Behavioral Changes in Transmuting Multisession Successive Searches Over the Web

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Multisession successive information searches are common but little research has focused on quantitative analysis. This article enhances our understanding of successive information searches by employing an experimental method to observe whether and how the behavioral characteristics of searchers statistically significantly changed over sessions. It focuses on a specific type of successive search called *transmuting successive searches*, in which searchers learn about and gradually refine their information problems during the course of the information search. The results show that searchers' behavioral characteristics indeed exhibit different patterns in different sessions. The identification of the behavioral characteristics can help information retrieval systems to detect stages or sessions of the information search process. The findings also help validate a theoretical framework to explain successive searches and suggest system requirements for supporting the associated search behavior. The study is one of the first to not only test for statistical significance among research propositions concerning successive searches but to also apply the research principles of implicit relevance feedback to successive searches.

Introduction

Information search often takes place over successive searches in which multiple search sessions are performed for the same or similar information problems (Bateman, 1998; Choo, Detlor, & Turnbull, 1998; Huang, 1992; Robertson & Hancock-Beaulieu, 1992; Spink & Greisdorf, 1997; Spink, Greisdorf, & Bateman, 1998; Spink, Wilson, Ellis, & Ford, 1998; Spink, Bateman, & Jansen, 1999; Spink, Wilson, Ford, Foster, & Ellis, 2002). Understanding successive searches can help design and implement information systems that possess the memory to remember what users have done and the intelligence to support effective (e.g., finding useful information) and efficient (e.g., requiring less time and effort) search. This is in line with the studies that emphasize the importance of user modeling and web personalization (e.g., Chandler & Hyatt, 2003). With a better understanding of successive searches, information systems can tailor appropriate support for searchers based on their evolving needs in multiple sessions.

With the aim of improving our understanding of successive searches, various studies on successive searches have taken a qualitative approach and/or a cognitive perspective to characterize successive searches. This line of research has identified plausible cognitive and behavioral characteristics of successive searches. Two main theoretical frameworks in explaining successive searches are Information Search Process (ISP; Kulhthau, 1991, 1993) and Multiple Information Seeking Episodes (MISE; Lin & Belkin, 2000, 2005). The ISP framework identified the following six stages of the information search process: task initiation, topic selection, prefocus exploration, focus formulation, information collection, and search closure. ISP is one of the most influential theoretical frameworks on successive searches, affecting many subsequent works (e.g., Komlodi, 2001; Komlodi & Soergel, 2002; Liu & Belkin, 2010; Spink et al., 1998, 2002; Vakkari, 2001; Vakkari, Pennanen, & Serola, 2003; Xie, 2009). MISE identified eight different scenarios of successive searches that are

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differentiated based on the nature of the information problems prompting the search. In short, ISP is a stage-centered perspective on successive searches, whereas MISE is a problem-centered perspective. MISE can explain the entire information search lifecycle over an extended period of time and across different search tasks, whereas ISP focuses on different stages of the same information search task.

However, more quantitative studies that examine the statistical significance of these postulations are needed to deepen the understanding of successive searches. These studies could develop more replicable, generalizable, and actionable theories by going beyond descriptive accounts, while increasing predictive power.

To date, a limited number of empirical studies have quantitatively examined characteristics of successive searches, but with considerable limitations. The common research site of these studies—with the exception of Lin (2005)—are information search services available in libraries (e.g., Dialogu, Lexis/Nexis, etc.), which at the time only supported keyword querying and rarely incorporated hypertext browsing. As a result, many studies on behavioral variables have been limited to articulation of the information problems and evaluation of search output while overlooking browsing, organizing information collection, or monitoring the search goals (Lin & Belkin, 2005). Moreover, task types could affect search behavior (Kim & Allen, 2002; Lin, 2005; Liu & Belkin, 2010; Vakkari, 1999, 2001). Many of these studies on behavioral variables have not considered task types as possible moderating factors and tend to focus on students searching for information to write a term paper. Behavioral variables that are important in the task of searching for information for writing an academic paper may not be as important as in other search task types and vice versa.

To address these issues, this study first narrowed down the research scope and chose to focus on one of the eight scenarios of successive searches identified by Lin and Belkin (2000, 2005)—transmuting successive searches. Transmuting successive searches depict situations where the searchers learn about and gradually refine their information problems during the course of information search. Essentially, transmuting successively search is the exact type of successive search that the ISP framework and the studies built atop ISP have been examining. The purpose is to investigate a successive search phenomenon that is common to both ISP and MISE, maximizing this study's contribution. Second, this study used the web as the research site as opposed to library database systems. Third, the web is an information search system where the searchers perform full iterations of different information search activities, that is, articulation, evaluation, and monitoring (Lin, 2005; Marchionini, 1995). This enables us to take a purely behavioral perspective to examine different activities of successive multisession information searches rather than merely articulating information problems such as query terms. Finally, the study observed a representative task, that of planning a vacation itinerary.

In particular, the emphasis on a *behavioral* perspective on successive searches is worthy of note. Information retrieval literature has examined information search from a behavioral perspective known as implicit relevance feedback, in the sense that a search system can unobtrusively gather information about searchers' interests or evolving needs from their interactions with the system (e.g., Kelly, 2005; White, Ruthven, & Jose, 2005). The examples of interaction characteristics include, but are not limited to, time spent on a page/document (Kelly & Belkin, 2001, 2004; Konstan et al., 1997; Liu & Belkin, 2010; Morita & Shinoda, 1994; Oard & Kim, 1998; White, Jose, & Ruthven, 2003), number of query terms and operators (Spink, 1996; Spink et al., 1998), scrolling down the text on a web page (Claypool, Le, Waseda, & Brown, 2001), uploading, downloading, or reading documents (Wu, Liu, & Chang, 2008), and so on. Extending the notion of implicit relevance feedback to successive searches, if a search system can continuously collect data about searchers' explicitly observable interaction characteristics, it could infer or even differentiate the stages of the information-seeking process (Kuhlthau, 1991, 1993) that searchers are experiencing or the types of information problems explicated in the eight scenarios of successive searches (Lin & Belkin, 2000, 2005). As a result, the search system will be able to provide personalized support suitable for that particular stage of the information-seeking process or type of information problem.

Information retrieval literature on implicit relevance feedback has defined the scope of "behavior" as the searchers' physical interactions with the search system, yet the information seeking/search literature seems to define *behavior* in a broader sense. Wilson (2000, p. 49) defined *information-seeking behavior* as "the purposive seeking for information as a consequence of a need to satisfy some goal. In the course of seeking, the individual may interact with manual information systems (such as a newspaper or a library), or with computer-based systems (such as the World Wide Web)"; and *information-searching behavior* as "the 'micro-level' of behaviour employed by the searcher in interacting with information systems of all kinds. Information seeking behavior consists of all the interactions with the system, whether at the level of human computer interaction (for example, use of the mouse and clicks on links), or at the intellectual level (for example, adopting a Boolean search strategy or determining the criteria for deciding which of two books selected from adjacent places on a library shelf is most useful), which will also involve mental acts, such as judging the relevance of data or information retrieved." In the information-seeking literature, the term *behavior* seems to connote the notions of not only physical interactions with the search systems that are explicitly observable but also the cognitive activities in interacting with the information systems that are not explicitly observable.

In this article, we define the behavioral variables of successive searches as those that characterize searchers'

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interactions with the search system, *explicitly observable and quantifiable* by the system itself. This is aligned with the implicit relevance feedback literature as well as Wilson's definition of information search behavior (while excluding "the intellectual level" that might be muddy and confused with the cognitive activities or strategic/tactical intentions).

In summary, this article empirically explores the research questions and associated hypotheses: "How do the behavioral variables of transmuting successive searches on the web evolve over multiple sessions?" "What behavioral variables can best differentiate different stages of transmuting successive searches?"

Literature Review

Behavioral Characteristics in Information Search

The information-seeking process consists of the following three subprocesses: articulation of the information problems, evaluation of the search output (i.e., exercising relevance judgment of the information found), and monitoring of the search goals (i.e., determining whether one has searched for a sufficient amount of information to solve the problem at hand; Lin & Belkin, 2000, 2005; Marchionini, 1995). The MISE framework (Lin & Belkin, 2000, 2005) added an additional subprocess in navigation of the information space for the web-based information search environment. The vast majority of the behavioral variables in successive searches that have been studied are mainly concerned with the articulation of information problems and the relevance or utility of items retrieved. As noted in the Introduction, this is inadequate. This section reviews the behavioral variables that are explicitly observable and quantifiable in successive searches in terms of these four subprocesses of information seeking. Table 1 summarizes the behavioral variables in the successive search literature. The following subsections address these variables in successive search literature in more detail. Important behavioral variables that have been only studied in a single-session context but could and should be researched in successive searches will also be addressed.

Articulation of the Information Problems

Frequencies of query-related activities and tactics have been most commonly studied as behavioral variables for the articulation of the information problems in both single and successive searches.

Specifically, for successive search studies as shown in Table 1, changes of search terms in expression of the number and specificity, types of search formulation tactics, types of information resources, types of search strategies/actions, and genres or subject types are the most common behavioral variables researched in successive search studies. To articulate their problems with more clarity and accuracy, searchers change search terms. About two thirds of the participants changed their search terms in subsequent search sessions, whereas the rest continued to use the same terms (Spink et al., 1999, 2002). In addition to changes in search terms, more specific terms were used in later sessions (Tang & Soloman, 1998). Vakkari (2000a) and Vakkari et al. (2003) also found that the more defined the users' information problem became, the more specified search terms were used in different search sessions.

Change of search operators was found to differ depending on whether it is an end-user search or mediated search. Although end users applied more search operators in their later search sessions (Vakkari, 2001; Vakkari et al., 2003), intermediaries used more operators during the first search except the "not" operator (Spink et al., 2002). However, both end-user search and mediated search showed the same pattern for the usage of search commands: More commands and tactics were applied in later search sessions. Vakkari et al. (2003) found that when users moved forward with the search stages, they also changed their search tactics. Although there was not much difference in terms of frequency for each type of search tactic, the change of search tactics was characterized by different uses of tactics in session I (prefocus stage) to session II (postfocus stage). For example, in applying the "vary" tactic, users tended to reformulate the query by replacing an existing query term with narrow terms or related terms in session I, and by replacing an existing term with synonyms in session II.

Broadening to general information-seeking contexts within a computerized information environment rather than the information-search context, the change of information resources reflects how searchers interact with different information resources or systems in different stages of successive searches. Users not only change types of information resources or systems during their successive searches but also change the instances of information resources of the same type. For example, users change from one database to another when using online databases. In the context of mediated searching, more than half of the participants changed databases during successive searches (Spink et al., 1999, 2002). In addition, Spink et al. (2002) also found that searchers repeatedly searched the same databases in successive searches and suggested that there were more database changes between the second and third search sessions than between the first and second sessions. Similar results were also found in end-user search contexts (Xie, 2009). Active online searchers searched in a greater variety of information sources (Johnson, Moe, Fader, Bellman, & Lohse, 2004).

