Cognitive and Task Influences on Web Searching Behavior

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Users' individual differences and tasks are important factors that influence the use of information systems. Two independent investigations were conducted to study the impact of differences in users' cognition and search tasks on Web search activities and outcomes. Strong task effects were found on search activities and outcomes, whereas interactions between cognitive and task variables were found on search activities only. These results imply that the flexibility of the Web and Web search engines allows different users to complete different search tasks successfully. However, the search techniques used and the efficiency of the searches appear to depend on how well the individual searcher fits with the specific task.

Introduction

The development of the World Wide Web has produced a significant increase in the use of hypermedia for information retrieval. The Web allows users to access databases and other on-line information resources within its hypermedia framework. The Web also supports flexible presentations of information and provides more options for finding information. Research investigating the use of hypermedia has suggested that differences in users' individual characteristics may be one of the most influential factors affecting search behavior (Ford, Wood, & Walsh, 1994; Qiu, 1993). Nielsen (1989) noted that individual differences in users accounted for four of the 10 most important factors affecting the usability of hypertext systems. He also found that task differences accounted for two of these 10 factors.

The investigations reported here were designed to explore the flexibility of information retrieval on the Web, and to investigate how system, task, and individual characteristics influence Web searching. Although the studies were conducted independently, and analyzed different variables, they each contributed to our collective understanding of Web searching, and allowed us to triangulate on specific factors that influence how users search for information on the Web.

The theoretical foundation of this research is the "user-oriented IR research approach" identified by Ingwersen (1992). This approach suggests that information system design and evaluation should be based on a firm understanding of how users interact with the information systems. Accordingly, our approach to understanding the Web is to examine in detail how users search for information on the Web, and to investigate the factors that influence how users use this particular type of information technology. Within the user-oriented approach, our specific theoretical focus was interactionism (Allen, 1997). We believe that search behaviors (like many other behaviors) are influenced by the interaction between individual characteristics and social contexts. Accordingly, our experiments were designed to address how individual cognitive characteristics (cognitive ability, cognitive style, and problem-solving style) interact with task differences to influence Web searching behavior and outcomes.

Related Research

Users' Individual Differences and Information Search

Using an information system requires at least three different cognitive processes: information seeking, knowledge acquisition, and problem solving. Individual differences in cognition influence how these cognitive processes occur. These investigations studied three individual differences in cognition: cognitive abilities, cognitive style, and problem-solving ability/style.
Cognitive Abilities

Individual users of information systems have different levels of cognitive abilities. These abilities influence the performance of the cognitive processes of information retrieval discussed above. When taken together, cognitive abilities are generally understood as "intelligence." However, intelligence has many different aspects, and factor analysis of results of intelligence testing has revealed the factors that contribute to intelligence. These factors are cognitive abilities. Previous research (Allen, 1998, 2000) showed that cognitive abilities influence search performance in a variety of information systems. For example, users with different levels of spatial abilities adopted different search strategies when searching a bibliographic information system. In addition, use of certain system design features (e.g., a "word map" that displayed search vocabulary in two dimensions) varied with levels of cognitive abilities. Some of these system design features were of particular help for users with lower levels of cognitive abilities, while others facilitated the searching of users with higher levels of cognitive abilities.

Cognitive Style

The key to the effective use of information systems is the ability to orchestrate the cognitive processes, and this ability is closely related to cognitive style. Cognitive style is defined as the individual's characteristic way of organizing and processing information (Goldstein & Blackman, 1978), and it has been found to influence the manner in which individuals prefer to learn and receive instructions (Mesick, 1976).

Among different cognitive styles, field dependence/field independence is one of the most extensively researched approaches. Field dependence (FD) versus field independence (FI) cognitive style describes the degree to which an individual's perception or comprehension of information is influenced by the surrounding perceptual field (Jonassen & Grabowski, 1993). FD individuals are more likely to be dominated or influenced by the prevailing field, and tend to be diffuse in their responses. On the other hand, FI individuals are adept at overcoming the influences of the field or embedded context, and are able to experience items as separate and discrete from their backgrounds (Witkin, 1973).

In hypermedia systems where information units are presented through different media and in a loose structure, FD individuals are likely to have difficulties because of their tendency to be easily distracted. In fact, a number of studies have shown that FD individuals do not perform as well as FI individuals using hypermedia information systems. The former tend to find information less accurately and efficiently than the latter (Ellis, Ford, & Wood, 1993; Ford et al., 1994; Korthauer & Koube, 1994). It has also been revealed that FD and FI individuals interact with hypermedia systems differently, although the learning outcomes of the two groups are usually the same (Fitzgerald & Semrau, 1998; Ford & Chen, 2000; Leader & Klein, 1996; Liu & Reed, 1994). In general, the FIs explored the hypermedia system in a linear mode while the FIs navigated in a nonlinear way. Similar effects of cognitive style have been observed in Web searching (Palquist & Kim, 2000; Wang, Hawk, & Tenopir, 2000). The FIs tended to find information more efficiently than the FDs, with shorter search time and fewer search steps, and navigated the Web in a nonlinear mode.

