	20	0.42	0.02		
W x T	1	0.06	0.06	5.000	0.049 *
W x T x Z	1	0.06	0.06	5.000	0.049 *
W x T x S/z	10	0.13	0.01		
A x W x T	2	0.04	0.02	1.000	0.386
A x W x T x Z	2	0.04	0.02	1.000	0.386
A x W x T x S/Z	20	0.42	0.02		
Total	143	40.16	17.13		

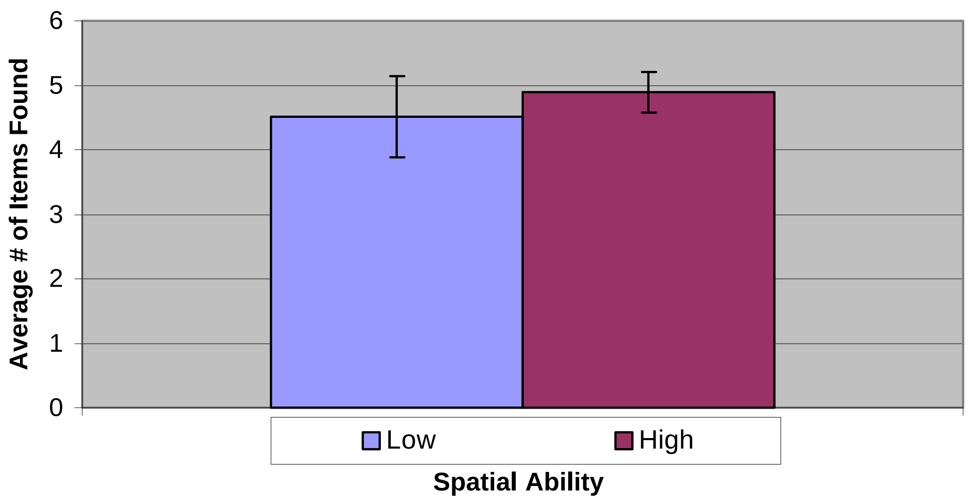

Figure 18. Average Number of Answers Located for Different Spatial Ability Groups

A significant interaction (p=.025) was observed between the navigational aid used and spatial ability level. A Newman-Keuls analysis was performed, and the interaction displayed in Figure 19. At an α=.05 significance level, people in the low spatial ability group and using the three-dimensional overview map found significantly less items than when they used either of the other two maps or any of the people in the high spatial ability group. There were no significant differences for people in the low spatial ability group between the one and two-dimensional navigational aids. Another significant difference was found between people in the low spatial group using the one-dimensional navigational aid and those in the high spatial group using either the two or three-dimensional aids. No significant differences were found between the three navigational aids within the high spatial ability group.

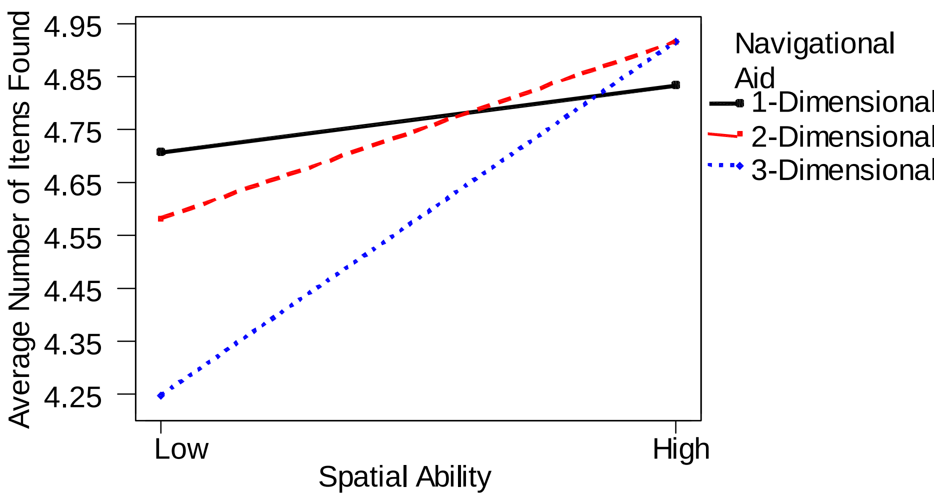

Figure 19. Interaction of Navigational Aid and Spatial Ability for Total Items Found

Another significant interaction (p=.049) with spatial ability was found with the trial factor as displayed in Figure 20. Again, a Newman-Keuls analysis was performed on the trial by spatial ability interaction. At an α=.05 significance level, significant differences were found between all combinations except for people within the high spatial group who found the same number of items.

A significant interaction (p=.049) was discovered between the Web site and trial factors. A Newman-Keuls analysis on the treatment pairs was performed at an α of .05 to investigate this effect. Participants found significantly fewer items in the small web site during than second trial than the first. However, no significant differences were discovered between trials for the larger, ISE site. Finally, a three-way interaction was significant (p=.049) between the Web site used, trial, and spatial ability factors. Appendix 6 contains the results of a Newman-Keuls analysis used to examine for significant paired comparisons in this interaction at an α of .05.

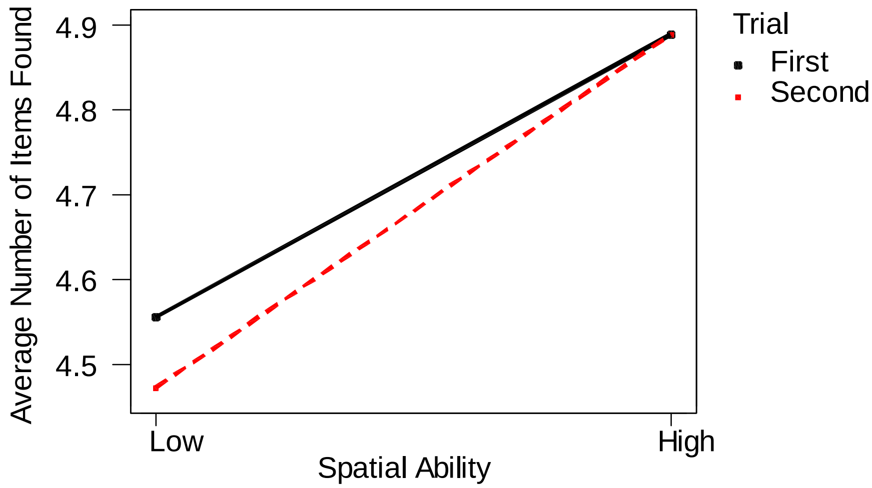

Figure 20. Interaction of Trial and Spatial Ability for Total Items Found

Survey Results

The "After-Task Survey" results were analyzed in two separate ways. First, a Kruskal-Wallis test was used to examine if any significant differences in responses existed for the between-subject factor, spatial ability. Next, a Friedman test was used to explore response differences for the within-subject factor of navigational aid. Table 19 and 20 presents these respective results. All analysis were done at an α=.05 significance level and question medians per group are displayed when a statistically significant difference existed.

Table 19. Kruskal-Wallis Test Results for Spatial Ability in the Survey

Question	p-value	Significant ?	Median		
			Low Spatial	High Spatial	Overall
1. Please rate how well you could use the navigational aid. (1-Very Easy, 5-Very Difficult)	0.013	*	2.75	2.00	2.50
2. Please rate your experience when using the navigational aid. (1-Very Enjoyable, 5-Very Unpleasant)	0.030	*	2.75	2.50	2.50
3. Please rate the legibility of the text displayed in the navigational aid. (1-Very Easy to Read, 5-Very Hard to Read)	0.421	No	n/a	n/a	2.5
4. Please rate the organization of the items (pages and links) within the navigational aid.	0.266	No	n/a	n/a	2.83
5. While browsing on the last Web site, did you ever become “lost” amongst all the Web pages, not remembering how to get back to where you where, or how to get where you want to be? (1-This always happened to me, 9-This never happened to me)	0.911	No	n/a	n/a	6.25
6. It would have been (selected answer) to find the answers to the search tasks using only the browser. (1-Much Easier, 5-Much Harder)	0.06	No	n/a	n/a	3.33
7. The amount of time required to find the answers would have been (selected answer) by only using the browser. (1-Much Less, 5-Much More)	0.024	*	3.25	4.00	3.75
8. The number of visited pages needed to find the answer would have been (selected answer) if only using the browser. (1-Much Less, 5-Much More)	0.000	***	3.00	4.00	3.75

Table 20. Friedman Test Results for Navigational Aid in the Survey

Question	p-value	Significant ?	Median			
			!D	2D	3D	Overall
1. Please rate how well you could use the navigational aid. (1-Very Easy, 5-Very Difficult)	0.057	No	n/a	n/a	n/a	2.50
2. Please rate your experience when using the navigational aid. (1-Very Enjoyable, 5-Very Unpleasant)	1.000	No	n/a	n/a	n/a	2.50
3. Please rate the legibility of the text displayed in the navigational aid. (1-Very Easy to Read, 5-Very Hard to Read)	0.011	*	2.00	2.50	3.00	2.5
4. Please rate the organization of the items (pages and links) within the navigational aid.	0.368	No	n/a	n/a	n/a	2.83
5. While browsing on the last Web site, did you ever become “lost” amongst all the Web pages, not remembering how to get back to where you where, or how to get where you want to be? (1-This always happened to me, 9-This never happened to me)	0.913	No	n/a	n/a	n/a	6.25
6. It would have been (selected answer) to find the answers to the search tasks using only the browser. (1-Much Easier, 5-Much Harder)	0.161	No	n/a	n/a	n/a	3.33
7. The amount of time required to find the answers would have been (selected answer) by only using the browser. (1-Much Less, 5-Much More)	0.423	No	n/a	n/a	n/a	3.75
8. The number of visited pages needed to find the answer would have been (selected answer) if only using the browser. (1-Much Less, 5-Much More)	0.572	No	n/a	n/a	n/a	3.75

In the final survey, participants were asked to rank order their preference for each of the three navigational aids. They provided this ordering for the ISE and HFEC sites as well as stating overall preferences. This data is represented in Figures 21-23. Using the spatial ability groups that were previously defined, the data is delineated so as to see how people in each group reacted. The total number of people ranking a particular navigational aid either their first, second or third choice is displayed. In general, more people preferred the two-dimensional navigational aid. However, people in the high spatial ability group very infrequently chose the one-dimensional navigational aid as their first or second choice as opposed to those in the low spatial ability group.

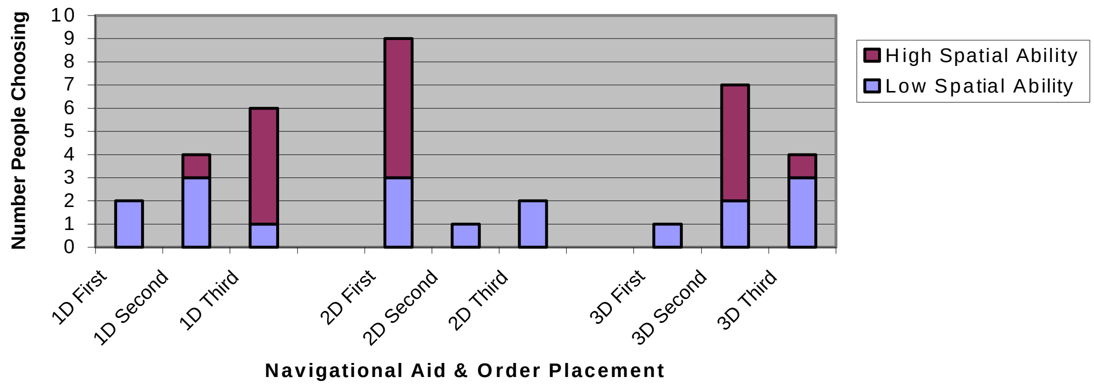

Figure 21. Ranking of Navigational Aid Preferences for the ISE WWW Site

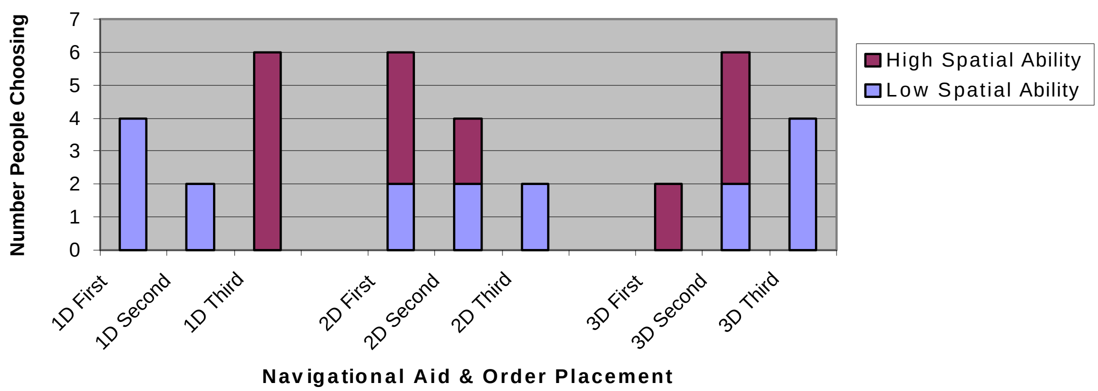

Figure 22. Ranking of Navigational Aid Preferences for the HFEC WWW Site

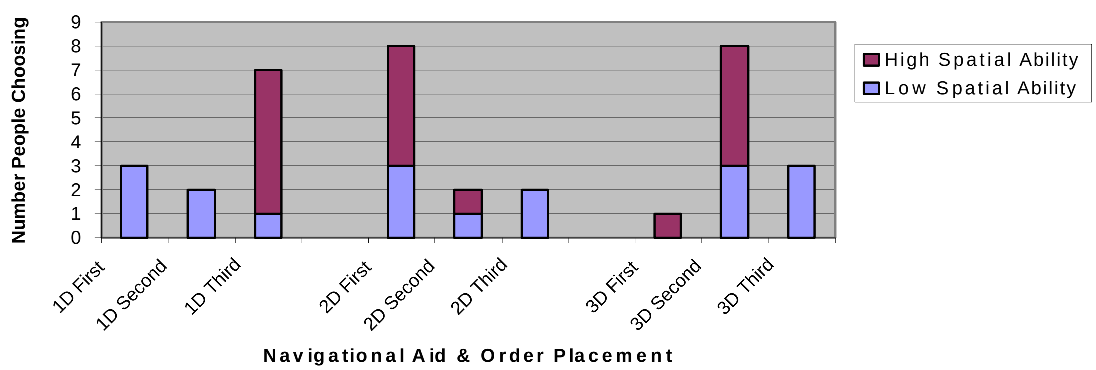

Figure 23. Ranking of Overall Navigational Aid Preferences

Also from the Final survey, subjects were asked to list various features about the various navigational aids that they liked and disliked and why they may or may not want to use such a device. This information is contained in Appendix 5. Eleven out of the twelve participants responded that they would want to use a navigational aid device while browsing the internet if it was made available to them – especially if it was their preference as outlined above. Before each session had ended but after finishing with a particular navigational aid, subjects were also asked to estimate the size of each Web site. This data is presented in Figure 24. Participants generally underestimated the size of the hypertext systems, especially in the ISE site. And they tended to incorrectly think that the HFEC site was largest.