In single-session information-seeking research, many studies tried to measure frequency and length of query activities based on search log data, including the number of unique query terms and query length (Kelly, 2009), number of terms used per query, query interval (time elapsed between query submission), page viewed, number of Boolean operators, and others (Wolfram, Wang, & Zhang, 2009). Future studies need to investigate how these behavioral variables could differ for different stages of successive searches or for different types of information problems.

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TABLE 1. Behavioral variables in successive search literature.

Variable	Conceptual/operational definition	Author/publication year
Number of search sessions	Number of search requested by information seekers (Spink et al., 1999).	Spink (1996); Spink, Griesdorf, and Bateman (1999)
ARTICULATION OF THE INFORMATION PROBLEM		
Number of search terms	The mean number of search terms per search (Spink et al., 2002).	Spink et al. (1998); Spink et al. (2002); Vakkari (2000a); Vakkari et al. (2003)
Changes in search terms	Selecting different search terms from previous searches, sessions, or resources. The number of sessions of term modification was counted to measure the variable (Spink, 1996).	Spink (1996); Spink, Greisdorf, and Bateman (1998); Vakkari (2000a); Vakkari et al. (2003)
Search formulation tactics	Intersect: Intersect a set with a set representing another query component (Vakkari, 2000a). Vary: To alter or substitute one's search terms in any of several ways (Vakkari, 2000a). Parallel: To make the search formulation broad by introducing synonyms or conceptually parallel terms (Vakkari, 2000a). Reduce: To subtract one or more of the query elements from an already-prepared search formulation (Vakkari, 2000a).	Vakkari (2000a); Vakkari et al. (2003)
	Search operator: How search operators were used across successive search (Spink et al., 2002).	Spink et al. (2002); Jansen & Spink (2006)
Changes of information resources/ databases	Select different information resources (databases) from the previous one (Xie, 2009).	Xie (2009); Spink et al. (2002); Johnson et al. (2004)
Changes of genres	Genres of search explain search behavior that, while situated within a larger information problem, is driven by a range of information needs (Bowler, 2009, p.120).	Bowler (2009)
NAVIGATION OF THE INFORMATION SPACE		
Revisiting a web site	How quickly the users revisit a web site and how many web pages they revisit.	Bucklin and Sismeiro (2003)
EVALUATION OF THE SEARCH OUTPUT		
Number of relevant documents	Number of items judged relevant to a search topic. (Spink et al., 2002).	Spink et al. (2002); Vakkari and Hakala (2000); Wang and Soergel (1998); Wang and White (1999)
Time spent on documents	Dwell time: the time duration from each point when the user starts reading a document to when the user leaves the document. Display time: total duration of a document between when it is opened and when it is closed. Decision time: the first dwell time.	Liu and Belkin (2010)
Effectiveness of searches using different information filtering techniques	Recall: the number of retrieved documents that are relevant divided by the number total retrieved documents. Precision: the number of retrieved documents that are relevant divided by the number of total relevant documents specified by experts. Topic similarity: how similar the topics of each search session or transaction to each other.	Wu et al. (2008)
MONITORING OF THE SEARCH GOALS		
Frequency of using a bookmark	How frequently users revisit their book-marked pages.	Aula et al. (2005)

Query reformulation is another critical aspect in relation to articulation of search processes. Types of query reformulation were explored by several researchers (Boldi, Bonchi, Castillo, & Vigna, al., 2009; Huang & Efthimiadis, 2009; Jansen, Spink, & Narayan, 2007; Liu, Gwizdka, Liu, Xu, & Belkin, 2010; Rieh & Xie, 2006). Based on the analysis of 313 search sessions of query logs from the Excite Web, Rieh and Xie (2006) characterized the facets of content, format, and resource for query reformulation and identified different types of query reformation—such as specialization, generalization, parallel movement, term variation, and error correction. They further posited that an interactive reformulation tool can be designed to identify and guide users in the process of query reformulation. Based on the exploration of query patterns from more than a half million users during web search sessions, Jansen et al. (2007) classified different types of query reformulation into specialization, content change, and generalization. More machine learning studies

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incorporating linguistics rules into information retrieval algorithms are needed to make query reformulation observable and interpretable by the system automatically and to become a potential differentiator for stages of successive searches or for types of information problems prompting successive searches. Huang and Efthimiadis (2009) developed algorithms to define 13 types of query reformulations and to detect each type of reformulation from AOL query logs.

Navigation of the Information Space

Navigation of the information space refers to moving from one information object to another. In the web environment, it could be following links, traversing directories, or revisiting web pages. The two major factors relating to navigation are orientation (knowing where one is) and continuation (knowing how and where to go next; Lin, 2001; Lin & Belkin, 2005).

Little research has investigated navigation behaviors in successive information-seeking situations. Of the few studies on successive searches, website revisiting was the main research focus. Bucklin and Sismeiro (2003) examined browsing behavior in terms of users' decisions to continue browsing within a site or exit the site and the length of time spent in viewing each page based on log data. They found that website users changed their within-site browsing behavior due to learning effects, within-site lock-in (i.e., topical involvement), time constraints, and cost–benefit trade-offs. Specifically, 97.5% of revisits took place within 15 days of the previous visits, and repeat visits to the same website resulted in fewer pages views, but had no effect on page-view time. Bucklin and Sismeiro (2003) further posited that fewer page visits in repeat visits to the same site could explain a typically shorter session duration in subsequent sessions of the same site, as reported by Johnson, Bellman, and Lohse (2003). As web browsers continue to improve and evolve, measurement of revisitation needs to be updated as well. Concerned by the problem of underestimating the revisitation rate merely by calculating the number of http requests, Zhang and Zhao (2011) suggested pages viewed in tabbed browser windows as a more accurate measurement for web page revisitation.

Although not concerned with successive searches per se, research on navigation has used explicitly observable user behavioral data to identify types of navigation activities and patterns. Such studies have uncovered important navigation behavioral variables that could be worthy of further investigation for successive searches in the future.

For navigation activities, Catledge and Pitkow (1995) found that anchor (i.e., selection of hyperlinks on a web page) and back (i.e., the usage of the back button) accounted for 92.5% of browsing activities. Weinreich, Obendort, Herder, and Mayer (2006) had a similar finding in their longitudinal study of 25 participants ranging from 52 to 195 days. They found that although selection of hyperlinks on a web page remained the most common action for navigation, form submission and simultaneous displays of multiple browser windows had become more common, and the use of the back button became a relatively less dominant form of navigation. Recognizing the commonness of parallel browsing behavior (i.e., users visiting web pages in concurrent "tabs" in a web browser), Huang and White (2010) posited that such behavior can be signified by outclicks and tab switches, where outclicks refer to opening a hyperlink in a new tab of a web browser, and tab switches mean changing of the navigation focus between opened tabs. They found that both outclicks and tab switches conformed to a power rather than an exponential distribution and that on average users viewed the same number of pages overall but divided their browsing across multiple tabs. They concluded that tabs did not result in users viewing more pages, it simply led to multitasking. Dubroy and Balakrishnan (2010) reported that Firefox users preferred the use of tabs over multiple windows, and they switched tabs more than using back buttons.

For navigation patterns, Gwizdka and Spence (2007) found that task success (i.e., effectiveness of information search task) was associated with such browsing behavioral characteristics as low compactness (deeper and less disperse hierarchical navigation), high stratum (more of a linear style of navigation), and greater similarity between the user navigation path and the optimal navigation path to find the information. For more experienced users, these characteristics differ according to the task phase: (1) exploration, (2) resolution, and (3) completion (Shih, Mate, Sanchez, & Munoz, 2004). In addition, Gwizdka and Spence (2007) found that the greater similarity between the user navigation path, the optimal navigation path, and time on task were also indicators of cognitive lostness (i.e., disorientation) resulting from navigation.

Future studies can examine the frequencies of different browsing activities and patterns in different stages of successive search sessions.

Evaluation of the Search Output

Evaluation of the search output refers to the assessment of the information objects encountered for relevance. The notion of evaluation is fraught with layers of complexity including the cognitive elements required for evaluation (Bade, 2007; Barry, 1998; Borlund, 2003; Fitzgerald & Galloway, 2001; Saracevic, 2007a, 2007b; Schamber, 1991; Vakkari, 1999; Vakkari & Hakala, 2000). Users often spend more time determining the value of a given document through evaluation than the other types of information search activities (Xie, Benoit, & Zhang, 2010).

Despite the importance of the evaluation activity, few studies have examined the behavioral variables of the evaluation process in successive searches. The number of relevant information objects found is the most common behavioral variable in the evaluation process that has been studied in the context of successive searches, but none of the studies have enough respondents to test statistical significance for the

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changes in the number of relevant information objects found in different sessions. The studies did make research propositions based on the data observed, but there has been no agreement among them on whether the number of relevant information objects found will increase or decrease over different sessions of the search process. Spink et al. (1998) took a naturalistic approach to study successive searches. In their study, searchers engaged in a different number of sessions, and thus no statistical tests about change in the number of relevant information objects between different sessions could be conducted. Nevertheless, they confirmed that the percentage of items judged relevant increases as the number of search increases. However, Vakkari and Hakala (2000) suggested a decrease in the number of relevant documents in later stages of information searching. For the seemingly conflicting research propositions, Vakkari and Hakala (2000) explained that the two studies used different methodologies and that Spink et al. (1998) did not consider the stage of search as a variable. However, after using a naturalistic approach and observing only eight mediated searches over an extended period of time, Spink et al. (2002) postulated that the ratio of the number of the relevant documents over the number of documents found may not necessarily increase over sessions at all.

For time spent on retrieved documents in successive searches, Liu and Belkin (2010) investigated how three types of time spent on a retrieved document (dwell time, display, and decision time, as defined in Table 1) predicted the usefulness of retrieved documents in different stages of successive searches (i.e., start, middle, end), and for two different types of tasks: parallel tasks vs. dependent tasks. For decision time, the findings showed that task stage can help infer document usefulness differently in different stages, especially for parallel tasks. For not useful documents, users spent longer decision time in the "start" and "end" stage, but less time in the middle stage. For very useful documents, users spent less time in deciding usefulness of documents in later stages. Decision time could also infer document usefulness, but only for dependent tasks and not considering task stages. For the display time, it was found to predict document usefulness for each task type—alone or regardless of task type—when not considering the task stages. But when task stage was considered, display time could only predict document usefulness if task types were not a factor. When tasks were not distinguished, the display time for very useful documents was longer in later stages than the "start" stage. For dwell time, it was found to predict document usefulness for both task types only when task stages were not a factor.

Relevance feedback also has been examined in relation to successive searches, although not directly. Wu et al. (2008) designed and tested an information-filtering technique with task-stage identification that incorporated the implicit feedback signified by downloading, uploading, and reading behaviors, as well as explicit feedback based on users' rating of documents. They conducted a preliminary evaluation with four subjects in each of the three search stages: prefocus, focus-formulation, and postfocus, with the purpose of evaluating the effectiveness of their information filtering technique against the baseline and other techniques. The variables that measured effectiveness were traditional information retrieval metrics: precision and recall. Because of the limited number of subjects, no statistically significant conclusion could be drawn. Nevertheless, based on the results of the preliminary testing, the authors posited that their proposed long-term document support model for task stages is effective. To operationalize the three stages of searches, the authors also developed a task-needs pattern similarity analysis method. This analysis classified different search sessions and transactions of the same searchers into three stages, based on the correlation value of task needs of each session and transaction, where a task need was operationalized in terms of topics in the domain ontology. They concluded that there is a low or negative correlation between tasks needs of search sessions and transactions in the prefocus task-stage, whereas there is at least a moderate correlation between tasks needs of search sessions/transactions in the postfocus stage.