Problem-Solving Style

According to Brown (1991) information seeking is a goal-driven activity in which needs are satisfied through problem solving. This view is comparable to Wilson's model of information seeking (1999), which considers information seeking as a problem-solving process driven to reducing uncertainty. Several models have been developed to understand steps of and actions involved in information search process (Ellis, 1989; Kuhlthau, 1991). Although a number of scholars have understood information seeking to include elements of problem solving, there has been little effort made to investigate the relationship between problem-solving styles and information-seeking behavior in information science literature.

According to Wu and his colleagues (1996), problem-solving style is a tendency to respond in a certain way while addressing problems (not as the steps employed in actually solving problems). Zamble and Gekoski (1994) found that individuals with emotion-focused problem-solving style tended to make themselves feel better about a problem without changing the problem itself. In contrast, individuals with problem-focused style made changes in their situation to make it less stressful or no longer stressful. In an exploratory study, Kim (1999) found that individuals with different problem-solving styles demonstrated different navigational styles on the Web. In general, problem-focused individuals navigated the Web in a nonlinear mode. They also tended to spend more time for front-end analysis, checking nodes available in the same level (i.e., "breadth first"). Emotion-focused individuals, on the other hand, navigated the Web in a linear mode, mainly following embedded links. Their navigation pattern could be characterized by "depth first"—traversing several layers of nodes with little front-end analysis. It was also found that search performance was influenced by searchers’ problem-solving style: problem-focused searchers outperformed emotion-focused ones.

Search Tasks

Ingwersen (1992) pointed out that for effective information retrieval we must understand tasks or problems that the user brings to the system. Information needs and information-seeking processes depend on the task of the user, because the task imposes information requirements that must be met for the task to be completed (Wersig, 1975).
A number of studies were conducted to investigate effects of task on information search behavior, and supported the premise that users’ search performance and/or patterns differ depending on task. In an on-line database system, Allen and Kim (2000) found that higher recall was obtained by participants completing a newspaper article writing task than a term-paper writing task. In another study on on-line database systems, Saracevic and Kantor (1988) found that search task, especially its specificity and complexity, had an impact on the search performance. For example, tasks with broad questions resulted in higher precision while those with specific questions lower precision. Several studies used tasks with different levels of specificity to investigate the impact of tasks on search behavior. Marchionini’s “closed” and “open” tasks (1989), Qiu’s “general” and “specific” tasks (1993), Kim’s “topical” and “factual” tasks (2000), and “subject” and “known-item” searches, typical search tasks of on-line catalog users (Matthews, Lawrence, & Ferguson, 1983), are comparable to Saracevic’s tasks with broad and specific questions. Marchionini (1989), Qiu (1993), and Kim (2000) found that tasks influenced users’ search behaviors on on-line, hypertext, and Web systems, respectively.

There are some other studies analyzing search tasks that users brought to the Web (Jansen, Spink, & Saracevic, 2000; Spink, Wolfram, Jansen, & Saracevic, 2001). These studies relied on transaction logs provided by search engines, and took alternative approach of direct observation of searches. Although revealing popular topic areas of searches, the studies did not investigate relationships between search tasks and search behavior/performance.

**Research Questions and Hypotheses**

The research questions addressed in these investigations were as follows: (a) How do users’ cognitive differences influence Web searching behaviors and outcomes? (b) How do task differences influence Web searching behaviors and outcomes? (c) How do different Web search capabilities contribute to Web searching behaviors and outcomes? (d) How do these three sets of variables (cognitive differences, task differences, and search capability differences) interact with each other to determine Web searching behaviors and outcomes?

These research questions gave rise to a large number of hypotheses. In each case, these hypotheses are listed as alternative hypotheses. The null hypothesis in each case would, of course, be that the specified effect would not be found.

**Effects of Cognitive Variables**

**Cognitive styles.** The hypothesis was that different cognitive styles would be associated with different levels of search activities and outcomes. This hypothesis was tested in Experiment 1.

**Problem-solving styles.** The hypothesis was that different problem-solving styles would be associated with different levels of search activities and outcomes. This hypothesis was tested in Experiment 1.

**Cognitive abilities.** The hypothesis was that different levels of cognitive abilities would be associated with different levels of search activities and outcomes. This hypothesis was tested in Experiment 2.

**Effects of Task Variable**

The hypothesis was that differences in search tasks would be associated with different levels of search activities and outcomes. This hypothesis was tested in both Experiment 1 and Experiment 2.

**Effects of Web Search Capability Variable**

The hypothesis was that search engines with different search capabilities would be associated with different levels of search activities and outcomes. This hypothesis was tested in Experiment 2.