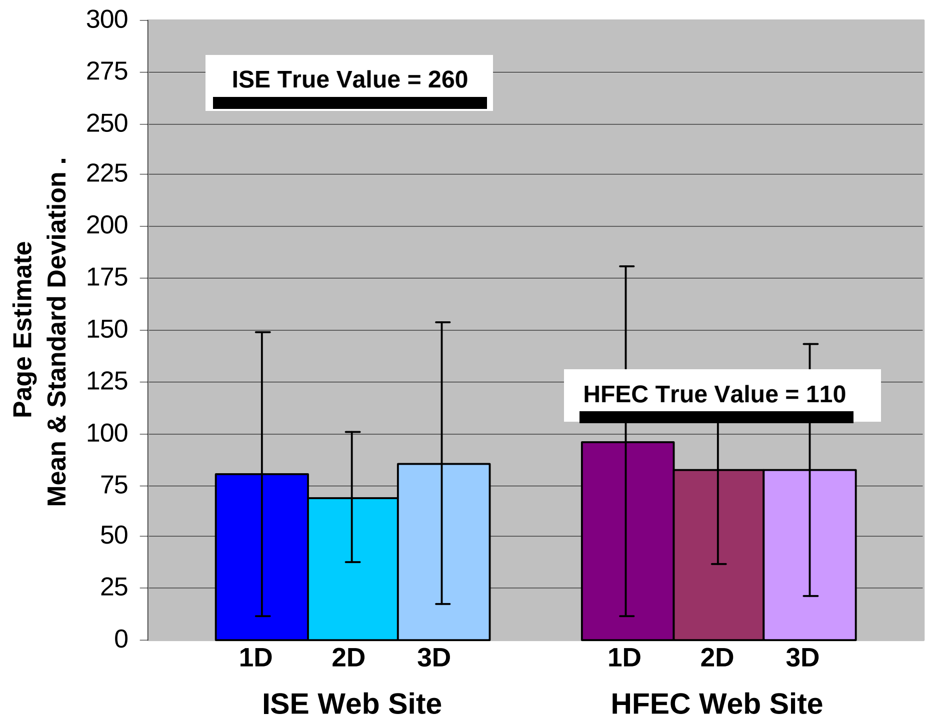

Figure 24. Participant Estimate of Web Site Size for Each Navigational Aid

The Preliminary Survey can be used to create an additional profile of the subjects. Four out of the twelve participants were female. Also, their responses to questions inquiring of their background and experience are shown in Table 21. In general, participants used computer applications frequently and reported a feeling of disorientation within Web sites roughly half the time when using browsers outside of the study.

Table 21. Preliminary Survey Responses

Question	Response
#1 How often do you use the Internet and a World Wide Web Browser like Netscape Navigator or Microsoft Internet Explorer? (1- At least once-a-day; 9 - I have never done this)	mean =1.16 median =1
#2 How often do you perform activities on a computer which involve significant hand-eye coordination such as playing video games? (1- At least once-a-day; 9 - I have never done this)	mean = 4.08 median = 3.5
#3 How often do you use a computer (for word-processing, email, spreadsheets, or any other miscellaneous task)? (1- At least once-a-day; 9 - I have never done this)	mean = 1.17 median = 1
#4 While browsing on an Internet site, have you every become “lost” amongst all the Web pages, not remembering how to get back to where you where, or how to get where you want to be? (1- This always happens to me; 9 - This never happens to me)	mean = 5.4 median = 5

To further investigate this data, a correlation analysis was done. Information from the preliminary survey (Question #1, 2, 3, and 4) and the cognitive exams were included as well as gender (coding 0 as female, 1 as male). This is displayed in Table 22 with interesting results in yellow. Some observed trends were:

- As age increased, scores on the spatial ability test decreased. (r=0.69)
- People who scored highly on the spatial ability exam reported performing computer activities which involved significant hand-eye coordination, such as playing video games, more frequently. (r=.57)
- As people grew older, they reported performing fewer computer activities involving significant hand-eye coordination. (r=.77)
- Females reported becoming “lost” within Web sites more frequently than males. (r=.57)

Table 22. Correlation Analysis of Preliminary Survey and Cognitive Tests

	Spatial Ability	Visual Memory	Verbal Ability	Age	Gender	#1 Browser Experience	#2 Handeye Activities	#3Computer Usage	#4 How Often Lost
Spatial Ability	1								
Visual Memory	0.387896	1							
Verbal Ability	-0.19206	-0.14526	1						
Age	0.692836	0.275611	-0.35816	1					
Gender	-0.24992	-0.09258	-0.54443	0.037976	1				
#1 Browser Experience	0	0.327207	-0.11449	0.408305	0.316228	1			
#2 Handeye Activities	0.568975	0.254322	-0.14358	0.766512	-0.13528	0.496252	1		
#3 Computer Usage	-0.09032	-0.35476	-0.20164	0.456341	0.316228	0.4	0.188234	1	
#4 How Often Lost	-0.3544	-0.31189	-0.42417	0.190474	0.57213	0.2352	-0.02632	0.343754	1

Summary of Results

A summary of important results is presented below to help review much of the previously presented material. While many effects and interactions were discovered in different places, they will not all be listed individually:

- No main effect for navigational aid was discovered in any analysis.
- A significant main effect (p=.006) for the Web site factor was discovered which indicated participants performed better while finding information in the larger, ISE site.
- A significant interaction (p=.033) was discovered between Web site and navigational aid. Post-hoc analysis showed that the 3D map provided better performance with the HFEC site, but often worse performance in the ISE site.
- A significant main effect for trial (p=.000) suggested people performed better on the second trial.
- No important effects were discovered containing the visual memory factor.
- Participants with low verbal ability took twice as long to find answers as those with medium or high levels (p=.040).
- The spatial ability factor did not provide significant effects in the time and number of pages measures.
- Participants with high levels of spatial ability found more items (p=.039) regardless of the type of navigational aid used (p=.025). This was demonstrated by a significant main effect and interaction, respectively. They also tended to dislike the 1D map more than the other group.

- All participants tended to underestimate the overall size of the web sites, and thought that the HFEC site was larger.

DISCUSSION

An examination of the study results is presented. The various factors involved in the study (navigational aid, hypertext system, and individual differences) are reviewed first. This is followed by a discussion of some of the participant strategies and behaviors that were observed in the study as well as some of their recommendations for improving navigation. This information allows an analysis of the various conditions under which navigational aids may be most effective.

Navigational Aid

The success of the various navigational aids used in this study can be examined in several different ways. The goal was to provide an overview map to users of a hypertext system that would eliminate the ‘getting lost in hyperspace’ syndrome by reducing the cognitive overhead of the browsing and searching task. It was hypothesized that navigational aids with more dimensions, such as a 3D map, would tap more cognitive resources of the subject than simpler varieties. This effect would be demonstrated by decreased performance as dimensionality increased. However, no main effect for navigational aid was discovered in any analysis.

The most probable cause for this result is that interface actions necessary to manipulate each navigational aid were equivalent in time and difficulty. The one-dimensional interface relied on a familiar metaphor (an operating system file displays like Windows95 Explorer), shown in Figure 6, that was commonly used by subjects. But to get to a page that was buried deep within the system, users had to open many sub-levels of the index which took additional time. The three-dimensional navigational aid was more elaborate to manipulate but fostered faster zooming into a buried node. Similar analogies can be made for the two-dimensional map.

This does not mean that the navigational aids were not successful. The significant main effect for trial indicates that a cognitive map was being constructed within the participants. This means that they were able to remember the location or pathways to items. They needed roughly half as much time and number of pages to locate answers on the second trial as opposed to the first. This result does have practical significance. One study reports that an estimated 58% of an individual’s page visits during ordinary Web navigation are revisits to the same place that they have been previously (Tauscher and Greenberg, 1997). This indicated that users could benefit from some type of navigational system which allows them to return to prior locations very efficiently. The navigational aids studied could assist in that respect. Participants also seem to agree. They were asked what their performance would be if they had never viewed a navigational aid but were brought in to do the same tasks with just a browser. The responses leaned towards that they would need more time and page visits to locate the same answers, as shown in Questions 7 and 8 in Table 20.

Overall, subjects had a very positive reaction to the navigational aids. Only one of the twelve reported that they would not want to use a navigational aid if presented the opportunity. However, in general, they rated them ‘average’ as far as their ease of use and enjoyability as the survey results in Appendix 5 indicate. They reported liking them because it allowed them to “skip more pages thus taking less time” (Participant #12), “evaluate the content of a site without having to download multiple page" (Participant #6), or because "it gives you some idea about where you are and where you can go without having to hit the back button all of the time and becoming lost" (Participant #8). These and other comments suggest that saving time was very important to the participants. They felt that the maps could help them by providing a more direct route to a page or by preventing them from wasting time by being lost.

Elsewhere, they also did report less sensation of being lost. Before beginning the study, participants were asked how often in internet browsing they "become lost amongst all the Web pages, not remembering how to get back to where you were, or how to get where you want to be." The median score for this question was 5 (with 1 being always and 9 never). During the study they were asked the same questions and the median score was 6.25. Clearly, the navigational aids were providing some benefit to the participants.

At this point, it is important at this point to return to Elm and Woods (1985) definition of getting lost in hypertext. Again, they define it by a performance decrement as opposed to subjective feelings of being lost. While this study did show an improvement in subjective ratings, performance measures were also significant. On return visits to the same page to relocate an answer, subjects were able to do it quicker and by visiting fewer pages. This would indicate that in fact the navigational aids helped the participants generate and follow various routes around a hypertext environment. These are key issues in helping eliminate the problem of disorientation.

Hypertext System

The two hypertext systems chosen for evaluation, the Industrial and Systems Engineering (ISE) Department and Human Factors Engineering Center (HFEC) Web sites, were picked primarily because of their differences in size. Previous research has shown that smaller hypertext systems yield better performance on the part of their users. This finding is understandable in light of the fact that users would have fewer pages to look through when accomplishing a search task. As Table 5 displays, the ISE site contains over twice as many individual and unique HTML pages as the HFEC site. Therefore, a similar result was hypothesized for this study: the ISE site would yield worse performance than the HFEC site.

The actual experimental findings provided the opposite result. Subjects found answers in approximately 25% less time and page visits in the ISE site versus the HFEC site. Similarly, they also found fewer answers in the HFEC site. While this finding was unexpected, it does make sense in light of other aspects. The complexity of the site and the nature of the three navigational aids were found to be more important than the hypertext system size.

The complexity of the Web sites were an important element to influencing the participants' abilities to find information. While both sites approximate a hierarchical structure, how information is presented within that framework differs. When asked, participants responded by generally thinking that the ISE site was better organized. The reason behind this becomes apparent when examining how the test HFEC site was constructed. Two additional Web sites (the Human-Computer Interaction Laboratory and the Macroergonomics and Group Decision Systems Laboratory) were also added as links off the HFEC home page which are traditionally not there. In essence, three distinct, but small hypertext systems existed within the HFEC site. This created problems because much of the content has similar themes. For instance, if a subject was given a search task involving a person, any of the "three" small Web sites potentially contained the answer because each had a section referring to "People" as shown in gray in Figure 25. However, given a similar question in the ISE site, all the personnel pages are generally grouped under one major area. Therefore, searching for the answer in the HFEC site was more difficult even though it is physically smaller.

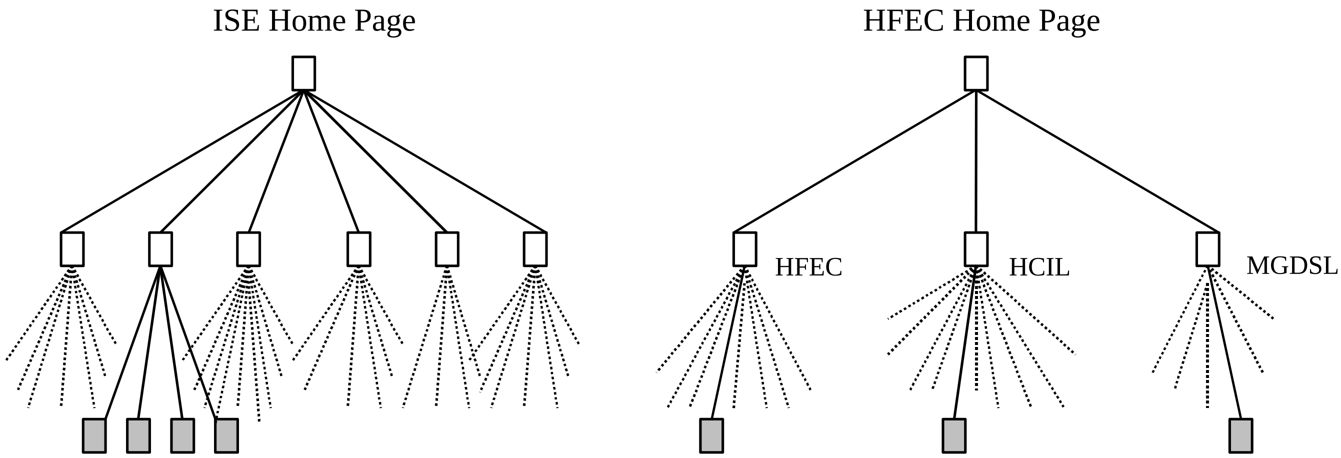

Figure 25. Portion of the ISE and HFEC Web Sites. (Some pages referring to people shown in gray.)