In single search sessions, evaluation of the search output has been measured by number of search results viewed, and time spent in the search result page to understand users' evaluation scope of the search output (Jansen & Spink, 2003; Wolfram et al., 2009). Jansen and Spink (2003) found that about 54% of the users viewed only one result page. Users on average viewed about eight web pages with two to three documents per query. More than 55% of web users viewed only one result per query. As to time spent in evaluating, the mean time spent viewing a web document was about 16 minutes, whereas 75% of the users spent less than 15 minutes. About 20% of users spent less than a minute to view a web document. Similar to Jansen and Spink' Wolfram et al. (2009) found fewer differences in page browsing behavior (one or two pages on average) over time among the clusters, after comparing the three clusters representing different times of the day in average page viewed per query for web search engines.

Relevance feedback is a very active research topic in the interactive information retrieval field, but has not been directly or thoroughly studied in the successive search context. Traditionally, relevance feedback has been measured by explicit feedback from the users, such as selecting the keywords suggested by the system, selecting and/or marking documents as relevant or partially relevant, or answering questions about their search interests. Recently, implicit feedback was demonstrated to be an effective approach for inferring relevance of an information object to a searcher. Implicit feedback is most frequently investigated by analyzing time spent on an information object (Kelly & Belkin, 2001, 2004; Konstan et al., 1997; Morita & Shinoda, 1994; Oard & Kim, 1998; White et al., 2003), bookmarking a page (Oard & Kim, 1998), printing a web page (Oard & Kim, 1998), selecting information objects from a search results list (Smyth et al., 2005; Smyth, Freyne, Coyle, Briggs, & Balfe, 2003), and scrolling down the text on a web page (Claypool et al., 2001).

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Clickstream data are another important source to generate implicit feedback. Hijikata (2004) tested mouse operation in terms of text extraction by selecting targeted text based on four types of operations: text tracing, link pointing, link clicking, and text selection. This study showed that a mouse-based method was four times more accurate in keyword extracting than a random method. Testing the reliability of clickthrough data as effective relevance feedback is a common theme in this stream of research. White et al. (2005) compared two systems, one applying an explicit feedback mechanism, and another with an implicit feedback mechanism, based on the assumption that viewing a document summary indicates an interest in the document. The results show that users performed well for both systems. Joachims, Granka, Pang, Hembrooke, and Gay (2005) found that relative preference based on clickthough data corresponded well with explicit judgments, even though it was difficult to interpret clickthrough data as the entire feedback. Jung, Herlocker, and Webster (2007) discovered that taking account of all click data can increase both precision and recall. Moreover, they also identified the last visited document of each search session as a more reliable indication for implicit feedback. In addition to clickstream data, Salojärvi, Puolamäki, and Kaski (2005) demonstrated that eye movement data can be used to predict implicit feedback when time series data and the task data are considered.

A systematic framework on taxonomy of evaluation behaviors has been developed. Oard and Kim (2001) proposed a framework classifing observable evaluation behaviors into four categories: examination, retention, reference, and annotation. The "examine" category covers viewing, listening to, and selecting an information object; the "retain" category includes bookmarking, printing, saving, deleting, purchasing, and subscribing to an information object; the "reference" category consists of copying-and-pasting, quoting, forwarding, replying to, linking and citing an information object; the "annotate" category comprises marking up, rating, and publishing an information object. Kelly and Teevan (2003) added a fifth category, "create," to describe the user behaviors when creating original information, such as typing, editing, and authoring an information object. These five categories of evaluation behaviors potentially can help identify important variables in successive searches.

Resonating with this framework, several studies have attempted to model the "information context" of the users to generate implicit relevance feedback. Operationalizing the "information context" as users' annotation, Golovchinsky, Price, and Schilit (1999) found that queries derived from users' annotations produced better retrieval performance than standard relevance feedback techniques. Budzik and Hammond (1999) derived the information context from numerous other information applications with which the users interacted, such as a paper a user is working on, but had no evaluation on their proposed "information management assistant" system, named Watson. Teevan et al. (2005) indexed information objects that the users created, copied, or viewed—including web pages, email messages, calendar items, and documents—and used that index as a rich representation of user profile and a source of relevance feedback to re-rank the search results returned by a search engine. They concluded that their approach significantly enhanced web search.

Monitoring the Search Goals

Monitoring is determining whether one has searched for a sufficient amount of information to solve the problem at hand (Lin & Belkin, 2005; Marchionini, 1995) or check the current status during the search process (Xie & Joo, 2010). This is a very understudied aspect of information search—single-session or multisession.

In the web environment of successive search, bookmarks are frequently used to assist successive searches, as a searcher may not remember the exact queries used or the information objects they have seen before. This despite the fact that the organization of bookmarks can be difficult and accessing them from different computers is a challenge, even for experienced users (Aula, Jhaveri, & Kaki, 2005). In the context of a single-session research, Shen and Zhai (2003) explored the use of query history to expand the current query. The results show the incorporation of search history improved (1) average precision and (2) precision at the first 20 documents, where average precision refers to the sum of each subject's precision divided by the number of subjects. Precision at the first 20 documents was the same except the precision was calculated based on the first 20 documents. Speretta and Gauch (2005) further built user profiles based on user search histories that included the submitted queries and snippets of user-selected results. The snippet-based profile was marginally better than query-based profile in terms of the improvement of personalized rankings.

Theoretical Foundation

Theoretical Framework: MISE

Transmuting successive searches were first characterized using the MISE framework (Lin, 2001; Lin & Belkin, 2000), and then empirically validated (Lin & Belkin, 2005). The newly revised MISE framework identified six classes of factors characterizing successive search experience, including searchers, search activity, search context, information attainment, information use activities, and systems.

Searchers are the persons who engage in searching for information themselves to ease or resolve their information problems without the intervention of intermediaries. *Systems* are the information systems that provide search features for information they collect, present, and maintain. *Search activity* is the interaction process between searcher and system. *Search context* entails the contextual factors that result from or influence the search activity. *Information attainment* is the physical product of search activity, such as a list of references

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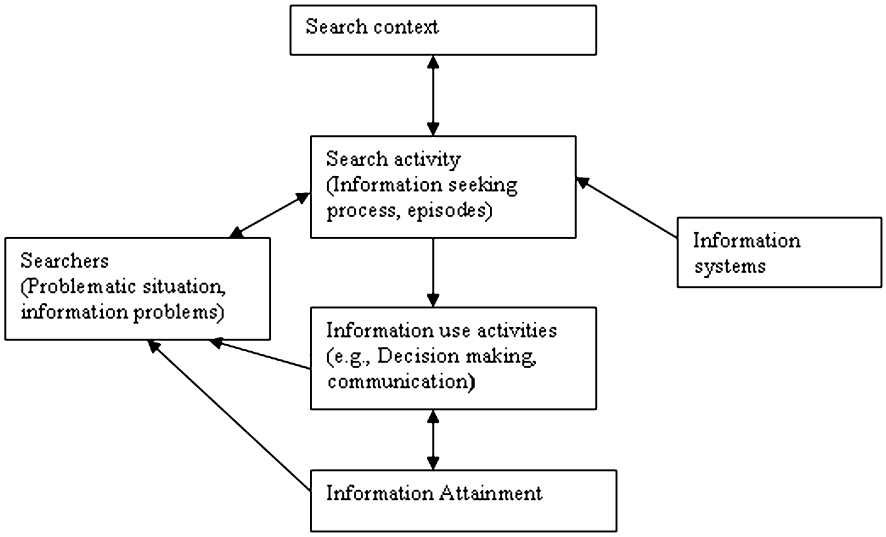

FIG. 1. The MISE model.

or set of information objects that would help resolve information problems. *Information use activities* are the activities in which the searcher uses information from information attainment to help resolve information problems. Furthermore, searchers are characterized in two dimensions: *problematic situation* and *information problem*. A problematic situation is the user's subjective perception and estimate of carrying out a goal with his or her existing knowledge in the objective context. An information problem is the result of that perception and estimate, requiring external information to explicate. *Information problem* is a term rooted in library and information science, conceptually similar to information needs. However, information *needs* imply a static state, while information problems acknowledge the evolution of motives for searching for information (Saracevic, 1996). Search activity also has two dimensions of variables: *information-seeking process* and *episodes*. The explication of the information problem is manifested in the information-seeking process, which is constituted by interacting with external information resources to search for information. Episodes are constituted by the activities in between the initiation and termination of interacting with a particular external information resource, concerning reasons why users reinitiate and terminate a search session.

During the search activity, the searchers exhibit cognitive and behavioral differences, which are effected by the variables of the other classes (e.g., searchers' problematic situation and information problems, the state of the information attainment, etc.). The cognitive activity of searchers consists of the four subprocesses of information seeking (i.e., articulation, evaluation, navigation, and monitoring) identified by MISE, whereas the behavioral variables are the manifestation of those subprocesses (e.g., number of query terms, number of information objects viewed or visited).

Each of these six classes, including the dimensions they entail, has a set of characterizing factors. The factors can be either properties that describe the class or the operations that the searcher would undertake with respect to those particular classes. For a detailed list of factors in the MISE model, please refer to Lin and Belkin (2005). Figure 1 depicts the relationship among these six classes.

Although the MISE model identified eight different scenarios of successive searches that could span across multiple sessions, it was not possible to arbitrarily specify the number of sessions in each scenario, as how each scenario is materialized could vary depending on the actual outcome of each session. Nevertheless, by depicting how each scenario of multisession search could have evolved, the MISE model could help build the use cases of the search process in each scenario. The case of transmuting search actually can be perceived as aligned with what the stage-centered perspective of successive searches has portrayed: a process in which the searchers continuously explore the information space to learn to refine their information problems.

In short, the factors in the MISE model depict transmuting successive searches as follows: with continuous cognitive involvement with information attainment, despite the constrains from the information systems and search contexts, searchers' clarity about the problematic situation, level of subject knowledge and definition of information problems will improve over the process which in turn would be manifested in searchers' cognitive abilities in the information-seeking process – in other words better ability to articulate information problems, navigate the information space, evaluate search output, and monitor different levels of search goals.