**Interactions between Cognitive, Task, and Search-Capability Variables**

**Interactions between task and cognitive style.** The hypothesis was that different search tasks would be associated with different levels of search activities and outcomes, but only for searchers with specific cognitive styles. This hypothesis was tested in Experiment 1.

**Interactions between task and problem-solving style.** The hypothesis was that different search tasks would be associated with different levels of search activities and outcomes, but only for searchers with specific problem-solving styles. This hypothesis was tested in Experiment 1.

**Interactions between cognitive style and problem-solving style.** The hypothesis was that searchers with different problem-solving styles would be associated with different levels of search activities and outcomes, but only for searchers with specific cognitive style. This hypothesis was tested in Experiment 1.

**Interactions between task and cognitive abilities.** The hypothesis was that different tasks would be associated with different levels of search activities and outcomes, but only for searchers with higher levels of cognitive abilities. This hypothesis was tested in Experiment 2.

**Interactions between task and search engine.** The hypothesis was that different search engines would be associated...
with different levels of search activities and outcomes, but only for a specific task. This hypothesis was tested in Experiment 2.

Interactions between cognitive abilities and search engine. The hypothesis was that different search engines would be associated with different levels of search activities and outcomes, but only for searchers with higher levels of cognitive abilities. This hypothesis was tested in Experiment 2.

Interactions between task, cognitive style, and problem-solving style. The hypothesis was that different combinations of searchers’ cognitive style and problem-solving style would be associated with different levels of search activities and outcomes, but only within specific types of search task. This hypothesis was tested in Experiment 1.

Interactions between task, cognitive abilities, and search engine. The hypothesis was that different combinations of task and cognitive abilities would be associated with different levels of search activities and outcomes, but only within specific search engines. This hypothesis was tested in Experiment 2.

Research Design

Participants

Eighty individuals participated in each of these studies. This number was selected to provide adequate power for statistical analyses, and to ensure that the sample reflected the population of university students. All of the participants were drawn from the general student population of the University of Missouri–Columbia, and were recruited through ads posted on campus. All participants were volunteers, and were offered monetary compensation for their participation. Analysis of the demographics of the participant groups suggested that they were a representative cross-section of the student body of this University. In Experiment 1, 33.8% of the participants were male, whereas 48.8% in Experiment 2. In both experiments, participants came from a wide number of disciplines. They were, for the most part, frequent users of the Web to find information. At least weekly use was reported by 98% of participants in Experiment 1 and by 87.5% of participants in Experiment 2.

Experimental Apparatus

Netscape Navigator 4.6 was used as the browser in both experiments. Netscape is one of the most widely used Web browsers, and the version used was the current version at the time of data collection. Using a scan converter and a videotape recorder, all the screen displays were videotaped. In Experiment 1, LittleBrother, a commercially available software program, was used to record all the URLs of Web pages visited and the duration of each visit. In Experiment 2, comments of participants were also recorded, using a microphone connected to the videotape recorder.

Independent Variables

Experiment 1. There were three independent variables in this experiment: cognitive style, problem-solving style, and search tasks. The participant’s cognitive style was determined by the Group Embedded Figure Test (GEFT) (Olman, Raskin, & Witkin, 1971). The GEFT is a test that is widely accepted and used for determining individuals’ cognitive styles. Based on a median split of scores from the GEFT, the participants were classified as either FD or FL.

Participants’ assessments of their own problem-solving ability/style were determined by the Problem-Solving Inventory (PSI) (Heppner, 1988). The PSI is a standardized paper-and-pencil test, which takes about 15 minutes to complete. The total score of the PSI is considered as the best overall index of one’s self-assessed problem-solving ability/style. Overall, low scores on the PSI indicate a positive appraisal of problem-solving ability/style (toward problem-focused style) while high PSI scores a negative appraisal (toward emotion-focused style). This problem-solving style variable was dichotomized using a median split.

Each participant was assigned two search tasks of different types: a “known-item” search and a “subject” search task. The operational definition of known-item search is a task requiring the searcher to find a piece of information that is known to exist and to give a specific answer to the question given. The target information is located in only one place. A subject search task, on the other hand, is defined as a task requiring the searcher to find different pieces of information that are related to the subject given and regarded as useful to the searcher. These tasks were designed to be relevant to the context in which the participants—university students—were embedded. The known-item search task was presented as follows:

Assume that your graduation is coming closer. You have been thinking of several options for your future, and one of the options is to pursue further studies in a graduate school. You are interested in pursuing your graduate studies at the University of Missouri–Columbia. You have decided to learn more about the requirements for the admission. Find information on general (not department specific) requirements for admission, for U.S. students applying for the MU graduate program. Bookmark the Web page on which you find the information.