Another way to categorize this complexity is to use definitions from the organizational design and management (ODAM) discipline. Here, complexity in organizations is categorized in a manner that would be applicable to hypertext systems. Vertical differentiation refers to the number of hierarchical levels from top to bottom. Horizontal differentiation is a measure of the degree of departmentalization, or in this case, the amount of content specialization in the various subsections. Spatial dispersion refers to the degree to how items are "geographically" dispersed. Increasing any of these three should increase the complexity of the hypertext system. Also following from ODAM theory, in order to achieve optimal functioning as complexity increases, the number of integrating mechanisms (methods of communication, co-ordination and control) must also increase (Hendrick, 1991). This could imply that the number of links and methods of navigating from one portion of a web to another should increase.

Using the ODAM definition, it is also clear that the HFEC site is more complex than the ISE site. Both sites have about the same number of levels or vertical differentiation. Similarly, at the third level in the hierarchy, both sites have approximately the same horizontal differentiation. What truly separates them is the spatial dispersion of items. The previous example again exemplifies this point. Pages related to "People" (and other concepts as well) are grouped together in the ISE site, while they are spatially or geographically separated in the HFEC site.

The three navigational aids were very successful at hiding the size of the sites, also making the size factor less important than the complexity issue. For instance:

- One-Dimensional Map – Pages are only visible when a user opens up a branch in the hierarchy displaying the substructure. And then within this substructure, additional pages may remain hidden until the user explodes or "grows" the branch.
- Two-Dimensional Map – Due to the fisheye nature of the display, distant pages or nodes are shown as very small objects. Distant branches off of these anchors may be too small to be shown at all.
- Three-Dimensional Map – Deeper pages within the hypertext structure are shown 'further' away from the user. Thus, these nodes are smaller or non-existent from their vantage point. As well, when users are zoomed into a particular area, they are not able to see pages around or behind them.

These issues may not be entirely positive attributes. Seeing the sizes of the systems or specific subsections could assist browsing by helping to focus in on areas that contain relevant information.

The fact that participants did not have a good feel for the overall size of the hypertext environment is exemplified in Figure 24. Subjects were asked to estimate the total size of each Web site after using each navigation aid. As can be seen, no navigational aid provided a clear representation of how many pages there truly were. Subjects tended to underestimate the sizes, especially so in the ISE condition. The sizes of the environments were incorrectly thought either to be similar or that the HFEC site was larger. When listening to subjects make their estimations, they always seemed to explain that the sites seemed to be similar in size (characteristic of the navigational aid), but that the HFEC site seemed more complex and therefore must be larger.

Increased amounts of site complexity can decrease performance due to additional cognitive overhead forcing more mental manipulations and items to be remembered (Conklin, 1987). While it was hypothesized that more multidimensional navigational aids would present a problem, the Web site complexity was not considered. This complexity argument is also justified by observing the significant interaction displayed in Figure 15. When examining this effect, it can be seen that participants actually tended to find fewer items on the second trial only when in the smaller HFEC Web site. The added complexity of the small, but complex HFEC site could have placed too much mental workload on the participants. This caused them to either actually forget where the search task is located or not have a clear mental model from the first attempt. Similarly, the interaction shown in Figure 17 demonstrated that participant's time between the first and second trials improved more when in the less complex ISE site.

Individual Differences

Hypertext designers cannot expect people to interact with their systems in identical ways. Therefore, one of the goals of this study was to examine how individual differences affect performance. Three different cognitive abilities were examined: visual memory, vocabulary, and spatial ability. Previous research has shown that spatial and verbal ability influence a user's capability to find information efficiently within a file system (Vicente, Hayes and Williges, 1987). A related hypothesis was made for this study. It was theorized that users with higher spatial and verbal abilities would perform better in the various search tasks. The results were mixed.

No statistically significant effects were observed with the visual memory measure. It was hypothesized that the cognitive test for this measure and the experimental task were very similar in nature and thus a correlation may exist. Both required the participant to remember where an object was previously located. However, as with previous literature (Vicente, Hayes and Williges, 1987) the measure did not prove significant. The most interesting finding would have been an interaction between the trial and this factor. Memory should play a much larger role in the second trial only. One possible reason that this test did not prove valuable is its sensitivity. As opposed to the other two cognitive ability exams, the scores did not vary substantially. Perhaps a more sensitive test that assesses memory would provide more significant results.

Participants whose scores placed them in the middle and high verbal ability groups found answers significantly faster than those in the lower group as shown in Figure 16. However, no statistically significant results were found with the other two dependent variables, number of pages needed and total items found. Vocabulary tests are generally a good indication of a person's total verbal ability. Therefore, it would stand to reason that people with low verbal abilities might be slower readers as well. This could explain the differences observed. As subjects attempt to locate the answers in the search task, they are required to read not only information presented in the navigational aid but that which is in the hypertext documents. People of differing verbal abilities seem to need to search through the same number of pages before locating the answer; it just takes them different amounts of time to examine the information present.

The spatial ability factor, which has been an important effect in other research, was only statistically significant when examining the total number of search items located. As shown in Figure 18, people in the high spatial group succeeded in locating more items than people placed in the low group. While the difference between the two groups is not large, it nonetheless represents an interesting finding that seems to validate previous literature. The ability to visualize and manipulate objects cognitively appears to be a skill that assists people in locating information within a hypertext system. Consider a typical search task scenario. The subject may search through different areas of the Web site eliminating them as possible sections where the answer is located. A heightened spatial ability will guide them into new areas which they have not explored and which may contain the answer. Thus, they are successful more times.

This was not the only difference that existed between the low and high spatial ability groups. The high group reported being able to use the navigational aids more easily and found the experience more enjoyable (Questions 1 and 2 in Table 19). They also seemed to depend more on the navigational aid. When asked about completing the same task with a browser by itself (having never viewed any overview map) they thought that it would take them more time and page visits to locate the answers (Questions 7 and 8 in Table 19). This is compared with people in the low spatial ability group who thought that it would take them roughly the same amount of time and page visits. People in the high spatial group seemed to view the navigational aid more as a usable tool that helped them achieve their goals in a more efficient manner. The possible reason for this is that the added complexity of having to deal with a navigational aid and a browser placed too many cognitive demands on the people in the low spatial ability group.

These additional cognitive demands also demonstrated themselves in the significant interaction that was present between navigational aid and spatial ability. This was one of the hypothesized results (though it was also expected and not found with the time and page visit measures). Figure 19 charted this effect. People in the high spatial ability group were equally successful in locating the answers regardless of the type of navigational aid used. However, for people in the low spatial ability group, their performance was shown to improve as navigational aid dimensionality lessened. Participants' preference for navigational aid also seemed to confirm this result as shown in the rankings displayed in Figures 21 through 23. People in the low spatial ability groups tended to prefer overall the one-dimensional navigational aid, while people in the high group ranked it last.

Similar differences are also demonstrated in the statistically significant interaction depicted in Figure 20. People in the low spatial ability group were more likely to find fewer items on the second trial. This indicates that they forgot where the answers were located. One possible reason for this is that with fewer cognitive reserves for spatial manipulations, the people in the low spatial group became easily confused by the navigational aid and the hypertext organizational complexity. Thus, they were not able to remember the location of items as well. Or it is possible that they never built a cognitive map of where the items were located. Perhaps, because they weren't as comfortable with the navigational aids, they were not using them effectively and may have accidentally stumbled across an answer on the first trial. Participants were observed not to remember well the path to Web pages that they randomly found the first time.

It is worthwhile to examine why the spatial ability factor did not influence the other dependent measures (time and page visits) as much. It has been suggested that the presence of graphical overview maps may augment user's cognitive ability (Chen and Rada, 1996). Therefore, the effect of spatial ability on performance measures is diminished. This study seems to support that conclusion, however it does extend previous research in that a variety of navigational are studied here which vary along a dimension (multidimensional:1D vs. 2D vs. 3D) that should be influenced by a person's spatial ability. Again, it is possible that perhaps another spatial ability test other than the VZ-2 may prove more successful in demonstrating trends.

The results obtained for spatial ability may also be generalized to other individual characteristics like age. Through a series of correlation shown in Table 22, those participants with high levels of spatial ability also tended to be younger and more likely to perform computer activities which involve significant hand-eye coordination such as playing video-games. The only person to respond that they would not prefer to use a navigational aid (Participant #5) also happened to be the oldest subject in the study. These findings, which support previous literature, indicate as age increases, a person's ability to use these aids may decrease (Westerman, Davies, Glendon, Stammers and Matthews, 1995). However, as age increases, people have generally move from more concrete to an abstract thinking process. This is characterized by increasing amounts of differentiation {the number of dimensions extractable from data} and integration {the number of interconnections between rules for combining structured data} that people are capable of (Hendrick, 1984). This would suggest that older people should be more successful at extracting information from web networks. The results from this study tend to contradict that hypothesis and suggest the need for more research into these areas.

Participant Behavior

When analyzing how best to use navigational aids to ease browsing disorientation, it is useful to consider many of the common strategies and activities that the participants employed when finding information. While no detailed interaction analysis was conducted for this study, the participants tended to act very similarly in certain circumstances.

Subjects were informally asked about their strategy used in locating the answer each day after the session had finished. Most stated that they used a form of word association. They looked for topic areas within the hypertext and navigational aid which matched key words within the questions. After navigating to that topic area, they would then refine their search again by looking at words in the questions. In general, this was a successful strategy as most of the search tasks were completed. Sometimes this reliance on key words did prove troublesome. When asked to find the answer to this question, "How high can the spring loaded push-pull gauges go up to in the Industrial Ergonomics Lab?," seven subjects out of twelve spent at least part of their searching efforts within the Macroergonomics and Group Decision Support Laboratory (MGDSL). When later asked about this behavior, most responded that it was the word "*ergonomics*" which was drew their attention immediately to the MGDSL (a link near the top of the structure; the Industrial Ergonomics Lab information was buried deep within the site). Thus, when users have little knowledge of the topic area they will rely on important words and phrases.

Participants also tended to rely on the navigational aid for assistance in finding answers without reading the Web pages. Frequently, clues (e.g., descriptions about what is in each topic area) would be given on the home pages of the Web sites that helped indicate where answers may be located. Instead of reading these items as they searched, subjects would skip ahead to where they thought the answer should be. And they were frequently wrong. This habit of looking to the navigational aid for advice also caused participants to incorrectly rule out pages to look in. For example, when looking for the answer to this question, "On March 19th, David Heyen is scheduled to be here. What company is he from?" – the subject may see Figure 26. Instead of correctly opening up the "Calendar – Virginia Tech ISE" anchor/page, they would avoid it because the links branching away from it "The Performance Center" and "FAIM Conference – 1997" did not sound like they matched the topic of the question.

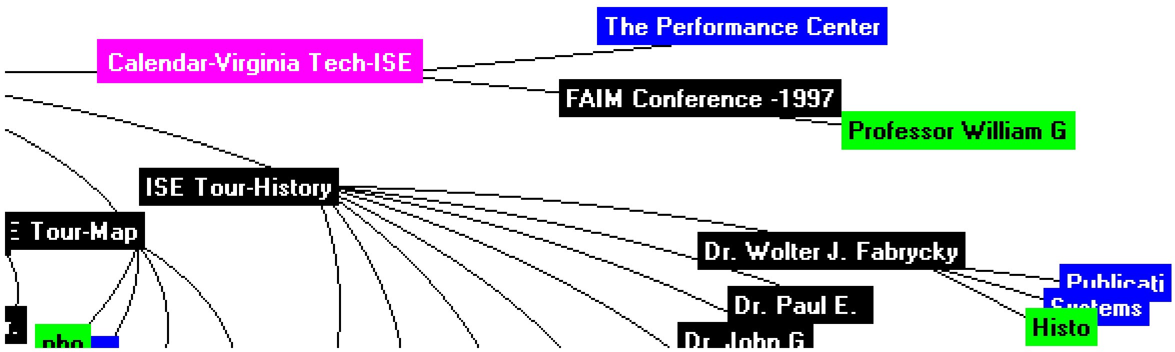

Figure 26. Enlarged Portion of Two-Dimensional Navigational Aid

Successful and efficient completion of the search task was also complicated by a *cognitive hysteresis*. Lewis and Norman (1995) explain this concept as a stubbornness whereby people tend to stick with a decision even after evidence shows it to be wrong. They explain that this is because it takes little information for someone to make a decision, but tremendous additional information, time and energy for them to change their mind. This behavior is seen in the current study. Participants frequently would use a key word in the sentence to find an area of hypertext they thought should contain the answer. Once the Web page is displayed, it may contain some information that appears relevant, but yet no answer. They may visit a couple of neighboring links but quickly return to the original page to read it more closely. Throughout this activity, they miss the fact that the answer is actually located in a completely different area of the Web site. Only by completely readjusting their strategy do they locate the answer – but, of course, they have already spent considerable time on the task.