The Theory-Based System Under Study: PERSIST

To derive system requirements for supporting transmuting successive searches, Lin (2002) suggested that the navigation, evaluation, and monitoring activities should require

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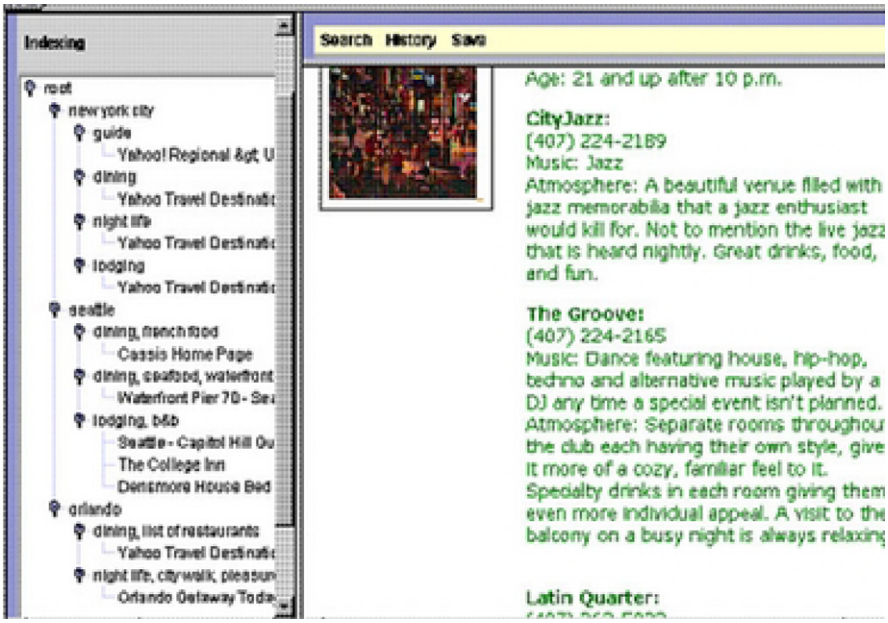

FIG. 2. Snapshot of PERSIST. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

more support than the articulation activity. With a lower level of subject knowledge and indefinite information problems, the searchers would be opportunistically looking for information cues to help clarify their problematic situation instead of proactively articulating their information problems with query terms. Lin (2002) additionally suggested the following directions to support successive searches: First, revisiting the information space of the previous sessions is crucial to improve navigation ability, because the searchers are likely to revisit information objects for reexamination of relevance, comparison with other information objects, or extraction of relevant information for explicating the transmuting information problems. Second, keeping track of relevance criteria is important to improve the evaluation of search output because the relevance criteria are dynamically evolving as the searchers' information needs are struggling to take shape. Third, estimating the sufficiency of information collection in coping with searchers' information problems is key to improving the monitoring activity. Thus, the information system supporting flexible organization of information objects to mitigate the current information problems could enable the searchers to quickly overview the strength and weakness of their information collection.

Lin (2002) accordingly prototyped PERsonalized and Successive Information Seeking Tools (PERSIST). To assist revisiting information objects, the Personalized Indexing feature (PI) of PERSIST enables searchers to use words to represent information objects that could be useful to help cope with information problems, making it easy to remember how to return. In addition, the History feature of PERSIST allows searchers to return by looking at the chronicle sequence of pages visited, and the "Save" feature of PERSIST allows searchers to "save" a page without assigning any indexing terms. The "Search" feature of PERSIST enables searchers to specify query terms to search against their own search history. To assist evaluating information objects with changing criteria, the PI feature of PERSIST allows searchers to compare their information attainment dynamically, based on the evolved criteria at hand as the indexing terms of the pages indexed would highlight what the pages were about. With PI, searchers can change the display of indexing terms by grouping the indexing terms on the fly. To assist monitoring the sufficiency of information attainment, PERSIST allows the searchers to help identify the weakness of information attainment and thus develop information problems by examining the indexing scheme in PI. PERSIST can be seen as an enhanced version of Favorites in Internet Explorer or Bookmarks in Firefox in the sense that it provides the users the ability to dynamically group and regroup all the indexed pages in one command. Figure 2 shows a snapshot of PERSIST.

Research Design

Experiment Tasks

A representative scenario of the transmuting successive search task is when the users attempt to search for information to plan a vacation when they do not have exact destinations identified, and have limited knowledge about those prospective destinations. Lin and Belkin (2005) offered a detailed explanation for how such a task satisfies the characterization of transmuting successive searches with MISE.

To study whether behavioral variables change significantly through different sessions, our research used an

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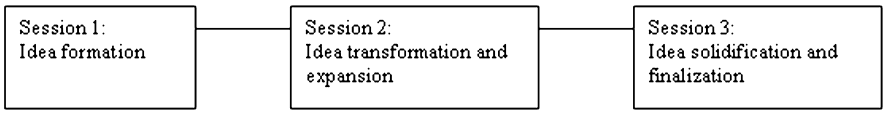

FIG. 3. The research model.

experimental method, in which the number of episodes had to be controlled. Our study comprised three sessions, with each embodying a different current search goal. The current search goal in each respective session was to formulate ideas, reformulate and expand ideas, and solidify and finalize ideas. Subjects were given the scenario and required to engage in three experimental sessions within 1 to 3 days of each other. To control the time factor, each session lasted between 20 and 30 minutes, but the searchers had a chance to wrap up their sessions, which would not be abruptly interrupted. Before the search started, subjects were informed that their leading search goal was to plan as detailed an itinerary for a chosen destination as possible by the end of the third search session. The first search session was controlled in a way to formulate ideas for multiple prospective vacation destinations. Subjects were told to find general information for up to five vacation destinations. The second search session was controlled so that the participants would reformulate and expand their ideas of the vacation with newly found information. Subjects were asked to narrow down the number of prospective destinations based on what they have found in the first session and then to continue to search for information for these places to ultimately decide on the final vacation destination. The third search session was controlled to ensure that the participants would wrap up the search process by solidifying and finalizing their ideas on a specific vacation plan. Subjects were instructed to tie up the loose ends by finding as much information as possible to fulfill the leading search goal: planning the itinerary for their chosen vacation destination. Figure 3 summarizes the current search goals of the three controlled search sessions.

Subjects

Twenty-two subjects were recruited from an undergraduate communication course at a state university. Subjects were required to have some experience in using the web and in taking or planning vacations. Twenty of them successfully completed the study, with an equal number of males and females. The average age was 22.55; they were either in their junior or senior year. The incentive each participant received was extra credits for the communication course they were taking.

Data Collection

All the subjects used Internet Explorer as the web browser, supplemented with PERSIST, to search. Data were collected with either the computer log maintained by the search system, or screen captures via both screen-cam software and videotapes, as shown in Table 2. Screen-cam software captured entire search sessions while logs were created by PERSIST to record explicit and quantifiable behavioral data, such as number of web pages visited.

Data Analysis

First, related variables in relation to the proposed hypothesis were identified and analyzed. Table 2 presents the names, operational definitions, examples, and data collection methods for all the observed variables.

One-way repeated-measures analysis of variance (ANOVA) was conducted to examine the overall effect size and significant changes of each behavioral variable across sessions. For all the results of the one-way repeated-measures ANOVA, we reported the multivariate tests instead of univariate tests, avoiding "the controversy surrounding the sphericity assumption" (Green, Salkind, & Akey, 2000, p. 213). Multivariate tests are the most robust tests of the null hypotheses for repeated measures (Biderman, 2012). Multivariate tests do not require a test for homogeneity of the variance within subjects, such as the sphericity test (Green et al., 2000; Seltman, 2012). Tabachnick and Fidell (2006, p. 445) noted "If the sample sizes are equal, evaluation of homogeneity of variance-covariance matrices is not necessary." In our study, the number of observation cases was 20 for all the dependent variables. Thus, we would not report the homogeneity test results. In addition, repeated-measures tests such as ANOVA are robust to non-normality (Biderman, 2012; Cheng & Ku, 2009; Tabachnick & Fidell, 2006) and with a sample size of 15 observations per level of the within-subjects factor, the assumption of normality may be violated (Cheng & Ku, 2009; Green et al., 2000, p. 210). Thus, despite that a few moderate to severe departures from normality were found upon examination of skewness and kurtosis, no transformation of variables was performed. In all the tests of one-way repeated-measures ANOVA, the factor was the session and the dependent variables were behavioral variables. The effect size for the multivariate test associated with Wilks's Lambda value is the difference between 1 and the Lambda value. That is, the greater the Wilks's Lambda value is, the smaller the effect size is.

Once the ANOVA yielded a significant result, a pairwise *t* test helped assess whether the means differences between sessions differ significantly from each other. To control Type I error, that is the family-wise error rate across the three tests at the .05 significance level, we used the Holm's sequential

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TABLE 2. Conceptual definition and operationalization of behavioral variables.

Variable	Definition	Examples or further explanation	Data collection
INFORMATION OBJECTS ENCOUNTERED			
Number of all pages visited	The number of the web pages a searcher visited in each session, including those which were viewed more than once	If a searcher has visited the following web pages, the number will be 8. Google.com Google.com/q=Hawaii+vacations Gohawaii.com Google.com/q=Hawaii+vacations Hawaii.com www.hawaii.com/travel/maui_travel_specials.php Hawaii.com Google.com/q=Hawaii+vacations	Screen capture software
Number of unique pages visited	The number of the web pages a searcher visited in the current session, each of which has a unique URL	If a searcher has visited the following web pages, the number will be 5 in session 1, 3 in session 2, 2 in session 3 (travelocity.com). In Session 1 Google.com Google.com/q=Hawaii+vacations Gohawaii.com Google.com/q=Hawaii+vacations Hawaii.com www.hawaii.com/travel/maui_travel_specials.php Hawaii.com Google.com/q=Hawaii+vacations In session 2 Hawaii.com Google.com Yahoo.com Google.com In session 3 Gohawaii.com Travelocity.com	Screen capture software
Number of true unique pages visited (this session first)	The number of the web pages a searcher visited in the current session, each of which has a unique URL, excluding those which were visited in prior sessions. If a page was seen in an earlier session, it won't be counted, even if that page was only visited once in the current session.	If a searcher has visited the following web pages, the number will be 5 in session 1, 1 in session 2 (yahoo.com), 1 in session 3 (travelocity.com). In Session 1 Google.com Google.com/q=Hawaii+vacations Gohawaii.com Google.com/q=Hawaii+vacations Hawaii.com www.hawaii.com/travel/maui_travel_specials.php Hawaii.com Google.com/q=Hawaii+vacations In session 2 Hawaii.com Google.com Yahoo.com Google.com In session 3 Gohawaii.com Travelocity.com	Screen capture software
INFORMATION PROBLEMS			
Number of topics searched	The number of topics a searcher has searched or browsed in each session. Definition of a topic: A topic is a conceptual entity about which one can search for information. A topic is a conceptual entity about which one searches for information. A topic can be composite, made up of different sub-topics, and presented in a tree-like structure.	When a searcher searched for information about lodging in Paris, the web site that provides a list of lodging options in Paris is considered as a topic. Vacation in Orlando as a topic can include sub-topics of accommodation, transportation, dining and activities. Each of these topics and sub-topics can be considered as a node. Accommodation as a topic can include subtopics or child nodes such as Hilton Hotel, Days Inn, and Holiday Inn. When counting the topic in this study, we only counted the nodes that have one-generation child nodes. Using the examples given, accommodation is counted a topic, while Hilton Hotel, Days Inn, Holiday Inn are not (because they don't have child nodes) and vacation in Orlando is not (because it has two-generations of child nodes such as Hilton Hotel).	Screen capture software