The subject search task was presented as follows:

Assume that your graduation is coming closer. Before your graduation, you want to collect information related to your future job and career. Find any information that you think will be useful for getting a job and for planning your future career. Bookmark the Web pages on which you can find useful information.
Experiment 2. There were also three independent variables in this experiment: search engines used, cognitive abilities of users, and tasks. Participants were assigned to one of four different search engines, selected to represent the variety of Web search engines available to users. Although they were free to switch to any other search engine, most participants completed their search using the one engine to which they were assigned. The search engines were selected to represent a realistic set of search engine choices, including a pure search engine (AltaVista), a directory-driven search system (Lycos), a hybrid search/directory approach (Excite), and a metacrawler (GoNet). The performance of many of these search engines has been studied previously (Gordon & Pathak, 1999; Su & Chen, 1999; Su, Chen & Dong, 1988). This previous research provided a baseline measure of search activities of users, with which we could compare the search activities of our participants. It appeared that participants in this investigation used the search engines in typical ways, and that the experimental situation produced behaviors similar to those that occur in uncontrolled searching.

Three cognitive abilities (perceptual speed, spatial scanning, and logical reasoning) were tested in this research. All of these abilities had been shown in previous research to be associated with differences in search activities and outcomes when university students searched bibliographic databases. It was hypothesized that similar differences in search activities and outcomes would be associated with different levels of these abilities in students searching the Web. The three abilities were tested using pencil-and-paper tests drawn from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Dermen, 1976).

Perceptual speed, tested using the Identical Pictures Test, is speed in comparing figures or symbols, or in searching through a visual field. Spatial scanning, tested using the Map Planning Test, is speed in exploring visually a wide or complicated spatial field. Logical reasoning, tested using the Diagramming Relationships Test, is the ability to evaluate the correctness of a conclusion or an answer.

Tasks are understood as being embedded in contexts. In this research, the participants were university students. The tasks were designed to generate different levels of search activity and different search outcomes, while remaining relevant to the context in which the participants were embedded. The first task asked users to complete a Web search preliminary to writing a term paper. The instruction read:

A few minutes ago you read an article on a topic. Now, assume that you have been asked to write an article in the student newspaper on this topic. To do this, you want to find additional information on the topic. You will be searching the Web to find as many sites as you can about the topic so that you can write a well-informed article. You will be bookmarking all of the sites that you think are useful.

Dependent Variables

The dependent variables were chosen to reflect a participant’s search behavior. In these studies, two different groups of dependent measures were adopted: search performance/outcome, and search activities. Dependent variables used for measuring search performance included precision and recall. In Experiment 1, relevant Web pages on the Web site were operationally defined as pages retrieved and bookmarked by at least 10% of the participant group. For calculating the recall ratio, the number of relevant Web pages retrieved by each participant was divided by the total number of relevant pages. For the precision ratio, the number of relevant documents retrieved by a participant was divided by the total number of Web pages retrieved. In Experiment 2, relevant Web sites were operationally defined as Web sites retrieved and bookmarked by at least two searchers, and recall and precision were calculated as in Experiment 1.

Measures of search activity included average time spent, average number of Web sites viewed, average number of bookmarks made, and average number of times a search/navigational tool was used for completing a search task. Search/navigation tools included keyword searches, vocabulary suggestion systems, embedded links, and jump options (including Go, History, etc.).

Procedure

Experiment 1. First, the PSI and GEFT were administered. Participants were also asked to fill out a questionnaire designed to collect data on their experience with computers, the Web, and Web searching, and also demographic information. The lab session started with a brief review of the Web basics, and an explanation of how to navigate the Web using Netscape Navigator 4.6 and how to formulate simple search queries on a search engine.

Then, two search tasks were given to the participants by means of printed instructions for each search task. The order of tasks alternated to minimize the order effect. As a result, half of the participants (n = 40) started their search sessions with the known-item search task and the other half with the subject task. For the subject search, the participants were asked to make bookmarks on the Web pages that they found relevant to the given topic. Making three or more bookmarks was encouraged. For the known-item search task, the participants were asked to make a bookmark of the Web page containing the target information. The participants had to continue searching until they found the target information.
When the participants felt ready to start searching, they asked the researcher to start recording the search session. When the participants completed the first search task, they asked the researcher to stop the recording. After the first task, the participants had a short break to reread the directions for the second search task. When the participants were ready, the recording started in the same manner as the recording of the first search session. The recording of the second search session ended when the searchers indicated completion.

**Experiment 2.** Each participant first completed three tests of cognitive abilities. They then read a brief (two-page) article on the topic of the effects of viewing television violence on childhood aggression. After reading the article, the participants were given one of two tasks.

Participants were assigned the tasks alternately until 40 participants had completed each task. Because the participants completed the task in no particular order, this approach had the effect of randomizing the task conditions. Participants then completed the Web search. Participants were assigned to one of four different search engines. These search engines were assigned in turn to the participants until 20 participants had used each search engine. Again, because the participants completed the task in no particular order, this approach had the effect of randomizing the search engine condition.

No help in Web searching was offered to participants unless they experienced major difficulties (e.g., inadvertently exiting from the browser). Participants were instructed to search until they felt they had enough information, or had exhausted the resources of the Internet. Participants were asked to bookmark any Web site that they considered useful for their searches.