Participant Suggestions

The study participants did provide suggestions as to ways in which to improve the navigational aids. First, the legibility of the text needs to be of higher quality. As previously indicated, subjects relied on information within the navigational aid and wanted to be able to read the titles on the anchors very clearly. The legibility issue was the only statistically (Question 3, Table 20) survey result involving the navigational aids. People indicated that the one-dimensional navigational aid was the easiest to read and the three-dimensional aid, the most difficult. The text on the latter map could become fuzzy, especially when the node was 'far away' from the user's view point in the 3D environment. The two-dimensional aid would have been rated more highly had it not cut off anchors that are on the edge of the screen. This effect is demonstrated in Figure 26: i.e., "Professor William G", but no last name. The complete anchor title would become visible if it were brought closer to the center of the screen (fish-eye) or if the user took advantage of "tool-tips."

Due to the empirical nature of the investigation, all confounding variables within the experiment had to be controlled for including the sizes of the displayed windows and screen resolution. However, several subjects expressed a desire to change these parameters. While their wish was not granted, their suggestions were important. For instance, Participant #7 (in Appendix 5) thought that the navigational aids would be useful if they didn't take up a significant portion of the screen. As well, the others wished to change the resolution to make the text easier to read or to increase the browser size.

Another major issue with the users was the lack of displayed internal links in the navigational aids. These are links that just point to a location further down the same page and not an external one. The effect of clicking them is for the page to automatically scroll down to an anchor (usually a large headline text) below. Participants became very accustomed to seeing all the links on the hypertext page show up in the navigational aid as anchors. When the internal links were not present, confusion occurred.

Many other suggestions were brought forth during the course of the study. For instance, participants used to playing certain video-games thought that the right mouse button should allow the user to zoom out while using the 3D navigational aid. Most everyone thought that the motion within the 3D map should also be smoother. The map was chosen because it provided a sense of visual momentum as the user travels through the environment. However, in certain circumstances, the animation of the map moves (or jumps) quickly causing mild, temporary disorientation.

Navigational Aid Implementation Considerations

The results of this research confirms many other studies performed which show the benefit of providing navigational aids for users of hypertext or Web systems. However, for the designer of such a system, the choice of what type of aid is not so clear. This study provides no absolutely definite answers, but it does offer some valid suggestions.

It is first interesting to note the significant interaction that occurred between the navigational aid and hypertext system factors which is displayed in Figure 14. For Web sites that are well organized, such as the ISE site used here, each navigational aid seems equally effective (no statistically significant difference were found amongst them). However, for smaller sites with high complexity, such as the HFEC, the three-dimensional navigational aid did foster quicker search times than either of the other two maps. One possible reason behind this result involves the way information is displayed within the 3D navigational aid. When viewing the site from the highest level, the user can read the titles on the anchors several levels deep. Thus, a user can quickly review practically the entire Web site without needing to perform any navigation. The same site seen in the 1D navigational aid would be completely hidden until the user begins to open up several layers of the index hierarchy. In the 2D map, those sublevels would not be readable because they would be at the edges of the screen and too small to be read quickly. Why this effect is neutralized in the large condition is probably due to the fact that the user finds it too difficult to scan greater amounts of information when presented all at once on the 3D map.

As a corollary to the above finding, it is not uncommon for large sites to have pages with many links on them (>20). As the number of links on any page increases, the usability of the 3D maps tends to deteriorate while the 1D index-style map begins to excel. The structure of the 3D map (and partially the 2D) is such that when many links are present, they are presented around the parent anchor in a curvilinear fashion. This is not the optimal structure for scanning through items. When presented in a vertical list format, similar to the 1D map, a user can quickly look through many links to find their target (provided it is organized effectively, i.e., alphabetically). Of course, at this point, the use of a navigational aid may be questioned. It may be easier to select the link directly from the hypertext page itself as opposed to finding its matching anchor in the map. It may even be well advised to terminate the navigational aid structure at pages with many links and force the user to select a hyperlink from the actual document.

If it is known that a population consisting of users of heterogeneous cognitive abilities will employ the hypertext system, it will be important to choose a navigational aid that ensures everyone can use it effectively. Again, from the significant interaction graphed in Figure 19, the choice of maps for users of high spatial abilities is irrelevant. They can find items at equal levels of success regardless of the navigational aid. However, to ensure that users of lower spatial abilities will find the information they are looking for, the simplest navigational aid (1D) should be selected.

Performance measures aside, considering user preferences are also important. Figures 21 through 23 indicate that subjects generally chose the two-dimensional navigational aid as their first choice. They indicated on the Final Survey that they liked how the interface functioned and enjoyed the animation of the map bringing different nodes into focus.

Suggestions for Web Designers

The following suggestions have been compiled from the results of this research:

- 3D navigational aids, which show an overview of the entire hypertext system, can help people find information especially when they can read the nodes several levels deep.
- Navigational aids were useful for gross positioning within the web sites used – however, for detailed link selection the actual browser provides quickest action. Therefore, it may not be necessary to display every hypertext page in the map.
- If designing for a general population where people will have different cognitive abilities, choose the simplest (1D) navigational aid.
- People tend to prefer the 2D navigational aid primarily because its interactive animation provided an *enjoyable* interface mechanism.
- Make the text on the navigational aid very legible.
- Ensure that the titles on the anchors are clear and adequately describe the page content.
- Use internal links cautiously if the navigational aid will not be displaying them.
- Provide consistency across other applications such as video games which the users may already be familiar with.

- Allow the user to customize various aspects about the navigational aid. This may include letting them resize the map window/frame or change the color codings.

Future Work

This was not the first study examining navigation in hypertext systems, nor should it be the last. The problem of disorientation has not been eliminated as the number of Web sites has increased. While the issues examined here are important, more can still be investigated. Many of the following suggestions explore the factors of this study in more detail.

First, a more detailed interaction analysis should be performed on the usage of navigational aids. Broad performance measures were recorded in this study, such as the amount of time to locate an item within a Web site. It would be insightful to know exactly how that time was distributed within the search tasks. Was the time primarily spent reading the Web pages, or was it manipulating the interface elements within the navigational aid? This information can be obtained by a detailed video analysis. For instance, after such investigation, it may be apparent that users are spending more time manipulating the 3D interface but that it requires less overall reading of the pages. Other actions also should be noted such as how often the user goes back to the home page or the top of the navigational aid to reorient themselves. This measure may be a good indicator of how "lost" a user was within the system. The user's path also could be recorded for comparison to others and to see what clues along the way guided them in that direction. This may be combined with a protocol analysis to examine user's thoughts and opinions throughout every step of the experimental task. It is recognized that they could offer suggestions for improvement as critical incidents occur which may not be easily remembered later.

Next, the issue of Web site complexity should be examined further. It was shown in this study that it was not the size of the hypertext system which was significant, but the complexity. This raises several new questions. For instance, what things make a Web site complex? How can the ODAM definitions be further extended to apply to hypertext systems? And when that is understood, what types of tools can be provided to users to assist them with hypertext systems which are already complex? The answers could involve many of the factors examined here. As well, the issue of disorientation can be further examined. Subjective reports have not previously been considered accurate ways to indicate disorientation. However, the free-modulus magnitude estimation technique may be an appropriate measure for such an effect. It has been used successfully before to estimate a user's level of presence within a virtual environment (Snow and Williges, 1998) and may also provide an excellent way to get a subjective feeling such as being lost in hypertext.

The sensitivity and generalizability of these results also can be extended. A control condition could be added where subjects just used the browser by itself to locate a series of answers. This would provide a good quantitative method of comparing which navigational aid yielded the most improved performance. As well, the distraction period (or the effect of trial) in this study before the user began their second trial was relatively short. It would be interesting to study the long-term effects of cognitive map building. If the same users were brought in days later for the same task, how would their performance change? Through this, the effect of practice may be observed. Also, different Web sites and hypertext systems (including multiple sizes and structures) to see if the results obtained here hold true. More subjects can be used to increase the power of the statistically results. And finally, the NASA TLX measure of mental workload could be used to provide a more detailed examination of the effects of cognitive overhead.

Finally, the role of new technologies should be investigated. This is especially true of the three-dimensional environments. Virtual Reality Modeling Language (VRML) could be used to create a similar 3D overview map. It would provide full six-degrees of motion that the HotSauce application limits. This would allow the user to roam freely through the information landscape. Also, the role of immersion and virtual/augmented reality could be investigated. For instance, the user could wear a see-through head-mounted display while interacting with a hypertext document on a CRT screen. This see-through display could create an overview map completely surrounding the user. If the user wanted to see what was ahead of them, they simply look up; if they want to see where they have been, they turn their head around and examine their path. This type of environment may more closely approximate normal human navigation and may prove to be a successful means of travelling through hypertext systems.

Conclusions

This research has yielded a number of important findings that both confirm previous literature and extend it into new areas. They are summarized as follows:

- Subject performance was expected to worsen as the navigational aid became more dimensional. However, no significant effects were discovered concerning the main effect of navigational aid.
- A significant difference was expected between the two hypertext conditions, with the smaller one yielding better performance. The research provided the opposite result. It is theorized that the reason the smaller site caused worse performance is due to its increased complexity and organization of its information.
- Subjects in the lowest grouping of verbal ability took longer to find information than those in the two higher groups as expected. However, no differences were found in the pages visited and total found measures.
- As hypothesized, subjects with higher spatial ability found more items than those with lower spatial skills. However, unexpectedly all took equal amounts of time and needed to examine equivalent numbers of Web pages before locating the answers.
- Subjects with higher visual memory abilities did not succeed in performing better on the second trial. This may indicate that the test was not sensitive enough.
- As predicted, a significant interaction existed between the hypertext system and the type of navigational aid used. Within the larger site, there were no significant differences between the navigational aids. However, the 3D map yielded the best performance in the smaller site.

- A significant interaction existed between subjects' spatial ability and navigational aid only for the total number of pages found measure. Subjects of high spatial ability succeed equally well regardless of the type of navigational aid used. However, subjects of lower spatially ability were more successful in finding items with navigational aids of lower complexity.
- Areas for future research include: interaction analysis of time usage, web site complexity issues, broadening the generality of the findings, and the roles of new advanced technologies.

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APPENDIX 1: INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants
of Investigative Projects

Title of Project: AN EXAMINATION OF HYPERTEXT NAVIGATION ASSISTED BY MULTIDIMENSIONAL NAVIGATIONAL AIDS WHILE CONSIDERING THE ROLE OF USER SPATIAL ABILITY.

Investigator: Brandon Satanek

I. The purpose of this Research Project

While using hypertext systems, like the Internet, people easily can become disoriented or lost in a sea of text, graphics and animation. They may not remember how they got where they are or how to get where they are going. The purpose of the experiment is to examine different navigational aids that help users find information within a hypertext environment and alleviate some of these problems. It will also look at how individual differences among people may predispose them to being helped by a particular navigational aid more than another. Twenty-four participants, each tested individually, will complete this experiment.

II. Procedures

In this study you will be asked to use a navigational aid to search for information within a particular World Wide Web site. You will use a personal computer that will be running both an Internet browser, such as Netscape, and an additional navigational application that you can use to visit pages within the browser. You will be asked to take three cognitive tests (spatial and verbal) that assess some of your individual abilities. Also, you will be asked to fill out questionnaires regarding your background and your reactions to the tasks. You will also answer some verbal inquires about your particular search strategy while performing the tasks.

This study will be conducted in three separate sessions occurring on three different days. This first session will take approximately two hours. The next two sessions should be approximately thirty minutes shorter. Unfortunately, not everyone can participate. A few individuals who do not meet certain criteria (vision), or when I have everyone I need of a particular spatial ability, must be turned away.

III. Risks

There are no risks associated with this study outside of those traditionally encountered from using a personal computer.

IV. Benefits of this Project

There are no direct benefits to you from this research (other than payment). No promise or guarantee of benefits has been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Your name will not appear on any of the data collected. A random subject number will replace your name on all documents. You have the right to see your data and withdraw from the study if you so desire. The data will be stored in a locked room within the Human-Computer Interaction Laboratory (530E Whittemore) and be disposed of after analysis in approximately three months.

Your interactions with the computer system will be videotaped. The video will focus on the computer and should not capture a significant portion of your face. The purpose of the video tape is to record the number of web pages you visit during the experimental tasks to supplement data collection. The video will not be shown to anyone without your written permission. The videotapes will be stored in a locked room within the Virginia Tech Human-Compute Interaction Laboratory. Access to the tapes will be under the supervision of Dr. Robert Williges. The tapes will be destroyed after analysis in approximately three months.

VI. Compensation

You will be paid $5 per hour for the time you actually spend in the experiment. If you do not work in whole hour increments, you will be given an additional dollar for every extra twelve minutes (which will be rounded up).

Payment will be made immediately after you have finished your participation.

VII. Freedom to Withdraw

You should know that at any time you are free to withdraw from participation in this research program without penalty. No one will try to make you continue if you do not want to continue, and you will be paid in full for the amount of time you participated.

VIII. Approval of Research

The research project has been approved, as required by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, by the Department of Industrial and Systems Engineering.

IX. Subject's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. I should not volunteer for participation if I now know I will not be able to complete all three sessions.

2. I should not volunteer for participation in this research if I am a student in the Industrial and Systems Engineering department.

3. I should not volunteer for participation in this research if I have extensive knowledge of the World Wide Web site for the Industrial and Systems Engineering department or the Human Factors Engineering Center.

4. After completion of this study, I will not discuss my experiences with any other individual for a period of two months. This will ensure that everyone will begin the study with the same level of knowledge and expectations.

X. Subject's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____ ____________________

Signature Date

Should I have any questions about this research or its conduct, I may contact:

Brandon Satanek 961-2095
Principal Investigator

Dr. Robert Williges 231-6270
Faculty Advisor

H. T. Hurd 231-5281
Chair, IRB Research Division

APPENDIX 2: SUBJECT INSTRUCTIONS

A. General Instructions

B. Question and Timer Application

C. One-Dimensional Navigational Aid

D. Two-Dimensional Navigational Aid

E. Three-Dimensional Navigational Aid

F. Additional Tips

General Instructions

This study is looking at various techniques for Internet browsing. As mentioned in the informed consent, you must complete two additional sessions after today. On each day, you will be using a different navigational aid that varies the way pages are displayed. You will receive training on how to use the various devices. The Industrial and Systems Engineering Department and the Human Factors Engineering Center web sites will be used in this study. You should not visit them at any other time until after you have completed all the sessions.