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TABLE 2. *(Continued)*

Variable	Definition	Examples or further explanation	Data collection
QUERYING			
Number of times searching with query terms	The number of times in which a searcher used search engines to search for information that involved query terms in each session.	If a searcher has used the following query terms to search in a single session, the count will be 3. The first time: Hawaii vacation The second time: Hawaii cruise The third time: Hawaii hotels	Screen capture software
Number of query terms	The number of words a searcher used to search in each session.	If a searcher has used the following query terms to search in a single session, the count will be 6. The first time: Hawaii vacation The second time: Hawaii cruise The third time: Hawaii hotels	Screen capture software
Number of unique query terms	The number of *unique* words a searcher used to search in each session.	If a searcher has used the following query terms to search in a single session, the count will be 4. The first time: Hawaii vacation The second time: Hawaii cruise The third time: Hawaii hotels	Screen capture software
INFORMATION ATTAINMENT			
Number of pages indexed	The number of the web pages that were indexed using the Personalized Indexing feature of PERSIST.	When a searcher used "Hawaii, portal" to "represent" Hawaii.com via the Personalized Indexing feature of PERSIST, the count will increment by 1.	Log file
Indexing ratio over unique pages visited	The ratio of the number of pages indexed over the number of unique pages visited.	If the number of the unique pages visited is 20 and the number of the indexed pages is 2, then the revisiting ratio is 1/10 (2/20).	Formula computed
Indexing ratio over all pages visited	The ratio of the number of pages indexed over the number of all pages visited.	If the number of all pages visited is 30 and the number of the indexed pages is 2, then the revisiting ratio is 1/15 (2/30).	Formula computed
Number of pages saved with the PERSIST "save" feature	The number of times a searcher has used the "save" feature of PERSIST in each session.	If a searcher has "saved" Hawaii.com with the "save" function of PERSIST, the count increments by 1.	Log file
Number of pages printed	The number of times a searcher has printed out the web page visited in each session	When a searcher printed out a web page, the count goes up by 1.	Screen capture software
Number of pages indexed and printed	The number of times a searcher has both printed out AND indexed (with the Personalized Indexing feature) the same web page. The page was printed in this session, but could be indexed in a prior session.	If a searcher has not only indexed a web page, but also printed it out in this session, the count goes up by 1. If a searcher has indexed a web page in a prior session but did not print it out until this session, the count goes up by 1.	Screen capture software
Number of the pages indexed and printed (same session)	The number of times a searcher has both printed out AND indexed (with the Personalized Indexing feature) the same web page. The page was indexed and printed in this very same session	If a searcher has not only indexed a web page, but also printed it out in this session, the count goes up by 1. If a searcher has indexed a web page in a prior session but did not print it out until this session, the count does not go up.	
Number of pages indexed, saved, or printed[a]	The number of times a searcher has engaged in *at least one* of the following three options with a specific web page in each session: (1) printed out, (2) indexed (with the Personalized Indexing feature), and (3) saved using the "save" feature of PERSIST (the pages printed could be indexed in the prior session).	Number of pages indexed + number of pages saved + number of pages printed − number of pages indexed and printed − number of pages indexed and saved − number of pages saved and printed + number of pages indexed and printed and saved	Formula computed
Number of pages indexed, saved, or printed (same session)	The number of times a searcher has engaged in *at least one* of the following three options with a specific web page in each session: (1) printed out, (2) indexed (with the Personalized Indexing feature), and (3) saved using the "save" feature of PERSIST (the pages printed must be indexed in the same session).	Number of pages indexed + number of pages saved (same session) + number of pages printed (same session) − number of pages indexed and printed (same session) − number of pages indexed and saved (same session) − number of pages saved and printed (same session) + number of pages indexed and printed and saved (same session)	Formula computed

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TABLE 2. *(Continued)*

Variable	Definition	Examples or further explanation	Data collection
Information attainment ratio over the number of *all* pages visited	Of all the pages visited in this session, percentage of pages have been indexed, saved, or printed.	Number of pages indexed, saved, or printed divided by Number of all pages visited	Formula computed
Information attainment ratio over the number of *unique* pages visited	Of all the *unique* pages visited in this session, percentage of pages have been indexed, saved, or printed.	Number of pages indexed, saved, or printed divided by Number of unique pages visited	Formula computed
Information attainment ratio over the number of all pages visited (same session)	Of all the pages visited in this session, percentage of pages have been indexed, saved, or printed *in the same session*.	Number of pages indexed, saved, or printed (same session) divided by Number of all pages visited	Formula computed
Information attainment ratio over the number of unique pages visited (same session)	Of all the *unique* pages visited in this session, percentages of pages have been indexed, saved, or printed *in the same session*.	Number of pages indexed, saved, or printed (same session) divided by Number of unique pages visited	Formula computed
REVISITING			
Overall revisiting ratio	The ratio of the difference between the number of the total pages visited and the number of the unique pages visited over the former.	If the number of the unique pages visited is 20 and the number of the total pages visited is 30, then the revisiting ratio is 1/3 ((30-20)/30).	Formula computed
Number of times using PI to return	The number of times a searcher has used Personal Indexing (part of PERSIST) to revisit a web page seen earlier in each session.	If a searcher has indexed Hawaii.com with index terms such as "Hawaii, portal" using Personalized Indexing and later returned to this page via Personalized Indexing, the count increments by 1. The return could take place within the same or in a later session.	Screen capture software
Number of times using PERSIST history to return	The number of web pages returned to via PERSIST History (Interaction Recorder).	Whenever a searcher used the PERSIST history feature to return to a page seen before, the count increments by 1. The return could take place within the same or in a later session.	Screen capture software
Number of times using PERSIST to return	The number of web pages returned to via PERSIST (Personalized Indexing or Interaction Recorder).	Number of times using PI to return + Number of times using PERSIST history to return	Formula computed
Revisiting ratio via PERSIST	The number of web pages returned to via PERSIST over the number of revisiting pages. The latter is the difference between total pages visited and the unique pages visited.	If the number of the unique pages visited was 20 and the number of total pages visited was 30, and 3 pages were returned via PERSIST, the ratio is 3/(30-20) or 3/10.	Formula computed
Revisiting ratio via PI	The number of web pages returned to via PI (part of PERSIST) over the number of revisiting pages. The latter is the difference between total pages visited and the unique pages visited.	If the number of the unique pages visited was 20 and the number of total pages visited was 30, and 2 pages were returned via PI, the ratio is 2/(30-20) or 2/10.	Formula computed

[a]The number of pages indexed and saved is 0 because there was no reason for a searcher to index and save at the same time because both saving and indexing would have the same effect of allowing one to return to the information object. Number of pages saved and printed is 0; few searchers actually used the "save page" feature. When they did save, they did not print, at least in this study. Number of pages indexed and saved and printed is 0 as well because the searcher simply did not index and save at the same time.

Bonferroni procedure. To reject the null hypotheses in this procedure, the smallest p value in a pair of sessions has to be smaller than .017 (0.5/3), the next smaller p value smaller than .025 (0.5/2), and the largest p value smaller than 0.05 (0.5/1) (Green et al., 2000, pp. 214–215).

The Behavioral Variables Studied and Hypotheses

The requirements of PERSIST are derived from the MISE framework, as PERSIST addresses the search problems by characterizing successive information search

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systematically with the variables in MISE (Lin, 2002). Thus, to study transmuting successive searches in the web environment with PERSIST and answer the research questions, the behavioral variables have to be derived from MISE and PERSIST and answer the two research questions: (1) How do the behavioral variables of transmuting successive searches on the web evolve over multiple sessions? (2) What behavioral variables can best differentiate different stages of transmuting successive searches?

As stated in MISE, the information-seeking process consists of the following four subprocesses: articulation of the information problems, navigation of the information space, evaluation of the search output, and monitoring of the search goals. Behavioral variables that manifest these four subprocesses include the following: information objects encountered, information problems, querying, revisiting, and information attainment.

Table 2 presents all the observed behavioral variables, their operational definitions, examples, and data collection methods. As the study was taking place in the web environment, the information object of interest is a web page, which is defined as those which can be identified with a *unique* and visible URL, including those which HTML frames could incorporate in more than one HTML file, and those which contain multitabbed panels. Below, the five categories of behavioral variables will be further explained and the hypotheses were proposed accordingly to help answer research question 1: "How do the behavioral variables of transmuting successive searches on the web evolve over multiple sessions?" In each category, the variable that has the most effect size could be considered as the strongest differentiator for stages of successive multisession search, or for status of the evolving information problem, which will help answer research question 2: "What behavioral variables can best differentiate different stages of transmuting successive searches?"

The category of information objects interacted with includes number of all pages visited, number of unique pages visited, and number of true unique pages visited. These variables could indicate the scope of searches the searchers conducted in three search sessions that embody different phases of successive searches. The total number of pages visited in each search session might not vary over the sessions, because the increasing level of subject knowledge from the information collected might be cancelled out by the increasing restriction of relevant criteria. However, the number of unique pages visited (unique not considering prior sessions, or, unique considering prior sessions) could decrease over the sessions. According to MISE's (Lin & Belkin, 2005) descriptive account of transmuting successive searches, the searchers explore the information space in earlier sessions, during which they skim the pages quickly as the purpose is to "discover" the interest. In later sessions, when the searchers are finalizing their ideas, they reaccess their information attainment to extract the useful information and thus visit fewer unique pages.

> Hypothesis 1a: The number of all pages visited does not change significantly across different search sessions.
>
> Hypothesis 1b: The number of unique pages visited does decrease across different search sessions.
>
> Hypothesis 1c: The number of truly unique pages visited does decrease across different search sessions.

The category of information problems includes number of topics searched. This behavioral variable reflects the nature of transmuting successive searches in that the searchers have to traverse through stages of idea formulation, idea transformation and expansion, and finally idea solidification and finalization. Xie (2009) found that changes of search topics in general occurred in their prefocus stage (i.e., idea formation), when student participants were still exploring the potential topics of the research proposal and needed to find enough useful information as well as cognitively engage in these topics. At the formation stage (i.e., idea transformation), some of the students only modified their topics by broadening or narrowing down their original topics. At the postfocus stage (i.e., idea solidification), no one changed or modified their search topics. Users also apply different search strategies during successive searches. Similar research findings also have been reported by Vakkari (2000b), Pennanen and Vakkari (2003), Kuhlthau et al. (2008), and Hyldegård and Ingwersen (2007). Thus, it was hypothesized that the number of topics searched will decrease over sessions.

> Hypothesis 2: The number of topics searched decreases as the session number increases.

The category of querying includes such behavioral variables as number of times searching with query terms, number of query terms, and number of unique query terms. As noted in the PERSIST design, searchers engaging in successive searches are likely to rely on navigating the information space (i.e., browsing) more than articulating the information problem (i.e., querying). Particularly in the idea formation stage, where searchers do not have a great deal of subject knowledge, they will likely browse more than search in earlier stages. As their subject knowledge increases over sessions, they might choose to query more frequently and use more specific query terms to find more specific information, as Vakkari (2000) found in his research results. Observing eight student searchers working with intermediaries over an extended period of time, Spink et al. (2002) inferred that the mean number of query terms per search session will not change as the session number increases, but the mean number of unique query terms per search session will change. For studies based on observation over end-user search, Vakkari (2001) found that the number of search terms did increase in later sessions, but that study only had 11 subjects. Vakkari et al. (2003) revisited the hypothesis again with more subjects (22), but did not find statistical significance to support the hypothesis, despite that the mean in the number of query terms used in a later session was higher than an earlier session. Given these empirical findings, the following hypotheses were made.