After the Web search, participants completed a brief questionnaire, which asked them about their experience in Web searching, familiarity with computers, and familiarity with the topic of the Web search. This questionnaire also collected data on demographic variables such as age, gender, academic level, and academic discipline.

In both experiments, the influence of independent variables on dependent variables was analyzed using ANOVA.

**Findings**

**Experiment 1**

Data analysis was based on 78 completed searches. For two of the participants, no detailed data was available because the equipment failed to record the search.

**Main Effect for Task**

The hypothesis was that differences in search tasks would be associated with different levels of search outcomes. There was a significant effect for task type on precision ($F(1,74) = 197.2, p < 0.001$). Average precision for the known-item search task was 0.95 whereas average precision for the subject search task was 0.42. There was also a significant effect for task type on recall ($F(1,74) = 3,500.3, p < 0.001$). Average recall for the known-item search task was 1, whereas average recall for the subject search task was 0.15.

It was also hypothesized that differences in search tasks would be associated with different levels of search activities. There was a significant effect for task type on search time ($F(1,74) = 89.22, p < 0.001$). For completing a task, searchers spent more time for the subject search task than for the known-item search task: Mean$_{subject} = 371.71$ sec., Mean$_{known-item} = 147.06$ sec. Similarly, there was a significant effect for task type on the number of Web pages viewed by searchers ($F(1,74) = 123.72, p < 0.001$). Searchers viewed more Web pages for the subject search task than for the known-item search task: Mean$_{subject} = 17.03$, Mean$_{known-item} = 6.76$.

There was also a significant effect for task type on the number of embedded links used ($F(1,74) = 135.84, p < 0.001$). For completing a task, searchers used embedded links more frequently for the subject search task than for the known-item search task: Mean$_{subject} = 16.93$, Mean$_{known-item} = 6.61$. Another significant effect for task type was found on the use of jump tools ($F(1,74) = 14.63, p < 0.001$). Searchers used jump tools more frequently for the subject search task than for the known-item search task: Mean$_{subject} = 0.52$, Mean$_{known-item} = 0.08$. Finally, there was a significant effect for task type on the number of keyword searches completed ($F(1,74) = 36.59, p < 0.001$). In general, searchers used keyword searches more often for the subject search task than for the known-item search task: Mean$_{subject} = 1.25$, Mean$_{known-item} = 0.20$.

**Main Effect for Cognitive Style**

The hypothesis was that different cognitive styles would be associated with different levels of search activities and outcomes. There was no significant main effect for cognitive style.

**Main Effect for Problem-Solving Style**

The hypothesis was that different problem-solving styles would be associated with different levels of search activities and outcomes. There was no significant main effect for problem-solving style on search outcomes. There was, however, a significant effect for problem-solving style on the number of keyword searches used by participants ($F(1,74) = 8.68, p < 0.01$). Overall, searchers who assessed their problem-solving ability/style negatively (searchers with emotion-focused problem-solving style) used keyword searches more frequently than those who assessed their problem-solving ability/style positively (searchers with problem-focused problem-solving style): Mean$_{negative} = 1.02$, Mean$_{positive} = 0.43$. 
TABLE 1. The number of Web pages viewed: task by problem-solving style interaction.

<table>
<thead>
<tr>
<th></th>
<th>Known-item search task</th>
<th>Subject search task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positively assessed</td>
<td>7.44</td>
<td>15.12</td>
</tr>
<tr>
<td>problem-solving ability/style</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negatively assessed</td>
<td>6.08</td>
<td>18.94</td>
</tr>
<tr>
<td>problem-solving ability/style</td>
<td></td>
<td></td>
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</table>

Interactions between Task and Cognitive Style

The hypothesis was that different search tasks would be associated with different levels of search activities and outcomes, but only for searchers with specific cognitive styles. There was no significant interaction between search task and cognitive style.

Interactions between Cognitive Style and Problem-Solving Style

The hypothesis was that searchers with different problem-solving styles would be associated with different levels of search activities and outcomes, but only for searchers with specific cognitive style. There was no significant interaction between cognitive and problem-solving styles.

Interactions between Task and Problem-Solving Style

The hypothesis was that different search tasks would be associated with different levels of search activities and outcomes, but only for searchers with specific problem-solving style. There was a significant interaction between task and problem-solving style in the number of Web pages viewed \( F(1,74) = 7.89, p < 0.01 \). A posteriori analysis indicated that, for the subject search task, those who assessed their problem-solving ability/style negatively viewed a significantly higher number of Web pages than those with positively assessed problem-solving ability/style (see Table 1).

There was also a significant interaction between task and problem-solving style on the number of keyword searches completed \( F(1,74) = 4.81, p < 0.04 \). A posteriori analysis indicated that those who assessed their problem-solving ability/style negatively used keyword search significantly more often than those with positively assessed problem-solving ability/style for the subject search task (see Table 2).