During this study you will be asked to find answers within the web sites to a series of questions. There are no trick questions, you should be able to find the answers to all the questions using the navigational aid with the browser. There may be an occasion when you do not see a path to the web page you desire, if so, you may need to search for an alternate path. If you absolutely cannot find an answer and want to give up, please let me know. Later on the same day, you will be asked to relocate the same answers. *Do not* try to actively memorize the path to the answer, instead just try to find them and work as quickly as possible. Even if you know the answer to a question, you must locate the web page that contains the information.

Each navigational aid displays the web pages as a series of "nodes." These nodes are labeled with the name of the link on the web page or the title of the destination page. You must select the node to display the page in the browser window. *Do not* click on the links within the web pages themselves, instead use only the navigational aid. It is realized that the best method is probably one where you can click on links in either the browser or navigational aid – however, to ensure that everyone has a similar experience (and to accurately compare between them), only the navigational aid will be used.

When the page is displayed in the browser window, remember to use its right-hand scroll bar as some answers may be located further down the page. Also be careful about internal links (links which just point to a location further down the same page and not a different one). Internal links are generally at the top of the screen and point to a larger headline below. Be careful because these links will no be shown in the navigational aid, you must use the browser's scroll bar to examine what is located off screen.

When you are looking for answers, do not feel as if you have to follow any particular pattern. You can start anywhere you want to; returning to the home page before beginning is not required. Also, feel free to open as many or as few links as necessary to find the answer.

Do you have any questions yet?

Instructions for the One-Dimensional Navigational Aid

Arrangement:

- Resembles an index or table of contents – presented in an outline format.
- Each page in the web site is listed (often more than once).
- Ignore the colors, they are unimportant for your use of this navigational aid.
- Ignore all other features (menus, toolbars, right-clicking…).
- All the links for a particular page are listed below it and indented.
    - These linked pages may have additional links to other pages…and so on.
    - The name listed is either the text from the hyperlink (blue, underlined words) or the title from the destination page.

How to use:

- Click once on any page to bring it into "focus". It will move to the center of the screen, turn purple, and present the other pages around it more clearly.
- Click once on the node to bring it into focus and then press "Enter" to display the desired page in the browser window. It will remain purple.
- If you cannot read the complete title on the node:
    - Make the map window active, and use "tool-tips."
    - Click on any part of the map and adjust it (move mouse) to pull the other pages into focus. This can also be done at any time to manipulate the map for your searching.

Remember:

- Do not click on the links in the browser.
- You can display as many or as few pages as you feel necessary during your search.
- You may only interact with the navigational aid after finish reading the question and press begin.
- If you do not see a link to the page you want in the navigational aid, you may need to try a different 'path'.
- Watch for internal links, and remember to use the browser's scroll bar.

Instructions for the Two-Dimensional Navigational Aid

Arrangement:

- Pages are laid out in a map. The pages/links closes to your present location are shown larger than those further away.
- Each page in the web site is listed (often more than once).
- Ignore the colors, they are unimportant for your use of this navigational aid.
- Ignore all other features (menus, toolbars, right-clicking…).
- All the links for a particular page are listed as branches moving away from it.
  - These links may have additional links to other pages…and so on.
  - The name listed is either the text from the hyperlink (blue, underlined words) or the title from the destination page.

How to use:

- Operates similar to Windows Explorer or Macintosh OS with expanding/collapsing branches (eg, folders).
  - Press "+" to expand, "-" to collapse.
  - Do not click on the "?", they will explore unneeded areas.
- Use the right-hand scroll bar to move up and down the list.
- Use the bottom scroll bar to see items that are too long to display across the screen.
- Click on the node to highlight it, then press "Enter" to display the desired page. It will remain highlighted (boldface print with a box around it).
- It will often help to 'clean up' during or after searches by pressing the "-"s. This will keep the list from becoming too long and cluttered.

Remember:

- Do not click on the links in the browser.
- You can display as many or as few pages as you feel necessary during your search.
- You may only interact with the navigational aid after finish reading the question and press begin.
- If you do not see a link to the page you want in the navigational aid, you may need to try a different 'path'.
- Watch for internal links, and remember to use the browser's scroll bar.

Instructions for the Three-Dimensional Navigational Aid

Arrangement:

- Pages are laid out in space. The pages/links closest to your present location are shown larger than those further away.
- Each page in the web site is listed (often more than once).
- All the links for a particular page are listed immediately beneath and around it.
  - The home page is shown as a link under the first node.
  - Different colors represent their depth within the site. Green pages are on top, followed by: red, yellow, purple (then the process repeats).
  - These linked pages may have additional links to other pages…and so on.
  - The name listed is either the text from the hyperlink (blue, underlined words) or the title from the destination page.

How to use:

- Click and hold the mouse button down, and aim towards the page which you wish to move closer to. It is best if you start in a black/blank area first.
  - Use the “Shift” key to move faster.
  - Use the “Ctrl” key to move backwards.
- Double-click on the page to display it in the browser window.
- Click and hold in the box surrounding the navigational aid to translate up/down, left/right.
- To move back to your starting point, click the “Menu” button and choose “To Top.”
- Additionally:
  - When there are many pages/links beneath a particular page, you may need to move carefully and slowly towards them. Or use an incremental approach.
  - Often to remove clutter or to see all of the links, you may need to zoom in a great deal to see everything clearly.
  - The pages can ‘jump’ around, keep an eye on them. It may be necessary to use the edge navigation.
  - If you accidentally move a page, simply click in a blank area and don’t worry about it. If you move an item dramatically, press “Reload.”
  - If you highlight some nodes (they will turn gray), simply click in a blank area.

Remember:

- Do not click on the links in the browser.
- You can display as many or as few pages as you feel necessary during your search.
- You may only interact with the navigational aid after finish reading the question and press begin.
- If you do not see a link to the page you want in the navigational aid, you may need to try a different ‘path’.
- Watch for internal links, and remember to use the browser’s scroll bar.

Instructions for the Question/Timer Application

Purpose:

- Will present items for you to look for without experimenters help (I will be out of the room).
- Asks questions (search tasks) for you to find the answer to in the web site, using the navigational aid. Each section will consist of five to six questions.
- Provides opportunity to type in your answer and responds if correct.
- Times the period which you are searching for the answer. Does not time when you are reading the question or typing in your answer.

How to use:

1. Experimenter will load series of questions and leave the room.
2. The question will initially appear in a window centered on the screen and also in the "Look For" area where it will remain during your search. The questions often will present details as to the way you should type in the answer (which information is really needed).
3. When you are ready to start searching, press the "OK" or "CANCEL" buttons on the question window in the center of the screen (or press "Enter") – this will start the timer.
4. Use the navigational aid and try to find the information in the web site. Even if you know the answer, you must locate and display the page which contains the information.
5. When you think you have found the page with the information needed, press the "Found Item" button.
6. At this point, you will be able to type in your answer. Afterwards, press "Enter".
7. If you typed in the correct answer, the computer will respond with a 'correct' button and sound. Press this button to be presented with the next question. Go to step 2.
8. If you typed in the wrong answer, the computer will respond with an 'incorrect' button. After you press this button, the timer will resume and you can begin to search again. Go to step 4.
9. A message will be displayed when you have finished with a section of questions. At this point please inform the experimenter.

Additionally…

- If anything abnormal happens during your search, such as the navigational aid breaking or crashing, immediately press the "Pause" button. This will pause the timer and allow the situation to be corrected.
- If after much searching you simply cannot find the answer to a particular question, press "Pause" and let the experimenter know of your difficulties.

Additional Tips:

- With these maps, it is very easy to look "into the future." Concentrate on where you are - you do not have to go to the very last node to find the answer (usually).
- Do not look for the answers in the navigational aid (or in the text on the nodes). Use it only as a guide to find the correct page.
- Remember to read the web pages as you navigate through the site. Only there will you find the answers. Therefore, do not be afraid to open as many or as few pages as you wish.
- The answers are usually not the actual links on a page. They are primarily found in the plain text.
- If you see visit a page that you think contains the answer remember to trust your instincts and maybe read a little closer.
- If you get stuck, it often helps to return to the home page and read through the descriptions located there to re-orient yourself. In other words, the answer may be located in a completely different area of the web site.
- Please be careful about internal links. They will usually be near the top of the screen but will never be shown in the navigational aid. Please use the browser's scroll bar.

APPENDIX 3. SEARCH TASK QUESTIONS AND ANSWERS

One-Dimensional Navigational Aid, ISE WWW Site

Task #	Task Description	Task Solution
1	What is the email address for Robert Williges? (enter the whole address, including @vt.edu)	williges@vt.edu
2	Who is the Vice President of the VT Chapter of the Institute of Industrial Engineers {IIE}? (enter only last name)	Miller
3	What is the room number of the ISE Computational Laboratory? (just the number)	111
4	The Web site contains a road map which shows Blacksburg. What town is shown in the furthest north-west corner? (enter only the town name)	Beckley
5	ISE undergraduates have the "Babcock and XXXXX" scholarship available to them. What is XXXXX?	Wilcox
6	What student is doing research on the project, "Empirical Investigation of Sociotechnical Issues in Engineering Design"? (enter only last name)	Meredith
7	You are finished with this section. Please ask for help to begin the next section.	

One-Dimensional Navigational Aid, HFEC WWW Site

Task #	Task Description	Task Solution
1	What model of SGI (Silicon Graphics computer) does the HCI laboratory own?	Indigo Extreme
2	How many former students are listed as affiliated with the Human Factors Engineerinc Center?	20
3	How many macroergonomics projects is 'Brian Kleiner' listed as a principal investigator? (enter number, #)	7
4	Garry Robinson received a B.S. in M.E. from which state's university? (enter whole state, not abbreviation)	Mississippi
5	The floorplan of the Usability Methods Research Laboratory shows how many chairs in the upper-left conference room? (hint: the UMRL is not a formal part of the HFEC)	16
6	Hope Doe graduated with a B.S. from which state's university (hint: student info is listed in more than one location)? (enter whole state, not abbreviation)	South Carolina
7	You are finished with this section. Please ask for help to begin the next section.	

Two-Dimensional Navigational Aid, ISE WWW Site

Task #	*Task Description*	*Task Solution*
1	Who is the sponsor of this research, "Development and Implementation of a Virtual Manufacturing Environment..."?	NIST
2	Which ISE class is a prerequisite to ISE4234? (enter only last four digits)	3204
3	In the robotics lab, what model of IBM industrial robot does the ISE department have? (enter just numbers)	7545
4	What is the phone number for Lisa Smith? (enter just last four digits)	6656
5	What is the president's phone number of the VT Chapter of the American Society of Safety Engineers {ASSE}? (enter only last four digits)	0814
6	On March 19th, David Heyen is scheduled to be here. What company is he from? (enter only first word)	Intel
7	You are finished with this section. Please ask for help to begin the next section.	

Two-Dimensional Navigational Aid, HFEC WWW Site

Task #	*Task Description*	*Task Solution*
1	What is the fax number of the Human Factors Engineering Center? (enter only the last four digits)	3322
2	The HCI Lab is co-directed by Dr. Williges and Dr. XXXXX. Who is XXXXX?	Barfield
3	Which two rooms contain the Macroergonomics Lab? (enter numbers with a dash: ###-###)	565-567
4	Sung Han spoke as a chapter activity of the Human Factors and Ergonomics Society. Which university in Korea is he from? (enter only the city name)	Pohang
5	How high can the spring loaded push-pull gauges go up to in pounds in the Industrial Ergonomics Lab? (enter just number)	500
6	XXXXX and Trist introduced 'Sociotechnical System' theory in the 1960's. Who is XXXXX?	Emery
7	You are finished with this section. Please ask for help to begin the next section.	

Three-Dimensional Navigational Aid, ISE WWW Site

Task #	Task Description	Task Solution
1	Adar Kalir is a graduate student in the ISE XXXXX Engineering Option. What is XXXXX?	Manufacturing
2	Harry XXXXX was the head of the ISE department from 1975 to 1979. What is his last name (XXXXX)?	Snyder
3	Which STAT class is required in the ISE human factors (HFE) Ph.D. program? (enter last four digits)	4504
4	Who is the co-operative (co-op) engineering advisor/director? (enter only last name)	Deisenroth
5	Which faculty member appears to be doing the most research in operations research? (enter only last name)	Sherali
6	Who is the director of the Modern Manufacturing Processes Laboratory? (enter only last name)	Shewchuk
7	You are finished with this section. Please ask for help to begin the next section.	

Three-Dimensional Navigational Aid, HFEC WWW Site

Task #	Task Description	Task Solution
1	How many total journal articles are attributed to people in the Macroergonomics Laboratory?	13
2	What year did Dave Herlong complete his thesis (hint: student info is listed in more than one location)? (enter four digits,	1988
3	What is the last name of the person to contact to receive a graduate application for HFE?	Cole
4	What is John Winter's work telephone number (hint: student info is listed in more than one location)? (enter last four digits)	9086
5	Sophie XXXX is a graduate stduent on research sponsored by Kodak. Who is XXXXX?	Davoine
6	Which Volvo GM division is a sponsor of macroergonomic research? (enter two words)	Heavy Truck
7	You are finished with this section. Please ask for help to begin the next section.	

APPENDIX 4: SURVEY QUESTIONNAIRES

A. Preliminary Survey

B. After-Task Survey

C. Final Survey

Preliminary Survey

Thank you for participating in this study. Before you begin, I would like to ask you to fill out this survey on your experience and background. You may circle your selection.

Age:______ Gender: male/female Major:________________________________

How often do you use the Internet and a World Wide Web Browser like Netscape Navigator or Microsoft Internet Explorer?

At least once-a-day	Several times per week	Around once per week	Several times per month	Around once per month	Several times per year	Around once per year	Every few years	I have never done this
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

How often do you perform activities on a computer which involve significant hand-eye coordination such as playing computer games?