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Hypothesis 3a: The number of times searching with query terms does increase significantly across different search sessions.

Hypothesis 3b: The number of query terms does not change significantly across different search sessions.

Hypothesis 3c: The number of unique query terms does increase across different search sessions.

The "information attainment" category includes many behavioral variables: number of pages indexed, indexing ratio over all pages visited, indexing ratio over unique pages visited, number of pages saved, number of pages printed, number of pages indexed and printed, number of pages indexed and printed (same session), number of pages indexed, saved, or printed, number of pages indexed, saved, or printed (same session), information attainment ratio over the number of pages visited, information attainment ratio over the number of unique pages visited, information attainment ratio over the number of all pages visited (same session), and information attainment ratio over the number of unique pages visited (same session). Cole, Mandelblatt, and Stevenson (2002) pointed out that undergraduates should apply a high recall search strategy with broad queries at the exploration stage (i.e., idea formation session in our study) of the process before they form clear ideas for their research. The PI feature functions like Bookmarks in Firefox and Favorites in Internet Explorer. An indexed page could signify one that is at least partially relevant to the user. Number of pages indexed could decrease over sessions, because the earlier sessions are directed by indefinite information problems and looser relevance criteria. Searchers are likely to index web pages freely early on, and postpone the decision about the full relevancy of these pages until later sessions when their information problems are more refined. The PERSIST SAVE feature allows the searchers to "save" a page without indexing it (i.e., assigning labels to the page). The same reasoning can be applied to the number of pages saved. Ratio could be a better indicator than pure number, as the former could normalize irregularities. That is why indexing ratio and information attainment ratio were also considered as variables. Indexing ratio could be expected to decrease for the same reason as number of pages indexed.

Hypothesis 4a: The number of pages indexed does decrease significantly across different search sessions.

Hypothesis 4b: The indexing ratio over all pages visited does decrease significantly across different search sessions.

Hypothesis 4c: The indexing ratio over unique pages visited does decrease significantly across different search sessions.

Hypothesis 4d: The number of pages saved does decrease significantly across different search sessions.

Like indexed pages, printed pages could also signify pages that are at least partially relevant to the user. But printed pages may indicate a greater amount of relevance because printing uses more resources (e.g., paper) than indexing. Printing may indicate a higher level of commitment to an information object than indexing. By the same token, pages both indexed and printed could indicate an even higher level of commitment to a web page than merely indexing or printing. Thus, we expected that number of pages printed, as well as number of pages indexed and printed, and number of pages indexed and printed (same session), to increase over sessions because the searchers would commit to their topics (i.e., destinations and activities) more in later sessions than earlier ones.

Hypothesis 4e: The number of pages printed does increase significantly across different search sessions.

Hypothesis 4f: The number of pages indexed and printed does increase significantly across different search sessions.

Hypothesis 4g: The number of pages indexed and printed (same session) does increase significantly across different search sessions.

The next block of behavioral variables for information attainment concerns the pages that interest the searchers enough for them to attain them. The information could be attained by printing, indexing, or saving. As we hypothesized opposite directions regarding number of pages indexed and number of pages printed, we suspected that this block of variables would remain significantly unchanged over the sessions. Again, the ratio variables were considered here in order to test which of the following would be stronger differentiators.

Hypothesis 4h: The number of pages indexed, saved, or printed does not change significantly across different search sessions.

Hypothesis 4i: The number of pages indexed, saved, or printed (same session) does not change significantly across different search sessions.

Hypothesis 4j: The information attainment ratio over the number of all pages visited does not change significantly across different search sessions.

Hypothesis 4k: The information attainment ratio over the number of unique pages visited does not change significantly across different search sessions.

Hypothesis 4l: The information attainment ratio over the number of all pages visited (same session) does not change significantly across different search sessions.

Hypothesis 4m: The information attainment ratio over the number of unique pages visited (same session) does not change significantly across different search sessions.

The "revisiting" category includes the following behavioral variables: overall revisiting ratio, number of times using PI to return, number of times using PERSIST History to return, number of times using PERSIST to return, revisiting ratio via PERSIST, and revisiting ratio via PI. Note that the variable "overall revisiting ratio" is different from the rest of revisiting variables involving PERSIST and PI, in that the former implies that the other pages that were "revisited" could be used via the "back" button, which may or may not have true return intention. According to Xie (2009), during the postfocus stage (i.e., idea solidification session in our study), more than 80% of participants used the

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pearl-growing strategies by going through their retrieved results and looking for documents like the relevant ones at hand based either on citations of these items or on subject areas mentioned in these articles. In the web environment, the searchers could revisit the pages they indexed or saved with the PERSIST SAVE feature in order to assimilate the information on the page and increase their subject knowledge or simply to reevaluate the relevance of that page. Based on Xie's finding (2009) and the descriptive account of transmuting successive searches with MISE, we hypothesized that revisiting will occur more frequently as the session numbers increase.

Hypothesis 5a: The number of times using PI to return does increase significantly across different search sessions.

Hypothesis 5b: The number of times using PERSIST history to return does increase significantly across different search sessions.

Hypothesis 5c: The number of times using PERSIST to return does increase significantly across different search sessions.

Hypothesis 5d: The revisiting ratio via PI does increase significantly across different search sessions.

Hypothesis 5e: The revisiting ratio via PERSIST does increase significantly across different search sessions.

Hypothesis 5f: The overall revisiting ratio does increase significantly across different search sessions.

TABLE 3. Means and standard deviations for information objects encountered ($N = 20$).

	Session 1	Session 2	Session 3
All pages:			
Mean	50.00	52.40	48.85
SD	14.65	16.29	20.86
Unique pages:			
Mean	29.40	31.35	28.50
SD	8.25	8.31	11.63
True unique pages:			
Mean	29.40	27.90	22.45
SD	8.25	7.80	9.80

TABLE 4. Means and standard deviations for querying behavioral variables ($N = 20$).

	Session 1	Session 2	Session 3
Number of times searching with query terms:			
Mean	3.40	3.00	2.50
SD	2.33	2.45	3.17
Number of query terms:			
Mean	5.45	5.90	5.25
SD	4.74	6.05	5.72
Number of unique query terms:			
Mean	4.15	3.70	3.90
SD	3.31	3.26	4.08

Results

The findings of this research answer the two research questions and associated hypotheses. Because hypotheses are the crucial components of the research questions, answers to the two research questions are presented after the report of hypotheses testing results at the end of the Results section.

Hypothesis 1a: The number of all pages visited does not change significantly across different search sessions.

Hypothesis 1b: The number of unique pages visited decreases across different search sessions.

Hypothesis 1c: The number of truly unique pages visited decreases across different search sessions.

Table 3 presents means and standard deviations for information objects encountered. The ANOVA tests revealed that the only significant result was for hypothesis 1c, Wilks's Lambda = .693, $F(2,18) = 3.98$, $p = .037$, multivariate = .307. The paired-sample t test showed a significant difference between session 1 and session 3, $t(19) = 2.648$, $p = .016$; the difference between session 2 and 3 was significant, $p = .027$, but had to be ruled insignificant when apply the Holm's sequential Bonferroni procedure (>.025). The results suggested that the number of true unique pages visited dramatically decreased in the last search session, significantly different from session 1 and borderline significantly different from session 2.

Hypothesis 2: The number of topics searched decreases as the session number increases.

The result of hypothesis 2 testing showed that the means and standard deviations for number of search topics were 9.80 (4.312) in session 1, 7.2 (3.318) in S2, and 5.7 (2.494) in S3. The results for the ANOVA indicated a significant session effect, Wilks's Lambda = .575, $F(2,18) = 6.647$, $p = .007$, multivariate = .425. The paired-sample t test showed a significant change between session 1 and 3, $t(19) = 3.727$, $p = .001$, and between session 1 and 2, $t(19) = 2.691$, $p = .014$, and between session 2 and 3, $t(19) = 2.173$, $p = .043$. The results confirmed the research hypothesis, suggesting that the number of search topics does decrease over the sessions significantly.

Hypothesis 3a: The number of times searching with query terms increases significantly across different search sessions.

Hypothesis 3b: The number of query terms does not change significantly across different search sessions.

Hypothesis 3c: The number of unique query terms increases across different search sessions.

Table 4 presents means and standard deviations for querying behavioral variables. The ANOVA results showed no significant changes. None of the query behavioral variables changed significantly across different search sessions.

Hypothesis 4a: The number of pages indexed decreases significantly across different search sessions.

Hypothesis 4b: The indexing ratio over all pages visited decreases significantly across different search sessions.

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TABLE 5. Means and standard deviations for indexing behavioral variables ($N = 20$).

	Session 1	Session 2	Session 3
Number of pages indexed:			
Mean	6.25	3.05	0.85
SD	4.72	3.24	1.57
Indexing ratio over number of all pages visited:			
Mean	0.15	0.08	0.03
SD	1.24	0.07	0.04
Indexing ratio over number of unique pages visited:			
Mean	0.25	0.13	0.04
SD	0.20	0.12	0.07
Number of pages saved:			
Mean	0.30	0.25	0.00
SD	0.66	0.64	0.00

Hypothesis 4c: The indexing ratio over unique pages visited decreases significantly across different search sessions.

Hypothesis 4d: The number of pages saved decreases significantly across different search sessions.

Table 5 presents means and standard deviations for indexing behavioral variables. The means and standard deviations for number of pages indexed were 6.25 (4.723) in session 1, 3.05 (3.236) in S2, and .85 (1.565) in S3. The ANOVA results showed that an overall significant session effect for number of pages indexed, Wilks's Lambda = .343, $F(2,18) = 17.214$, $p = .000$, multivariate = .657. The paired-sample t test revealed significant changes between session 1 and 3, $t(19) = 4.914$, $p = .000$, between session 2 and 3 $t(19) = 4.306$, $p = .000$, and between session 1 and 2, $t(19) = 2.886$, $p = .009$. The results suggested that the number of pages indexed indeed decreased over the sessions significantly. Hypothesis 4.a was supported.

For indexing ratio over all pages visited, the results for the ANOVA indicated a significant session effect, Wilks's Lambda = .402, $F(2,18) = 13.400$, $p = .000$, multivariate = .598. The paired-sample t test further uncovered significant changes between session 1 and 3, $t(19) = 4.655$, $p = .000$, between session 2 and 3 $t(19) = 3.480$, $p = .003$, and between session 1 and 2, $t(19) = 2.711$, $p = .014$. So, the differences in the indexing ratio over all pages visited among all the three search sessions were all significant. Hypothesis 4.b was accepted as well.