Interactions between Task, Cognitive Style, and Problem-Solving Style

The hypothesis was that different combinations of searchers’ cognitive style and problem-solving style would be associated with different levels of search activities and outcomes, but only within specific types of search task. There was a significant interaction between task, cognitive style, and problem-solving style on the number of embedded links used by participants \( F(1,74) = 5.51, p < 0.03 \). A significant interaction between task and problem-solving style was found only among FI searchers \( F(1,40) = 5.60, p < 0.03 \). In the group of FLs, those who assessed their problem-solving ability/style negatively used embedded links more frequently than those who assessed themselves positively for the known-item search (see Table 3).

Summary and Discussion

These findings indicate that task is an important variable affecting search outcomes and activities. Of the three independent variables studied, only task had a significant main effect on search outcomes as well as on several other search activities. In addition, task interacted with problem-solving style to determine the ways in which users searched the Web. Different search outcomes, measured by precision and recall, may be related to the characteristics of tasks. For the known-item search task, there was specific target information, and the searchers had to simply locate that information. For the subject search task, on the other hand, target information was not specifically defined. Thus, the searchers’ job was, first, to think about what they wanted to find, and then to locate the information they wanted. The subject search task required at least one more step, which meant that there was a higher probability that users would experience problems in completing the search. As expected, relatively high recall and precision ratios were obtained in the known-item search task. The subject search task resulted in more search activities. The task required searchers to spend more time, probably because they needed to view a higher number of Web pages by using more embedded links and jump tools. As the subject task had a general and broad search question, users were likely to try out various search options to find different pieces of information. The effects of the subject search task found in this study are comparable to those of
general tasks (Qiu, 1993) and open tasks (Marchionini, 1989). General and open tasks are also inclined to result in higher levels of search activities, such as longer search time, frequent use of links, and so on.

It is interesting to note that task and problem-solving style interacted and influenced the use of keyword search as well as the number of Web pages viewed. Only for the subject search task, those with negatively assessed problem-solving ability/style used keyword searches more frequently than those with positively assessed problem-solving ability/style. Apparently, the difference between those with effective/problem-focused (positively assessed) and ineffective/emotion-focused (negatively assessed) problem-solving styles becomes more visible when the searchers carry out tasks that are vague and ill structured (e.g., the subject search task). The ill-structured subject search task required searchers to plan their search operations. As those with ineffective problem-solving style are less likely to plan search strategies effectively, they are expected to carry out unsuccessful keyword searches, resulting in a higher number of Web pages viewed. When the success rates of the keyword searches for the subject search task were compared, searchers with effective problem-solving style carried out keyword searches significantly more successfully than those with ineffective problem-solving style: \( \text{Mean}_{\text{positive}} = 0.88, \text{Mean}_{\text{negative}} = 0.71 \).

The only three-way interaction found was on the use of embedded links. It can be explained by the two-way interaction between task and problem-solving style found among the FIs. The FIs with effective/problem-focused problem-solving style used embedded links less frequently than those with ineffective/emotion-focused problem-solving style, only for the known-item search task. As found in previous studies, the FIs are analytical, and can efficiently disemerge and easily find information they want. In the known-item search task, where everyone had exactly the same target information to find, the superior search performance expected from those who are analytical (e.g., FIs) became more evident when they had effective problem-solving style.

In sum, searchers' cognitive and problem-solving styles had an impact on the ways in which they searched for information on the Web. Although their way of searching information differed depending on user and task characteristics, all the searchers could eventually find information they needed. As suggested by other studies on hypermedia-based instruction/learning (Ford & Chen, 2000; Liu & Reed, 1994), the Web (a hypermedia-based information system) is so flexible that it can accommodate different needs and preferences of individuals. It appears that the Web has a potential for an information system where most, if not all, users can successfully find information they want, regardless of their individual differences including cognitive or problem-solving style differences.

**Experiment 2**

Data analysis was based on 77 completed searches. For three of the participants, no detailed data was available. In two cases, the equipment failed to record the search, and in one case, the search was abandoned by the participant before completing any search activities.

**Main Effect for Search Engine**

The hypothesis was that different search engines would be associated with different levels of search activities and outcomes. No significant main effect for search engine was found.

**Main Effect for Task**

The hypothesis was that different tasks would be associated with different levels of search activities and search outcomes. There was a significant effect for task on precision \( F(1,62) = 5.69, p < 0.02 \). Average precision for the newspaper task was 0.1678, and average precision for the term paper task was 0.2495. Because the term paper task was designed to produce more selective searches, the task effect worked as predicted.

**Main Effect for Cognitive Abilities**

The hypothesis was that different levels of cognitive abilities would be associated with different levels search activities and outcomes. No significant main effect for cognitive abilities was found.