At least once-a-day	Several times per week	Around once per week	Several times per month	Around once per month	Several times per year	Around once per year	Every few years	I have never done this
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

How often do you use a computer (for word-processing, email, spreadsheets, or any other miscellaneous task)?

At least once-a-day	Several times per week	Around once per week	Several times per month	Around once per month	Several times per year	Around once per year	Every few years	I have never done this
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

While browsing on an Internet site, have you ever become "lost" amongst all the web pages, not remembering how to get back to where you were, or how to get where you want to be?

This always happens to me	…very frequently…	…frequently …	…often	…occasionally…	…not often…	…infrequently…	…very infrequently …	This never happens to me
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

After-Task Survey

This survey is gauges your reactions to the task and web site you *most recently completed*. You may circle your selection.

Please rate how well you could use the navigational aid.

Very Easy	Easy	Average	Difficult	Very Difficult
(1)	(2)	(3)	(4)	(5)

Please rate your experience when using the navigational aid.

Very Enjoyable	Enjoyable	Average	Unpleasant	Very Unpleasant
(1)	(2)	(3)	(4)	(5)

Please rate the legibility of the text displayed in the navigational aid.

Very Easy to Read	Easy to read	Average	Hard to Read	Very Hard to Read
(1)	(2)	(3)	(4)	(5)

Please rate the organization of the items (pages and links) within the navigational aid.

Very Clear	Clear	Average	Confusing	Very Confusing
(1)	(2)	(3)	(4)	(5)

While browsing on the last web site, did you ever become "lost" amongst all the web pages, not remembering how to get back to where you were, or how to get where you want to be?

This always happened to me	…very frequently…	…frequently …	…often	…occasional ly…	…not often…	…infrequent ly…	…very infrequently …	This never happened to me
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Assuming:

- You were given the same search tasks to perform.
- You had to use exactly the same web site with a browser by itself (without a search engine).
- You were never provided with nor viewed any navigational aid for the web site.

The result would have been….

It would have been <u>(select your answer)</u> to find the answers to the search tasks.

Much Easier	Easier	The Same	Harder	Much Harder
(1)	(2)	(3)	(4)	(5)

The amount of time required to find the answers would have been…

Much Less	Less	The Same	More	Much More
(1)	(2)	(3)	(4)	(5)

The number of pages I would have needed to visit to find the answers would have been…

Much Less	Less	The Same	More	Much More
(1)	(2)	(3)	(4)	(5)

Final Survey

Thanks again for your time. Please complete this last survey regarding all three of the navigational aids which you experienced during this study. You may circle your response. {1D = the outline list, 2D = the spider-web map, 3D = the fly through space, ISE = Industrial & Systems Engineering Web Site, HFEC = Human Factors Engineering Center Web Site}

For the ISE web site, please rank your preference of navigational aids (1=best/first choice, 2=second choice, 3=last choice).

1D____ 2D____ 3D____

For the HFEC web site, please rank your preference of navigational aids (1=best/first choice, 2=second choice, 3=last choice).

1D____ 2D____ 3D____

Overall, please rank your preference of navigational aids (1=best/first choice, 2=second choice, 3=last choice).

1D____ 2D____ 3D____

Please tell me which features you liked and disliked about the 1D navigational aid.
Liked: *Disliked:*

Please tell me which features you liked and disliked about the 2D navigational aid.
Liked: *Disliked:*

Please tell me which features you liked and disliked about the 3D navigational aid.
Liked: *Disliked:*

While exploring the internet, if you were given the option to use a navigational aid in addition to the regular browser would you use it?

Yes No

Why or why not? (you may write your comments below or on back of this sheet).

APPENDIX 5. PARTICIPANT RESPONCES TO SURVEY

Subject ID: 1

Features liked on the 1D map:
Simple, no trick buttons

Features disliked on the 1D map:
Got too cluttered - couldn't see all the pages at one time

Features liked on the 2D map:
Could see most of the Web sites at one time

Features disliked on the 2D map:
Kind of slower

Features liked on the 3D map:
Able to zoom in and out quickly and easily

Features disliked on the 3D map:
The "jumping" of the Websites off the screen

Would use?
YES

Why or Why Not:
Yes, if I knew exactly what I was looking for. That way I wouldn't spend too much time wandering. But if I only had a vague idea, sometimes wandering can help narrow down a topic.

Subject ID: 2

Features liked on the 1D map:

Features disliked on the 1D map:
Tends to be cluttered on screen as the branches unfold all in-line with the previous.

Features liked on the 2D map:
The ability to see multiple links on screen at once (without having to scroll very far).

Features disliked on the 2D map:
Kind of slow redrawing as it moves.

Features liked on the 3D map:
The ability to scroll through the depths of the site and switch directions to scroll back out.

Features disliked on the 3D map:
It's often hard to tell what's adjacent to what when they are all bunched up together.

Would use?
YES

Why or Why Not:
The aid helps to jump from one location of the site to another when there aren't any links provided. It also provides a graphical overview of the entire site to help keep you oriented.

Subject ID: 3

Features liked on the 1D map:
Not much

Features disliked on the 1D map:
got way too long really quickly

Features liked on the 2D map:
Very easy to use. Could scroll through just about the whole site easily

Features disliked on the 2D map:
didn't really center the whole pic, just the home page

Features liked on the 3D map:
easy to understand layout

Features disliked on the 3D map:
very jerky. It seems like there way too much zooming to do

Would use?
YES

Why or Why Not:
2D only. Can make browsing when looking for a particular item easier, can be confusing when it comes to internal links.

Subject ID: 4

Features liked on the 1D map:
Simple, easy to read

Features disliked on the 1D map:
Could be overwhelmed with extraneous sites

Features liked on the 2D map:
Organization

Features disliked on the 2D map:
Scrolling and moving between nodes was difficult

Features liked on the 3D map:
Color-coded

Features disliked on the 3D map:
Scrolling and hard to read

Would use?
YES

Why or Why Not:
They, like site maps, helped me to scan quickly through large, complex Websites. However, they would be useless on easy-to-use sites like cnet or altavista.

Subject ID: 5

Features liked on the 1D map:
logical order

Features disliked on the 1D map:
didn't add much to using no guide

Features liked on the 2D map:
connectivity

Features disliked on the 2D map:
again, seemed, unneeded

Features liked on the 3D map:
perhaps color coding was useful (sort of)

Features disliked on the 3D map:
organization appeared chaotic; difficult to read and to access items

Would use?
NO

Why or Why Not:
I didn't find any gain, in fact a barrier between myself and the Web page. The embedded logic of the page was sufficient in all these cases - in fact often more apparent than when using the navigational aid.

Subject ID: 6

Features liked on the 1D map:
familiar interface

Features disliked on the 1D map:
easy get buried deep in sub-folders

Features liked on the 2D map:
can see a lot of information at once; easy to navigate

Features disliked on the 2D map:

Features liked on the 3D map:
easier to conceptualize content of a given site in 3d space

Features disliked on the 3D map:
slow, jerky; needs some refinement

Would use?
YES

Why or Why Not:
It is good to have options and alternatives. I like being able to evaluate the content of a site without having to download multiple pages. This probably makes a bigger difference with slower internet connections.

Subject ID: 7

Features liked on the 1D map:
More intuitive interface

Features disliked on the 1D map:
Less efficient usage of space; too linear

Features liked on the 2D map:
Could see more on screen at once

Features disliked on the 2D map:
Dead ends

Features liked on the 3D map:
Better feel for the layout of the site

Features disliked on the 3D map:
"Jumpy"; further back URL's obscured by closer ones

Would use?
YES

Why or Why Not:
I would use it if the Web sites became more well suited for aid use, and if the aid took up less than 1/2 of the screen, or if it would automatically retract.

Subject ID: 8

Features liked on the 1D map:
You could easily see where everything is.

Features disliked on the 1D map:
It can easily become a long jumbled list.

Features liked on the 2D map:
It was easy to control.

Features disliked on the 2D map:
Sometimes hard to read.

Features liked on the 3D map:
It was color coded.

Features disliked on the 3D map:
The jumping and it was hard to read until you zoom in pretty far.

Would use?
YES

Why or Why Not:
It gives you some idea about where you are and where you can go without having to hit the back button all of the time and becoming lost.

Subject ID: 9

Features liked on the 1D map:
I liked the feature of just clinking on the + or -.

Features disliked on the 1D map:
Not as fast as navigating with the 2D.

Features liked on the 2D map:
The design of the tree trunk was great!

Features disliked on the 2D map:
Some of the wording was confusing where there were labs with similar names.

Features liked on the 3D map:
The colors.

Features disliked on the 3D map:
Movement was too fast for me.

Would use?
YES

Why or Why Not:
2D Interesting to use.

Subject ID: 10

Features liked on the 1D map:
That everything was "lined up" for you.

Features disliked on the 1D map:
That sometimes you can't see everything available.

Features liked on the 2D map:
That you can see most everything.

Features disliked on the 2D map:
The many links extending from the page made it a little confusing.

Features liked on the 3D map:
The "flying through space" aspect.

Features disliked on the 3D map:
You can't see everything available.

Would use?
YES

Why or Why Not:
Yes, sometimes, if I was searching for specific things. Maybe instead of using a search engine to locate Websites.

Subject ID: 11

Features liked on the 1D map:

Features disliked on the 1D map:

Features liked on the 2D map:
It was simple -- not confusing.

Features disliked on the 2D map:
But it was confusing, but the nodes weren't labeled as well as they could have been.

Features liked on the 3D map:
It seemed like it may have had the most potential.

Features disliked on the 3D map:
But it also seemed like it will be more difficult to master.

Would use?
YES

Why or Why Not:
They offer a clear benefit, if they aren't too complicated.

Subject ID: 12

Features liked on the 1D map:
Not so much stuff on the screen. You can choose what you want opened.

Features disliked on the 1D map:
Some pages seemed to be listed too often causing more clutter on the screen.

Features liked on the 2D map:
could skip some pages by going directly to others.

Features disliked on the 2D map:
Hard to move around from one section to another.

Features liked on the 3D map:
Ability to zoom in and see what was ahead.

Features disliked on the 3D map:
Was sometimes difficult to pull out of a section.

Would use?
YES

Why or Why Not:
It usually allows you to skip more pages thus taking less time.

APPENDIX 6: RESULTS FROM INTERACTION ANALYSIS

A. AxWxM Interaction for Search Time

B. AxWxTxM Interaction for Page Visits

C. WxTxZ Interaction for Total Items Found

AxWxM Interaction for Search Time

This Treatment Combination …	Is Significantly Different (alpha <.05) from These Treatment Combinations…
323	221, 222, 322, 122
213	221, 222, 123, 313, 112
113	122, 123, 313, 112, 311, 121, 223, 211, 312

<u>Notation:</u>

Numbers reflect the various factor levels within the AxWxM Interaction:

AWM:

A: (1- 1D Navigational Aid, 2- 2D Navigational Aid, 3- 3D Navigational Aid)

W: (1- Small/HFEC Web Site, 2- Large/ISE Web Site)

M: (1- Low Visual Memory, 2- Middle Visual Memory, 3- High Visual Memory Group)

AxWxTxM Interaction for Page Visits

This Treatment Combination …	Is Significantly Different (alpha <.05) from These Treatment Combinations…
1111	1113
1112	1113, 2112, 2113
1113	1121, 1122, 1123, 1211, 1212, 1213, 1221, 1222, 1223, 2111, 2112, 2113, 2121, 2122, 2123, 2211, 2212, 2213, 2221, 2222, 2223, 3111, 3112, 3113, 3121, 3122, 3123, 3211, 3212, 3213, 3221, 3222, 3223
1121	2112, 2113
1122	2111, 2112, 2113
1123	1222
1222	2213, 3112, 3113, 3213, 3223
2111	2221, 2222, 3221
2112	2121, 2122, 2211, 2212, 2221, 2222, 2223, 3122, 3211, 3212
2113	2121, 2122, 2211, 2212, 2221, 2222, 2223, 3122, 3211, 3212
2222	3213
3112	3221
3213	3221

Notation:

Numbers reflect the various factor levels within the AxWxTxM Interaction:

AWTM:

A: (1- 1D Navigational Aid, 2- 2D Navigational Aid, 3- 3D Navigational Aid)

W: (1- Small/HFEC Web Site, 2- Large/ISE Web Site)

T: (1- Before/First Trial, 2- After/Second Trial)

M: (1- Low Visual Memory, 2- Middle Visual Memory, 3- High Visual Memory Group)

WxTxZ Interaction for Total Items Found

This Treatment Combination …	Is Significantly Different (alpha <.05) from These Treatment Combinations…
121	111, 112, 122, 211, 221, 212, 222
111	112, 122, 211, 221, 212, 222
112	212, 222
122	212, 222
211	212, 222
221	222

Notation:

Numbers reflect the various factor levels within the WxTxZ Interaction:

WTZ:

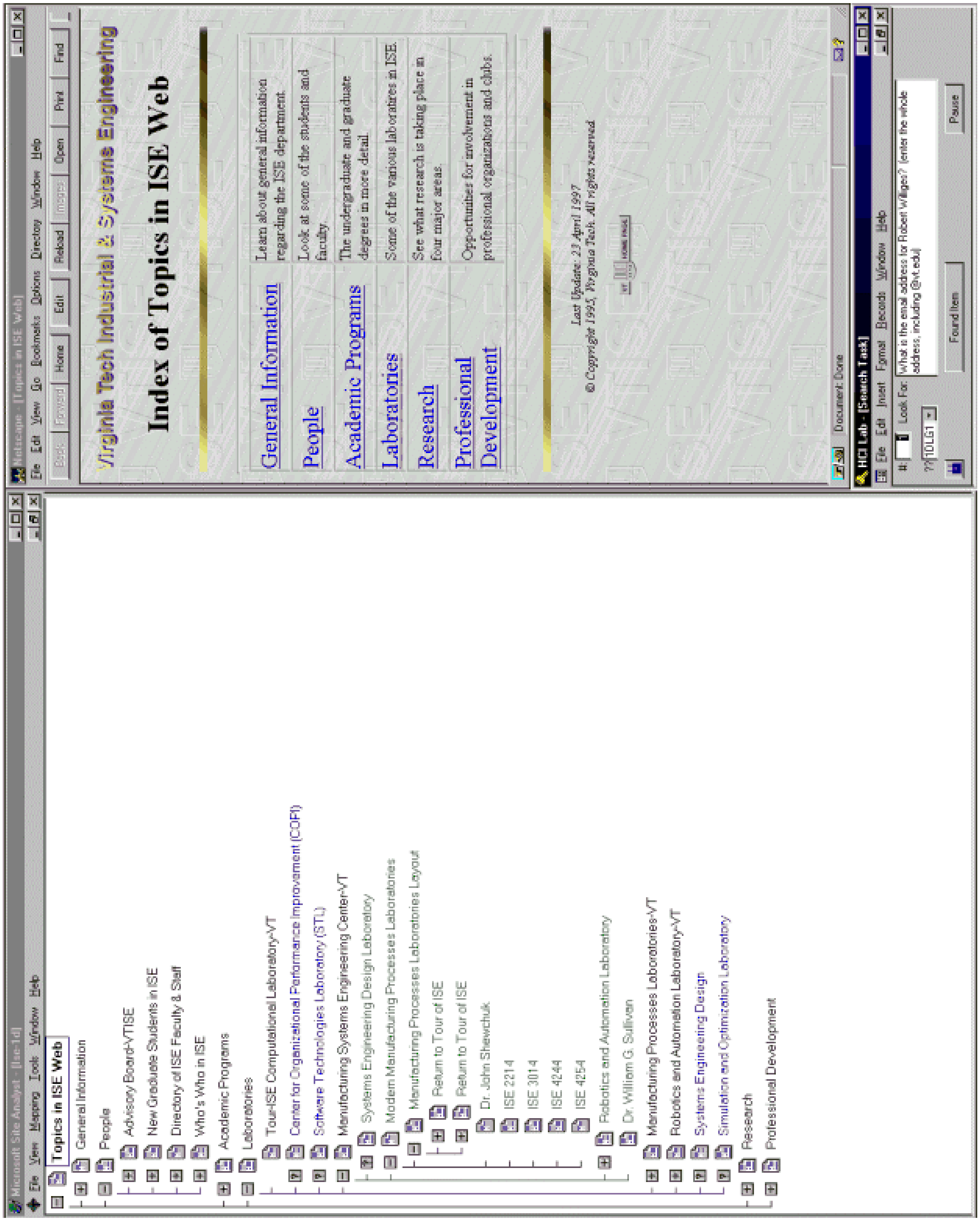
W: (1- Small/HFEC Web Site, 2- Large/ISE Web Site)

T: (1- Before/First Trial, 2- After/Second Trial)

Z: (1- Low Spatial Ability, 2- High Spatial Group)

APPENDIX 7. SCREEN PICTURES

1D – ISE



Microsoft Site Analyst - [Ise-1d]
File View Mapping Tools Window Help
Topics in ISE Web
General Information
People
Advisory Board-VTISE
New Graduate Students in ISE
Directory of ISE Faculty & Staff
Who's Who in ISE
Academic Programs
Laboratories
Tour-ISE Computational Laboratory-VT
Center for Organizational Performance Improvement (COPI)
Software Technologies Laboratory (STL)
Manufacturing Systems Engineering Center-VT
Systems Engineering Design Laboratory
Modern Manufacturing Processes Laboratories
Manufacturing Processes Laboratories Layout
Return to Tour of ISE
Return to Tour of ISE
Dr. John Shewchuk
ISE 2214
ISE 3014
ISE 4244
ISE 4254
Robotics and Automation Laboratory
Dr. William G. Sullivan
Manufacturing Processes Laboratories-VT
Robotics and Automation Laboratory-VT
Systems Engineering Design
Simulation and Optimization Laboratory
Research
Professional Development
Netscape - [Topics in ISE Web]
File Edit View Go Bookmarks Options Directory Window Help
Back Forward Home Edit Reload Images Open Print Find
Virginia Tech Industrial & Systems Engineering
Index of Topics in ISE Web
General Information
Learn about general information regarding the ISE department.
People
Look at some of the students and faculty.
Academic Programs
The undergraduate and graduate degrees in more detail.
Laboratories
Some of the various laboratires in ISE.
Research
See what research is taking place in four major areas.
Professional Development
Opportunities for involvement in professional organizations and clubs.
Last Update: 23 April 1997
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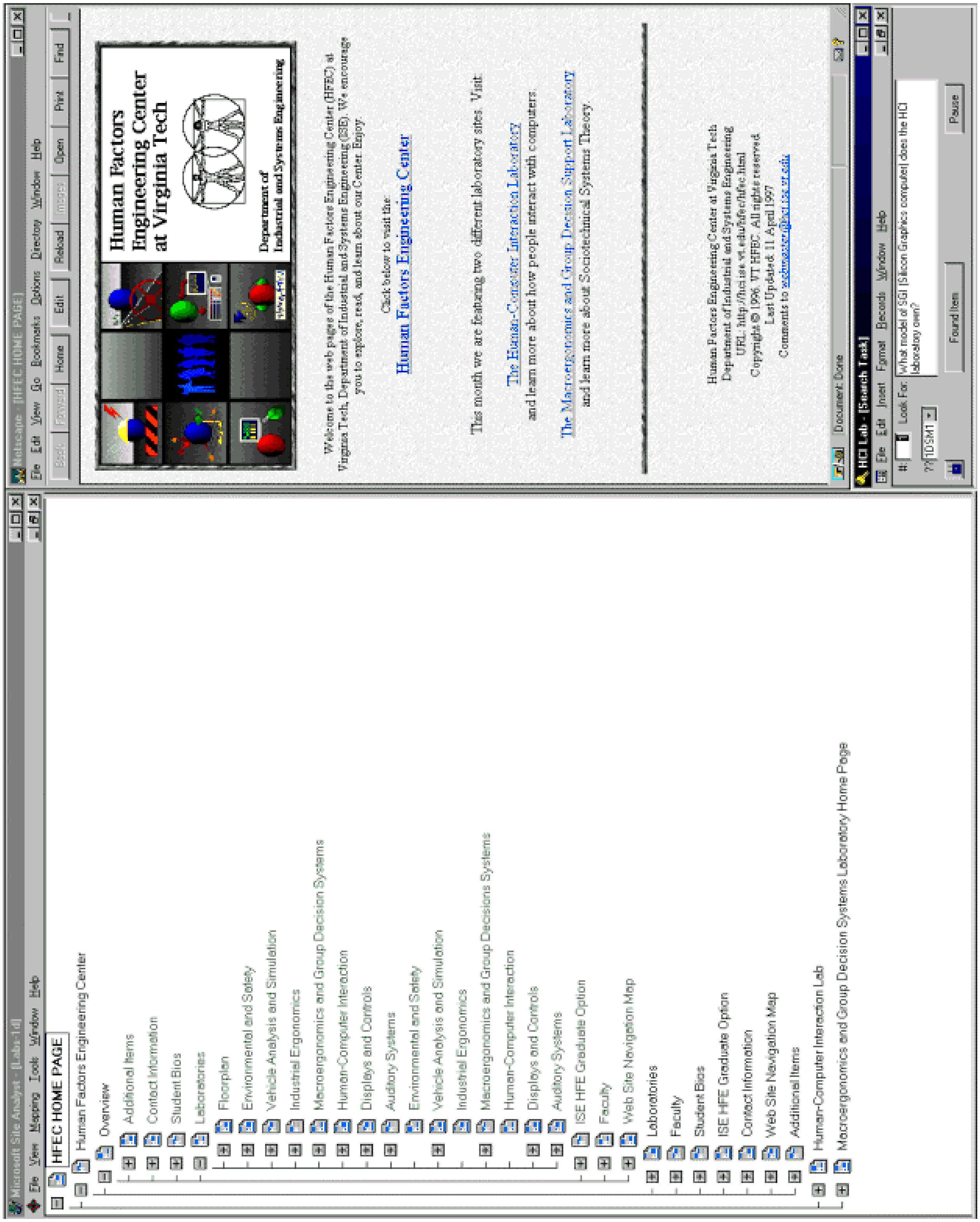
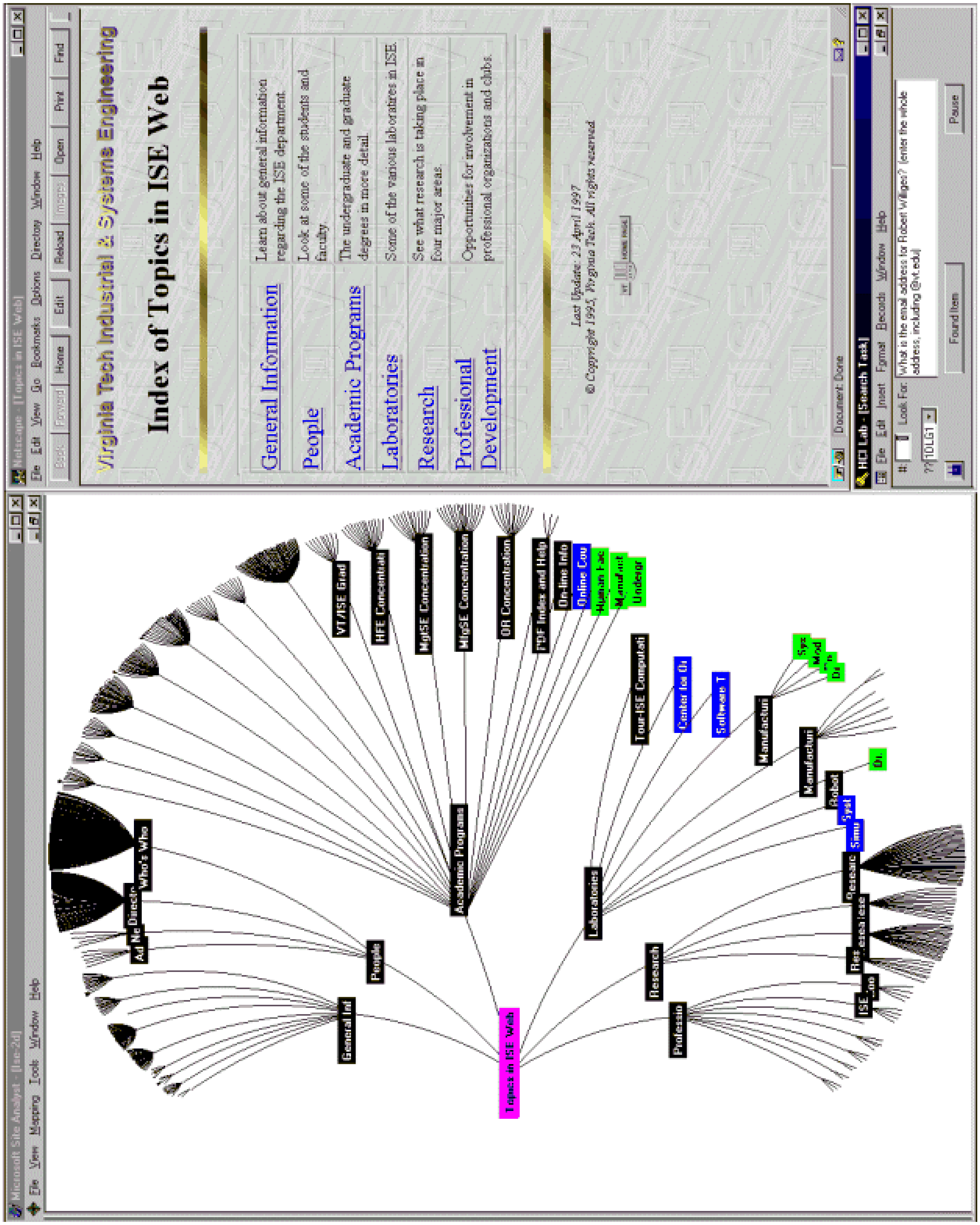
Document: Done
HCI Lab - [Search Task]
File Edit Insert Format Records Window Help
#: Look For:
What is the email address for Robert Willges? (enter the whole address, including @vt.edu)
?? 1DLG1
Found Item
Pause

1D - HFEC


Microsoft Site Analyst - [Labs-1d]
File View Mapping Tools Window Help
HFEC HOME PAGE
Human Factors Engineering Center
Overview
Additional Items
Contact Information
Student Bios
Laboratories
Floorplan
Environmental and Safety
Vehicle Analysis and Simulation
Industrial Ergonomics
Macroergonomics and Group Decision Systems
Human-Computer Interaction
Displays and Controls
Auditory Systems
Environmental and Safety
Vehicle Analysis and Simulation
Industrial Ergonomics
Macroergonomics and Group Decisions Systems
Human-Computer Interaction
Displays and Controls
Auditory Systems
ISE HFE Graduate Option
Faculty
Web Site Navigation Map
Laboratories
Faculty
Student Bios
ISE HFE Graduate Option
Contact Information
Web Site Navigation Map
Additional Items
Human-Computer Interaction Lab
Macroergonomics and Group Decision Systems Laboratory Home Page
Netscape - [HFEC HOME PAGE]
File Edit View Go Bookmarks Options Directory Window Help
Back Forward Home Edit Reload Images Open Print Find
Human Factors Engineering Center at Virginia Tech
Department of Industrial and Systems Engineering
Welcome to the web pages of the Human Factors Engineering Center (HFEC) at Virginia Tech, Department of Industrial and Systems Engineering (ISE). We encourage you to explore, read, and learn about our Center. Enjoy.
Click below to visit the:
Human Factors Engineering Center
This month we are featuring two different laboratory sites. Visit
The Human-Computer Interaction Laboratory
and learn more about how people interact with computers.
The Macroergonomics and Group Decision Support Laboratory
and learn more about Sociotechnical Systems Theory.
Human Factors Engineering Center at Virginia Tech
Department of Industrial and Systems Engineering
URL: http://hci.ise.vt.edu/hfec/hfec.html
Copyright © 1996, VT HFEC. All rights reserved.
Last Updated: 11 April 1997
Comments to webmaster@hci.ise.vt.edu
Document: Done
HCI Lab - [Search Task]
File Edit Insert Format Records Window Help
#: 1 Look For: What model of SGI (Silicon Graphics computer) does the HCI laboratory own?
?? 1DSM1
Found Item
Pause