The results for the ANOVA indicated a significant session effect for the indexing ratio over unique pages visited, Wilks's Lambda = .358, $F(2,18) = 16.157$, $p = .000$, multivariate = .642. The paired-sample t test further uncovered significant changes between session 1 and 3, $t(19) = 5.182$, $p = .000$, between session 2 and 3 $t(19) = 3.952$, $p = .001$, and between session 1 and 2, $t(19) = 3.077$, $p = .006$. The results suggested that the indexing ratio over unique pages visited decreased over the sessions significantly. Hypothesis 4.c was confirmed as well.

The ANOVA result for number of pages saved was not significant. Hypothesis 4d was rejected.

TABLE 6. Means and standard deviations for indexing and printing behavioral variables ($N = 20$).

	Session 1	Session 2	Session 3
Number of pages printed:			
Mean	1.50	3.35	5.00
SD	2.52	4.79	4.00
Number of pages indexed and printed:			
Mean	0.55	1.15	0.85
SD	1.19	3.03	1.69
Number of pages indexed and printed (same session):			
Mean	0.55	1.05	0.55
SD	1.19	3.03	1.40

Comparing these three behavioral variables regarding indexing, the effect size was the greatest for number of pages indexed (.657), followed by indexing ratio over unique pages visited (.642), and then indexing ratio over all pages visited (.598). All three behavioral variables seem good indicators of stages of successive searches.

Hypothesis 4e: The number of pages printed increases significantly across different search sessions.

Hypothesis 4f: The number of pages indexed and printed increases significantly across different search sessions.

Hypothesis 4g: The number of pages indexed and printed (same session) increases significantly across different search sessions.

Table 6 shows the means and standard deviations for number of pages printed, number of pages indexed and printed, and number of pages indexed and printed (same session). The ANOVA result indicated a significant session effect for number of pages printed, Wilks's Lambda = .499, $F(2,18) = 9.051$, $p = .002$, multivariate = .501. The paired-sample t test further uncovered the only significant session change between session 1 and 3, $t(19) = -4.341$, $p = .000$. Hypothesis 4.e is partially supported; the number of pages printed increased significantly only after session 2. The ANOVA results revealed no significance effects of sessions for number of pages indexed and printed and number of pages indexed and printed (same session). Hypotheses 4.f and 4.g were rejected.

Hypothesis 4h: The number of pages indexed, saved, or printed does not change significantly across different search sessions.

Hypothesis 4i: The number of pages indexed, saved, or printed (same session) does not change significantly across different search sessions.

Hypothesis 4j: The information attainment ratio over the number of all pages visited does not change significantly across different search sessions.

Hypothesis 4k: The information attainment ratio over the number of unique pages visited does not change significantly across different search sessions.

Hypothesis 4l: The information attainment ratio over the number of all pages visited (same session) does not change significantly across different search sessions.

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TABLE 7. Means and standard deviations for information attainment variables ($N = 20$).

	Session 1	Session 2	Session 3
Number of pages indexed, saved, or printed:			
Mean	7.55	5.95	5.20
SD	4.29	4.52	4.11
Number of pages indexed, saved, or printed (same session):			
Mean	7.55	6.05	5.50
SD	4.29	4.49	4.00
Information attainment ratio over the number of *all* pages visited:			
Mean	0.17	0.12	0.11
SD	0.12	0.84	0.84
Information attainment ratio over the number of *unique* pages visited:			
Mean	0.28	0.20	0.18
SD	0.18	0.15	0.14
Information attainment ratio over the number of *all* pages visited (same session):			
Mean	0.17	0.12	0.12
SD	0.12	0.08	0.08
Information attainment ratio over the number of *unique* pages visited (same session):			
Mean	0.28	0.20	0.19
SD	0.18	0.15	0.13

Hypothesis 4m: The information attainment ratio over the number of unique pages visited (same session) does not change significantly across different search sessions.

Table 7 shows the means and standard deviations for the behavioral variables in hypotheses 4.h to 4.m.

For the number of pages indexed, saved, or printed, the overall ANOVA test was significant but weak, Wilks's Lambda = .702, $F(2,18) = 3.823$, $p = .041$, multivariate = .298. The differences between sessions, however, were not significant after the Holm's sequential Bonferroni procedure was taken to control Type I error rates. This means the number of pages indexed, saved, or printed did not change significantly over sessions. The same effect for information attainment ratio over number of all pages visited, Wilks's Lambda = .711, $F(2,18) = 3.659$, $p = .046$, multivariate = .289. These two behavioral variables did not change significantly over sessions.

The ANOVA results indicated no significant values for number of pages indexed, saved, or printed (same session), and information attainment ratio over number of all pages visited (same session). These two behavioral variables did not change significantly over sessions.

The ANOVA results indicated significant values for information attainment ratio over number of unique pages visited, Wilks's Lambda = .664, $F(2,18) = 4.556$, $p = .025$, multivariate = .336, and information attainment ratio over the number of unique pages visited (same session), Wilks's Lambda = .712, $F(2,18) = 3.636$, $p = .047$, multivariate = .228. Information attainment ratio over number of unique pages visited did decrease over session, but only between session 1 and 3, $t(19) = 3.03$, $p = .007$. The difference between session 1 and 2 was significant, $t(19) = 2.17$, $p = .043$, but was not significant after the Holm's sequential Bonferroni procedure was taken to control Type I error rates. Information attainment ratio over the number of unique pages visited (same session) also did decrease over session, but only between session 1 and 3, $t(19) = 2.66$, $p = .015$. The difference between session 1 and 2 was significant, $t(19) = 2.11$, $p = .049$, but was not significant after the Holm's sequential Bonferroni procedure was taken to control Type I error rates.

These two behavioral variables might be differentiators of stages of transmuting successive searches, but information attainment ratio over number of unique pages visited had a stronger effect size than information attainment ratio over number of unique pages visited (same session).

Hypothesis 5a: The number of times using PI to return increases significantly across different search sessions.

Hypothesis 5b: The number of times using PERSIST History to return increases significantly across different search sessions.

Hypothesis 5c: The number of times using PERSIST to return increases significantly across different search sessions.

Hypothesis 5d: The revisiting ratio via PI increases significantly across different search sessions.

Hypothesis 5e: The revisiting ratio via PERSIST increases significantly across different search sessions.

Hypothesis 5f: The overall revisiting ratio increases significantly across different search sessions.

Table 8 shows the means and standard deviations for revisiting behavioral variables. The ANOVA results showed a significant session effect for number of times using PI to return, Wilks's Lambda = .624, $F(2,18) = 5.415$, $p = .014$, multivariate = .376., revisiting ratio via PERSIST, Wilks's Lambda = .667, $F(2,18) = 4.489$, $p = .026$, multivariate = .333, revisiting ratio via PI, Wilks's Lambda = .663, $F(2,18) = 4.585$, $p = .025$, multivariate = .337. Follow-up

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TABLE 8. Means and standard deviations for revisiting behavioral variables ($N = 20$).

	Session 1	Session 2	Session 3
Number of times using PI to return:			
Mean	0.55	1.20	2.30
SD	0.95	1.40	2.34
Number of times using PERSIST history to return:			
Mean	0.40	0.45	0.80
SD	0.99	0.80	2.73
Number of times using PERSIST to return:			
Mean	0.95	1.65	3.10
SD	1.19	1.50	3.11
Revisiting ratio via PI:			
Mean	0.04	0.07	0.14
SD	0.07	0.08	0.17
Revisiting ratio via PERSIST:			
Mean	0.05	0.09	0.17
SD	0.08	0.09	0.17
Overall revisiting ratio:			
Mean	0.40	0.39	0.41
SD	0.08	0.09	0.08

paired-sample t tests indicated that the only significant changes between sessions were between session 1 and 3; number of times using PI to return, $t(19) = -3.256$, $p = .004$, revisiting ratio via PERSIST, $t(19) = -2.966$, $p = .008$, and revisiting ratio via PI, $t(19) = -2.988$, $p = .008$. Thus, hypotheses 5a, 5d, and 5e were partially supported.

The ANOVA results showed a borderline-significant session effect for number of times using PERSIST, Wilks's Lambda = .721, $F(2,18) = 3.477$, $p = .053$, multivariate = .279. The paired-sample t test uncovered that the change between session 1 and 3 was significant, $t(19) = -2.680$, $p = .015$. Hypothesis 5c was partially supported.

Number of times using PERSIST History to return and overall revisiting ratio were simply not significant. Hypotheses 5b and 5f were rejected.

Answering the Two Research Questions

Table 9 summarizes all the hypotheses testing results. The column titled "RQ1" in this table answers research question 1 "How do the behavioral variables of transmuting successive searches on the web evolve over multiple sessions?" The testing results of the hypotheses with borderline significance were included here because this study was mainly exploratory. With a bigger subject pool and thus greater statistical power, these results could become significant. The column titled "RQ2" answers research question 2, "What behavioral variables can best differentiate different stages of transmuting successive searches?" It shows that information attainment behavioral variables involving indexing (e.g., bookmarking) are the best differentiators; not only do they have the largest effect size, but they also have significant changes in every stage of transmuting successive searches.

Discussion

Discussion of the Findings

The number of topics searched did decrease over sessions, as hypothesized. This confirmed that the 20 searchers participating in the study did follow through the controlled three stages transmuting successive searches process as designed.

The hypotheses group 1 (information objects encountered) suggested that the number of true unique pages visited in each session is a better differentiator for stages of transmuting successive searches than the number of all pages visited and the number of unique pages visited. It is about how many *new* web pages a searcher has encountered the first time in each session, and it must rule out the pages that were seen in prior sessions.

This finding was furthered augmented by the hypotheses group 5 (revisiting). The overall revisiting ratio (number of unique pages visited divided by number of all pages visited) did not change significantly over sessions; in fact, it was quite consistent in each session, around 40%. But the revisiting variables via PI (number of times using PI to return, revisiting ratio via PI, revisiting ratio via PERSIST) were all significant. This means that it is not just about revisiting the previously seen pages; it is about seeing the pages that users had deemed relevant. Moreover, while revisiting with PI showed an upward trend, as the stages of search evolved, the only significant difference was between the stage of idea formation and that of idea solidification. As the searchers got close to finishing their successive information search tasks, the need for revisiting relevant pages perked up significantly. By way of an aside, the consistent overall revisiting ratio (about 40%) reflects the reality that most searchers still prefer using the back button to get to the pages seen earlier in the same session.

PI appeared to be a preferable returning tool than the PERSIST history feature, because the hypotheses about revisiting concerning PI were significant, whereas those concerning PI history were not. This is consistent with the finding that the Bookmarks or Favorites features are more popular than the History features in most web browsers (Aula et al., 2005).

The importance of unique pages seen was also manifested in the findings that both "information attainment ratio over the number of unique pages visited" and "information attainment ratio over the number of unique pages visited (same session)" did decrease significantly between session 1 and 3. It was the ratios with number of unique pages visited as the divider (rather than number of all pages visited) that made the difference. These two behavioral variables were also the only two among the six information attainment variables that could differentiate the stage of idea formation from that of idea solidification, which may be explained by the high recall search strategy many searchers employ in the idea formation stage, as found by Cole et al. (2002).