**Interactions between Search Engine and Task**

The hypothesis was that different search engines would be associated with different levels of search activities and outcomes, but only for a specific task. There was a significant interaction effect on the number of Web sites viewed \( F(1,59) = 2.99, p < 0.04 \). Analysis of simple effects showed that there was a difference in the number of Web sites viewed by searchers that could be attributed to choice of search engine, but only in the newspaper article task (see Table 4).

A posteriori analysis indicated that, in the newspaper article task, GoNet and Lycos produced lower numbers of sites seen than Alta Vista and Excite.

**Interactions between Search Engine and Cognitive Abilities**

The hypothesis was that different search engines would be associated with different levels of search activities and outcomes, but only for searchers with higher levels of cognitive abilities. No significant interaction between search engine and cognitive abilities was found.

**Interactions between Task and Cognitive Abilities**

The hypothesis was that different tasks would be associated with different levels of search activities and out-
TABLE 4. The number of Web sites seen: search engine by task interaction.

<table>
<thead>
<tr>
<th></th>
<th>Newspaper article task</th>
<th>Term paper task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alta Vista</td>
<td>23.3</td>
<td>20.3</td>
</tr>
<tr>
<td>Excite</td>
<td>23.6</td>
<td>15.6</td>
</tr>
<tr>
<td>GoNet</td>
<td>12.4</td>
<td>19.0</td>
</tr>
<tr>
<td>Lycos</td>
<td>15.7</td>
<td>18.0</td>
</tr>
</tbody>
</table>

comes, but only for searchers with higher levels of cognitive abilities. In the case of perceptual speed, no interaction effect was found. In the case of spatial scanning, an interaction effect was found for the number of bookmarks made by participants ($F(1,61) = 4.53, p < 0.04$) (see Table 5), and the number of sites seen by participants ($F(1,59) = 6.59, p < 0.02$) (see Table 6).

In the case of logical reasoning ability, an interaction effect was found for the number of searches completed ($F(1,59) = 41.84, p < 0.001$). Table 7 illustrates this interaction.

All of these interactions show the same pattern. Participants with higher levels of cognitive abilities showed lower levels of activity while completing the newspaper article task than when completing the term paper task. Participants with lower levels of cognitive abilities displayed the opposite pattern, showing higher levels of activity while completing the newspaper article task, and lower levels of activity while completing the term paper task. Given the nature of the tasks, one would expect higher levels of activity for the newspaper article task. It appears that the participants with higher levels of some cognitive abilities acted against the task instructions, while participants with lower levels of those cognitive abilities followed the task instructions. It is possible that these reactions to task instructions were associated with different understandings of the task, or with different motivations to complete the task.

Interactions between Search Engine, Task, and Cognitive Ability

The hypothesis here was that different combinations of task and cognitive abilities would be associated with different levels of search activities and outcomes, but only within specific search engines. The only significant three-way interaction discovered by the statistical analysis involved recall. Within the participants who used the Excite search engine, the pattern of task by cognitive ability interaction identified above was discovered ($F(3,61) = 3.02, p < 0.04$).

TABLE 5. The number of bookmarks made: task by cognitive ability interaction.

<table>
<thead>
<tr>
<th></th>
<th>Newspaper article task</th>
<th>Term paper task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low spatial scanning</td>
<td>10.40</td>
<td>7.94</td>
</tr>
<tr>
<td>High spatial scanning</td>
<td>8.26</td>
<td>10.53</td>
</tr>
</tbody>
</table>

TABLE 6. The number of Web sites seen: task by cognitive ability interaction.

<table>
<thead>
<tr>
<th></th>
<th>Newspaper article task</th>
<th>Term paper task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low spatial scanning</td>
<td>20.32</td>
<td>15.00</td>
</tr>
<tr>
<td>High spatial scanning</td>
<td>16.59</td>
<td>21.05</td>
</tr>
</tbody>
</table>

Because this two-way interaction had already been identified, the three-way interaction added little to the pattern of results.

Summary and Discussion

The most important point to note about these findings is the importance of the task that users were accomplishing. Of the three independent variables, only task showed a significant main effect. And, task interacted significantly with both search engine and cognitive abilities to determine how users searched the Web. In the main effect on precision, the task effect worked as hypothesized: higher precision was obtained for the term paper task.

Similarly, it is easy to understand why there should have been a difference between the search engines in terms of the number of sites users viewed, and why this difference occurred only within the newspaper task. The newspaper task mandated a more thorough search of the Web. The search engines designed for traditional research produced better results than the simple metacrawler or the directory-based system.

The interaction between cognitive abilities and task is of particular interest. In these findings, there is evidence that individual and social influences combine to influence search behaviors. In particular, individuals with lower levels of cognitive abilities followed the expected pattern of activities for each task, while individuals with higher levels of cognitive abilities produced a pattern of activities that were the reverse of what was expected. One explanation for these findings can be found in the “fit” between the individual searchers and the tasks they were accomplishing. It is probable that users with higher levels of cognitive abilities are better students (i.e., more accustomed to success in their academic activities). For these users, a term paper is an opportunity to excel academically, and they search for information more completely in an attempt to excel. The social norms associated with the term paper task overrode the task instructions themselves.