2D - ISE



Virginia Tech Industrial & Systems Engineering
Index of Topics in ISE Web
General Information
Learn about general information regarding the ISE department.
People
Look at some of the students and faculty.
Academic Programs
The undergraduate and graduate degrees in more detail.
Laboratories
Some of the various laboratories in ISE.
Research
See what research is taking place in four major areas.
Professional Development
Opportunities for involvement in professional organizations and clubs.
Last Update: 23 April 1997
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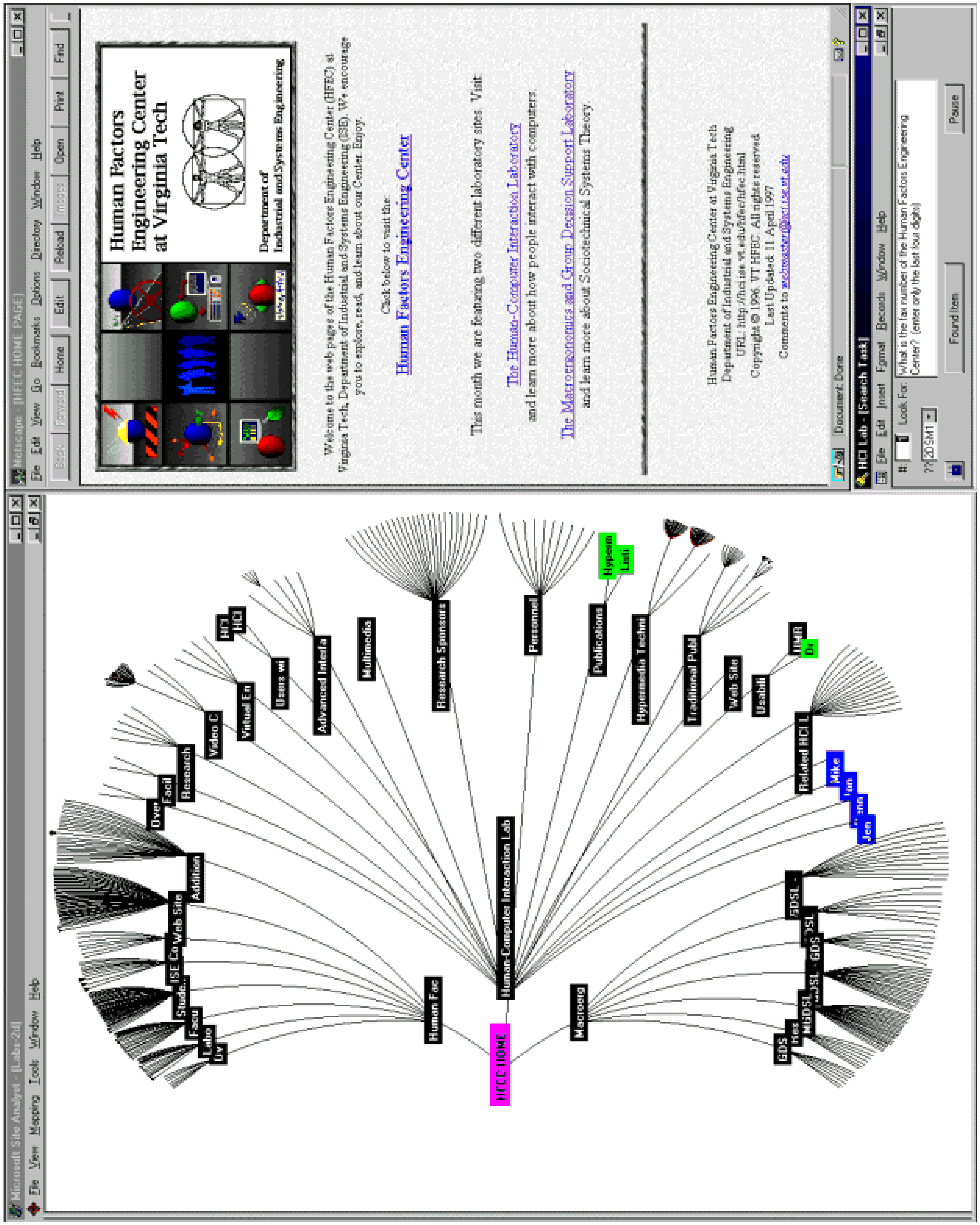
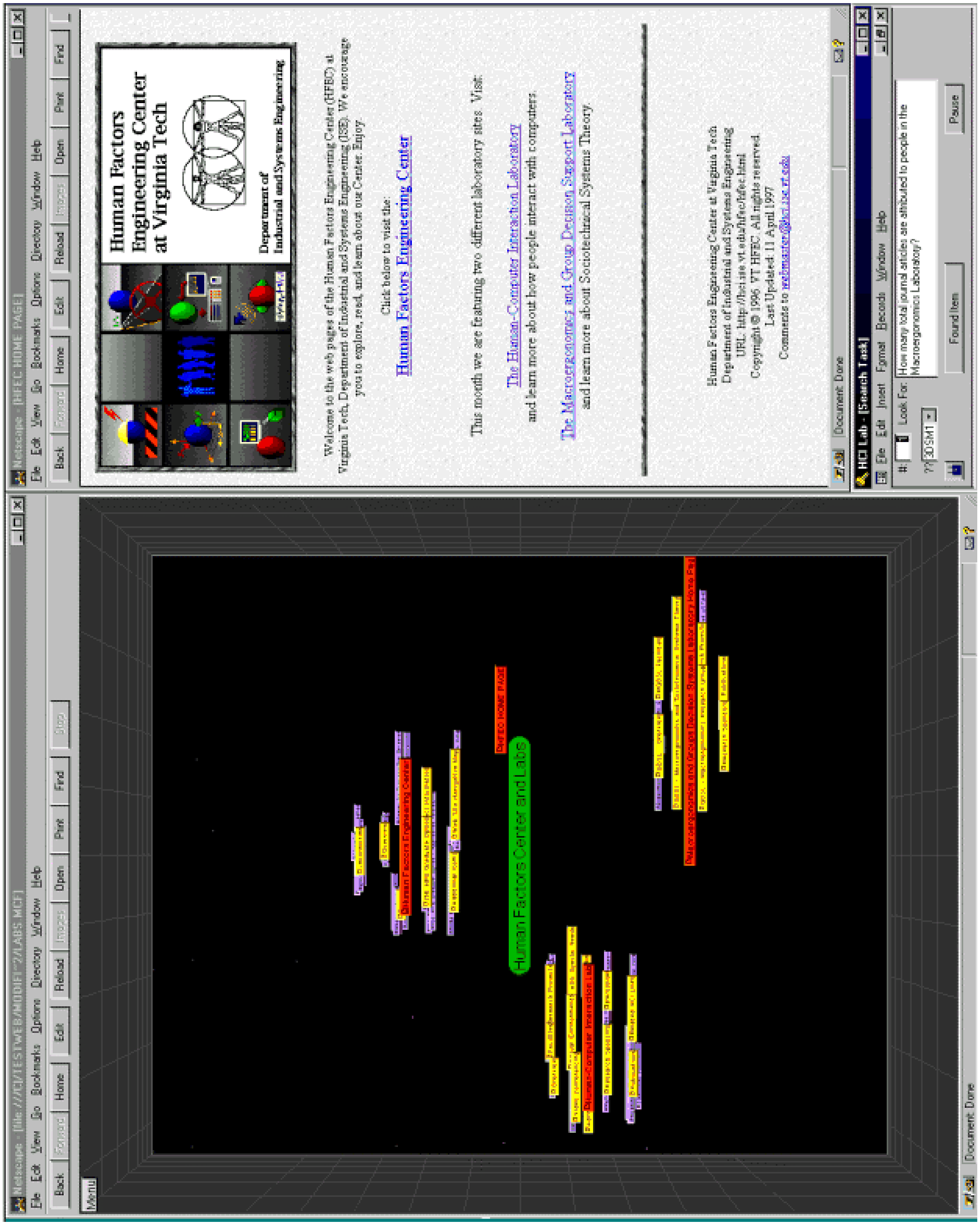
Topics in ISE Web
General Inf
People
Who's Who
Academic Programs
Laboratories
Research
VT/ISE Grad
HFE Concentrati
MgtSE Concentration
MfgSE Concentration
OR Concentration
PDF Index and Help
On-line Info
What is the email address for Robert Willges? (enter the whole address, including @vt.edu)
Found Item
Pause

2D - HFEC

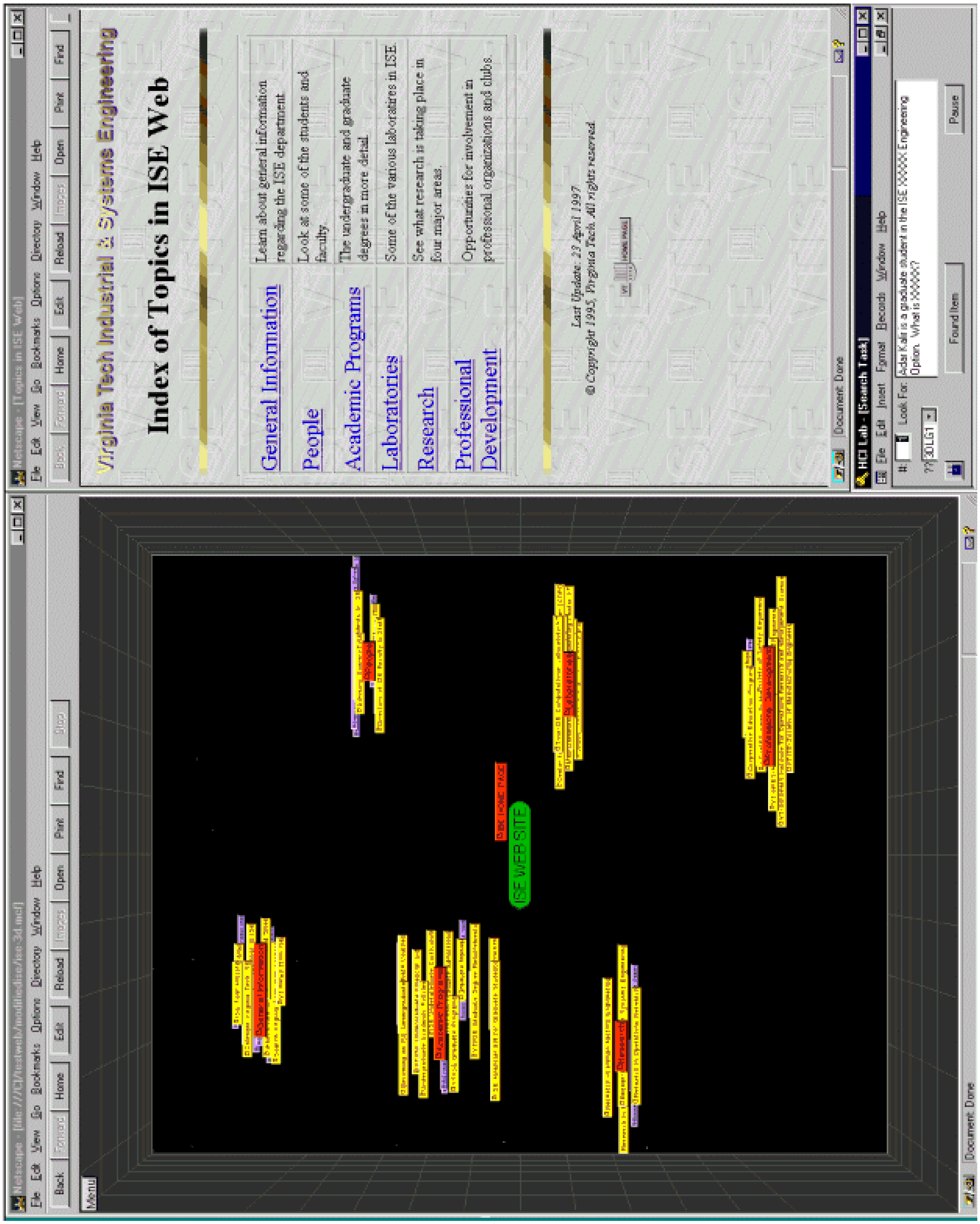


Human Factors Engineering Center at Virginia Tech
Human Factors Engineering Center
HFEC HOME
Human-Computer Interaction Lab

3D - HFEC


Human Factors Engineering Center at Virginia Tech
Human Factors Engineering Center
Human Factors Center and Labs

3D – ISE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Academic Programs
Laboratories
Research
Professional Development
ISE WEB SITE

APPENDIX 8: NAVIGATIONAL AID MOVIES

(All movies depict moving towards the “People” section in the ISE site.)

One-Dimensional

Two-Dimensional

Three-Dimensional

VITA

Brandon L. Satanek

Brandon Satanek attended The Pennsylvania State University from August 1990 till May 1995. He graduated with a Bachelor of Science in Industrial Engineering. During and following this time he worked as a co-op and full-time Industrial Engineer with Tritex Sportswear in Altoona, Pennsylvania. Starting in August of 1996 he began work on his Master of Science degree at Virginia Tech in the Industrial and Systems Engineering Department. He followed the human factors option area and worked in the Human-Computer Interaction Laboratory while pursuing similar interests. After graduating in May 1998, he was employed by Analysts International Corporation as a human factors engineering consultant with Lexmark International in Lexington, Kentucky.