The behavioral variables concerning indexing (number of pages indexed, indexing ratio over number of all pages

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TABLE 9. Summaries of the testing results for all the hypotheses and the answers to the two research questions.

Variables	RQ1: Findings (in the order of sig. level)	RQ2: Effect size
INFORMATION OBJECTS ENCOUNTERED		
Number of all pages visited	Not sig.	
Number of unique pages visited	Not sig.	
Number of true unique pages visited (this session first)	S1–S3 S2–S3 (Borderline significant)	.307
INFORMATION PROBLEMS		
Number of topics searched	S1–S3 S1–S2 S2–S3	.425
QUERYING		
Number of times searching with query terms	Not sig.	
Number of query terms	Not sig.	
Number of unique query terms	Not sig.	
INFORMATION ATTAINMENT		
Number of pages indexed	S1–S3 S2–S3 S1–S2	.657
Indexing ratio over unique pages visited	S1–S3 S2–S3 S1–S2	.598
Indexing ratio over all pages visited	S1–S3 S2–S3 S1–S2	.642
Number of pages saved with the PERSIST 'save' feature	Not sig.	
Number of pages printed	S1–S3	.501
Number of pages indexed and printed	Not sig.	
Number of pages indexed and printed (same session)	Not sig.	
Number of pages indexed, saved, or printed	Not sig. (overall significant, but no sessions significant after controlling type I error rates)	
Number of pages indexed, saved, or printed (same session)	Not sig.	
Information attainment ratio over the number of *all* pages visited	Not sig. (overall significant, but no sessions significant after controlling type I error rates)	
Information attainment ratio over the number of *unique* pages visited	S1–S3 (S1–S2, not significant after controlling type I error rates)	.336
Information attainment ratio over the number of *all* pages visited (same session)	Not sig.	
Information attainment ratio over the number of *unique* pages visited (same session)	S1–S3 (S1–S2, not significant after controlling type I error rates)	.228
REVISITING		
Number of times using PI to return	S1–S3	.376
Number of times using PERSIST history to return	Not sig.	
Number of times using PERSIST to return	S1–S3	.279
Revisiting ratio via PERSIST	S1–S3	.333
Revisiting ratio via PI	S1–S3	.337
Overall revisiting ratio	Not sig.	

visited, and indexing ratio over number of unique pages visited) appear to be the best differentiators of stages of successive search than any other behavioral variables. They can not only differentiate all three stages while most other behavioral variables can only differentiate between the stages of idea formation and idea solidification, but their effect sizes are also greater than all others.

The number of pages indexed decreased over sessions, while number of pages printed increased between session 1 and session 3. This seems to suggest that indexing (or bookmarking) was perceived as a tool for pages with any level of relevance, whereas printing may be perceived as a tool more for preserving highly relevant pages because the searchers would have to gather all the important information at the stage of idea solidification. However, number of pages that were not only indexed but also printed did not change over sessions. The web pages that were both indexed and printed did not indicate a more stringent level of relevance as hypothesized.

The hypotheses group 3 (querying) were not all significant. The literature has conflicting postulations regarding query terms used in successive searches (e.g., Spink et al., 1998, 2002; Vakkari, 2000), but none of the studies thus far

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has applied any statistical significance test in relation to these variables. Our study showed that query terms (frequency, number of all words, and number of unique words) are not good differentiators for stages of transmuting successive searches. Based on our observations over the searchers' searches, we also found that querying was not a predominant search activity for the vacation planning task. Many searchers resorted to web portals (e.g., Yahoo has a subportal just for vacation and travel) to engage in most of their search because these travel portals have provided many relevant links with categories like accommodation, points of interests, things to do, where to eat, and so on. Navigation of the information space, as MISE predicted, was indeed more important than articulation of the information problems.

Theoretical Implications

These hypotheses about searchers' behavioral characteristics together support many of the MISE propositions: as the searchers progress in their transmuting multisession successive information search, they could exhibit different behavioral characteristics in different sessions. Particularly, in earlier sessions the searchers are more likely to have vague and less-defined information problems; they are focusing on gathering more information to develop ideas. Seeing more unique pages is a sign of information gathering. As information problems are ill defined, searchers are also more likely to be uncertain about the relevance of web pages. They will use more fuzzy criteria to evaluate information objects in earlier sessions when candidate pooling and weighting are significant subtasks (Lin & Belkin, 2005). More information objects therefore will be perceived as at least partially relevant and indexed. At the same time, they are likely to build on the information attainment of previous search sessions to develop information problems and gain subject knowledge. The searchers would index web pages for revisiting later on in order to (1) reexamine the relevance of web pages, (2) follow the links in the collected web pages to explore more content, (3) assimilate the information within the collected web pages, and (4) extract the information from the collected web pages to complete a task product (e.g., a travel itinerary plan). In sum, the findings support the descriptive power of the MISE framework for transmuting successive searches, one of the eight multisession search scenarios, which is also better known as stage-centered successive searches.

The task of vacation planning, in our experimental setting, is similar to the task of writing an academic paper in the sense that they both manifest the classic stage-centered information-seeking process as described by Kuhlthau (1991, 1993). But noticeable differences still exist. The former could be more structured than the latter. Most stage-centered successive searches are not only transmuting (e.g., prefocus, focus formulation, postfocus), but also *spawning subtasks* (i.e., different aspects of the focus, no matter whether the focus is the topic of an academic paper or a vacation destination), another scenario of successive searches identified by MISE (Lin & Belkin, 2005). The identification of subtasks in vacation planning (e.g., accommodation, transportations, activities, dining) could be much easier and occur earlier than writing an academic paper (e.g., subtopics) as specified by Vakkari (2003). Consequently, searchers, when planning vacations, could perform these subtasks as either parallel tasks or dependent tasks (as described by Liu & Belkin, 2010), or even move freely between these two task types, as they are more likely to know about these subtasks even in *the prefocus stage*. By contrast, writing an academic paper is likely to be more of a "dependent task" type, as searchers could not as easily decompose a potential topic to multiple subtopics, and may not discover a subtopic until *the focus formulation stage*. As a result, searches would proceed in a relatively linear or "dependent" fashion. Such differences between information searches for the vacation planning task and the academic paper writing task highlight the importance of incorporating task type in studying information-seeking phenomena.

Much of the literature, particularly implicit relevance feedback, has focused on observing searchers' behavioral characteristics to infer the relevance of the information objects with which the searchers interact. Like Liu and Belkin (2010), our study is one of the first to explore the idea of using explicitly observable behavioral characteristics to predict the stages of transmuting successive searches. In a way, it unites the approach taken by the implicit relevance feedback field with the theoretical framework on successive searches. It is unique, important, and deserves more research attention in the future.

Practical Implications

Our findings have implications for system design. The results found behavioral variables that could differentiate different stages of successive searches. The information system needs to provide not only an information retrieval mechanism but also a personalized information search environment where it can detect stages of a searcher's search and tailor appropriate support tools to assist the search.

A personalized information search environment should be equipped with a search support tool such as PERSIST, as PERSIST provids effective ways to support revisiting and monitoring information attainment. With PERSIST, the searchers can dynamically and quickly reorganize the categorization of the information attainment to reflect the current state of their information problem. Portals, which organize all task-specific relevant information into categorized links, for example, travel.yahoo.com, can also be considered as effective support tools for idea exploration and expansion, based on our observations of 20 searchers. Information filtering techniques such as term suggestions to assist articulation activity (Wu et al., 2008), and using the time spent on viewed documents to predict usefulness of documents to assist the evaluation activity (Liu & Belkin, 2010) could also be helpful. In addition, tools such as text

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summarization, text extraction, or event planning (e.g., itinerary planning tool in most travel brokerage sites like travelocity.com or orbitz.com) can be useful in enhancing the monitoring activity of the information search process, and thus may be appropriate to support the final stage of idea solidification, as the monitoring behaviors occur more frequently in the ending phase of the search process (Xie & Joo, 2010). Further research can continue to design and test the effectiveness and efficiency of different search supporting tools, including PERSIST, in assisting different stages of transmuting successive searches.

Our study suggests that the information system can automatically detect stages of searchers' successive search sessions from different types of observable behavioral data. If searchers bookmark significantly fewer pages, search for fewer topics, and visit fewer unique pages as the session number increases, it is a good indication that the searchers are traversing the stages of idea formation, idea transformation, and finally idea solidification. If searchers start to more significantly rely on the bookmarks to return to previously seen pages, and print significantly more pages, it might be an indicator that the searchers are finalizing their searches. In addition, Wu et al. (2008) provided a different technique to detect the stages of users' search processes, based on changes of topics of the documents that users viewed in sessions. A personalized information search environment should build user profiling by incorporating empirical findings from our study and other related studies regarding these behavioral characteristics, detecting the stage of searchers' information search process or type of successive information problems (Lin & Belkin, 2005), and tailoring the support accordingly.

Study Limitations and Future Studies

Like all research, this study has its limitations. An experiment like ours, which controlled the number of sessions and forced different sessions to represent different stages of transmuting successive searches, enables direct comparison of behavioral variables and testing of their statistical significance. How these findings can be applicable to a real-life setting remains to be seen. Future research needs to replicate our study in a naturalistic setting in order to further examine the validity and reliability of our findings.

Our study also had only 20 valid searchers from a university setting. To increase the predictive power of the findings, more searchers with different backgrounds and tasks need to be recruited and participate in such studies.

Future studies can also explore other behavioral variables in differentiating stages of successive searches, or investigate how behavioral variables can differentiate different types of information problems prompting successive searches, like the other seven types of successive searches depicted in the MISE conceptual framework (Lin & Belkin, 2000, 2005).

Conclusion

Most successive search studies have been qualitative in nature and aimed to provide a better understanding of successive searches. Many of these studies have also not had enough searchers to use statistical methods to test the statistical significance of their findings. Our study is one of the few to demonstrate an experimental method with which we could quantitatively investigate how explicitly observable behavioral characteristics of searchers could evolve over different sessions or stages of transmuting successive searches. The study provides evidence to strengthen the validity of the descriptive propositions regarding transmuting successive search phenomena laid out in previous literature, particularly the MISE and ISP framework, as transmuting successive searches are types of successive searches that are common in these two frameworks.

The study is one of the first to apply the principles of the information retrieval research stream in implicit relevance feedback to the information-seeking research stream in successive information searches. Instead of using behavioral characteristics to infer the relevancy of the information objects encountered by searchers, we explored the possibility of using the behavioral characteristics of searchers to differentiate and thus detect the stages or sessions of transmuting successive searches. The implications are considerable, as they can be quite useful to the research streams in user modeling and web personalization and to practical system designers who aim to create a more effective and efficient information search environment to assist the searchers, rather than merely supplying an information retrieval mechanism.

Overall, the results of this study enhance our understanding of successive searches and validate the descriptive and explanatory powers of MISE, a conceptual model of successive searches. The study also helps validate the legitimacy of system requirements derivation from MISE to PERSIST. In the end, it helps revise the requirements of PERSIST and provides suggestions to other designers of information search environments because it also notes how PERSIST and other search support tools could be used to support successive searches.

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