Discussion

The search activities of users who search the Web for information, and the outcome of their searches, depend

TABLE 7. The number of searches completed: task by cognitive ability interaction.

<table>
<thead>
<tr>
<th></th>
<th>Newspaper article task</th>
<th>Term paper task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low logical reasoning</td>
<td>7.32</td>
<td>5.61</td>
</tr>
<tr>
<td>High logical reasoning</td>
<td>3.72</td>
<td>7.25</td>
</tr>
</tbody>
</table>
cruelly on the nature of the tasks users are accomplishing. This finding, reinforced by both of the experiments reported here, sounds obvious. Previous research into searching of bibliographic databases also found that the information task influenced search activities and outcomes, but the task effect found in the research was not as consistent as that found in this study. The consistently strong finding of task effects in this research points out the difference between traditional bibliographic information systems and the Web. It remains to be seen exactly what features of the Web are associated with task effects. One might expect that the hypermedia environment featuring ease of navigation, availability of full-text information, and availability of a wide range of search options would contribute to the flexibility of the Web in responding directly to tasks.

Cognitive variables investigated in this research included cognitive abilities, cognitive style, and problem-solving style. It is interesting to note that of these variables, only problem-solving style had a direct influence on search activities. However, cognitive abilities and problem-solving style interacted with the task effect in influencing search activities. Interactions between cognitive ability/problem-solving style and task variables were found to influence the number of searches completed, the number of sites seen, the number of keyword searches and the number of bookmarks made. This finding of interactions between task variables and cognitive variables is in marked contrast to previous research (Allen & Kim, 2000), which included investigations of searching in both bibliographic databases and the Web. In previous research, separate and independent effects for cognitive and task variables were found. However, the interaction effect, showing the “fit” between personal and situation variables, was absent. According to Snow (1994), interaction between tasks and individual characteristics can be understood as a “fit” between a person and a situation, each of which is independent. In certain situations, some individuals perform well because their characteristics “fit” with those of the situation. In our research, an interaction between task and problem-solving style/cognitive ability variables was consistently found on search activities, although it was not found on search outcomes. The interaction found on search activities (i.e., the “fit” between tasks and users) implies that the Web is flexible enough to allow searchers to use different search options/tools for different tasks. As individuals with different characteristics can choose and use search options/tools that fit with their characteristics for completing tasks, they can ultimately find information they want.

Conclusions

The implications of these experiments for the design and use of the Web and Web search engines are clear. The flexibility of the Web in presenting a variety of ways of finding information appears to contribute to greater variability in search activities, and to allow task and cognitive variables to influence search activities and outcomes. Maintaining a combination of hypermedia navigation, keyword searching, and subject directories appears to be crucial to flexibility in information retrieval, and helps users with different characteristics and tasks find information they want. The integration of both hypermedia and keyword search features in an information system has also been advocated by others for the similar reason (Wofram & Dimitroff, 1998).

The flexibility of the Web allowed all users to achieve results consistent with the tasks they were carrying out. However, the manner in which users completed their searches depended on the fit between personal and task variables. Search activities, such as the use of specific search and navigation features, time spent in searching, number of sites visited, and number of bookmarks created were all found to be influenced by an interaction between cognitive and task variables. In some cases, the fit between individual users and the tasks they were accomplishing led users to devote more time and effort to a task than was appropriate.

It follows that although Web searching can be used effectively and successfully to meet academic information needs, some users are less efficient than others. This variation in search efficiency is determined by person–task interactions. Consequently, some users may need help in searching the Web efficiently when they are completing certain tasks. For example, users with inefficient problem-solving style would need help especially when carrying out general/ill-structured search tasks (e.g., subject search task) that require a higher level of planning and problem-solving than specific tasks (e.g., known-item search task). In some instances, greater efficiency in searching might be achieved if the range of search options were restricted to those that are most appropriate to the task. In the case of newspaper tasks that require an exhaustive search, for example, using search engines with keyword search capability should be good enough. The use of directory-based systems that encourage browsing would lower the search efficiency for such tasks, because finding many pieces of information by browsing only could be extremely time-consuming. In other instances, efficiency may be improved simply by making “help” screens that provide advice to searchers more accessible. However, because there are many cognitive variables and an indefinitely large number of tasks, it is difficult to suggest design alternatives that address all possible fits between user and task characteristics, and that will improve the efficiency of searching for any particular user accomplishing any particular task.

These investigations demonstrated the flexibility of hypermedia information retrieval on the Web, and the contributions of individual and task variables to Web search activities and outcomes. They add to the growing body of user-centered investigations of Web searching that will help designers refine Web search engines and their retrieval capabilities. Although it might not be an ideal system for efficient information searches, the Web has a great potential.
for effective and successful information retrieval for everyone.

References


