Seeking Beyond With IntegraL: A User Study of Sense-Making Enabled by Anchor-Based Virtual Integration of Library Systems

Shuyuan Mary Ho
Florida State University, College of Communication and Information, School of Library and Information Studies, 142 Collegiate Loop, Tallahassee, FL 32306-2100. E-mail: smho@fsu.edu

Michael Bieber
New Jersey Institute of Technology, College of Computing Sciences, Information Systems Department, University Heights, Newark, NJ 07102-1982. E-mail: bieber@njit.edu

Min Song
Department of Library and Information Science, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul, Korea. E-mail: min.song@yonsei.ac.kr

Xiangmin Zhang
Wayne State University, School of Library and Information Science, 106 Kresge Library, Detroit, MI 48202. E-mail: ae9101@wayne.edu

This article presents a user study showing the effectiveness of a linked-based, virtual integration infrastructure that gives users access to relevant online resources, empowering them to design an information-seeking path that is specifically relevant to their context. IntegraL provides a lightweight approach to improve and augment search functionality by dynamically generating context-focused "anchors" for recognized elements of interest generated by library services. This article includes a description of how IntegraL's design supports users' information-seeking behavior. A full user study with both objective and subjective measures of IntegraL and hypothesis testing regarding IntegraL's effectiveness of the user's information-seeking experience are described along with data analysis, implications arising from this kind of virtual integration, and possible future directions.

Introduction

The availability of information has significantly influenced people's lives (Meyers, Fisher, & Marcoux, 2009). The more information one acquires and the quicker one identifies the source of information acquired, the more potential that piece of information has to impact one's perception, decision making, and actions. How can we help people make better sense of the information they find online? Information generally is not transsituational but grounded in a specific situation and context, which is then subject to an individual's experience, existing knowledge, and circumstance. The meaning of information that is sought and used does not remain "objective" or static in a person's mind but subjectively evolves based on each person's interpretation, framed in the context of time and space. People make sense of information as best they can, and in exploring and interpreting it they take deliberate, critical steps to bridge gaps caused by their own perceptions of the world during the information-seeking process (Dervin, 1983a, 1983b, 1999; Dervin & Nilan, 1986; Savolainen, 2006). Metaphorically, sense-making is a continuous step-taking process to properly reflect a user's perceived reality (Savolainen, 2006; Taija, 1996). However, because acquired information becomes subjectively interpreted, people's information-seeking practices should be designed into the architecture of information-seeking support systems (Courtright, 2007). Taylor (1968) noted that the "ease of access" to an information system is more significant than "amount (quantity) or quality of information" available (p. 6).

Dervin (2003) cautioned against the promise of new search technology, noting that relevance in interdisciplinary

Received October 6, 2012; revised December 5, 2012; accepted December 5, 2012

 • Published online 22 July 2013 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/asi.22904

human research is the most critical element (Mizzaro, 1997). Many information-seeking studies have attempted to focus on the new technologies, but have failed to take into account why and how users adopt them (Dervin, 2003). In this research, we primarily focuses on how to design a fine-grained, access-enhanced digital library system that can assist a user in information-seeking, utilization, and sense-making (Dervin, 1983b). Furthermore, how effective is this digital library system to user-defined relevance criteria in information-seeking and use (Barry, 1994; Belkin, 1980; Belkin, Oddy, & Brooks, 1982; Taylor, 1962, 1968, 1985, 1988)? This includes understanding the extent to which users constructively bridge gaps between the objective, material world (i.e., what is available through the web structure) and the subjective, interpretative world (i.e., what is understood by the user after searching).

> **RQ1:** Can enhanced access to information through virtual integration help users more effectively find and make sense of information from multiple library resources?

One reason that people sometimes cannot effectively complete a specific task can be lack of resources and poor access to information (Dervin, 1999; Taylor, 1968). In our study, we therefore also wanted to know whether virtual integration ameliorates this problem and encourages users to more effectively access and utilize library resources.

> **RQ2:** Can enhanced access to information through virtual integration increase the accessibility and utilization of library resources?

Users' knowledge and perceptions based on the feedback of the library systems are important factors in determining the success of a user's information-seeking process, and this process is dynamic (Belkin, 1980; Belkin et al., 1982; Taylor, 1962, 1968, 1985). In this vein, we propose a user-centric information-seeking system (IntegraL) with a very scalable and "lightweight" infrastructure that brings a plethora of relevant resources directly to users (IntegraL stands for INTEGRAting Libraries, though its applicability is much broader.) By virtually integrating heterogeneous digital libraries with other online sites and search services, IntegraL dynamically provides links to relevant information in diverse repositories related to the elements on the page the user is currently viewing. These links enable users to access and explore additional facets of these elements and thus deepen their understanding and help make better sense of the information that they are seeking. This article presents a design and an implementation of virtual integration, which extends the boundaries of how we think about and interact with digital libraries. It then describes a user study that demonstrates its success in deepening user comprehension.

IntegraL facilitates a virtual restructuring of public web spaces and services and makes digital library services interoperable through a single sign-on while taking advantage of numerous finer grained interrelationships. IntegraL helps users to effectively search through structured content based on identified name entities across heterogeneous digital libraries. Users not only interact with the libraries and search engines but also see extra link anchors, the *i*-icons ( ) illustrated in Figure 1. Upon selecting one link anchor, IntegraL dynamically generates a list of links. Currently, these links point to search engines that are relevant to the type of element that the user has selected. Extensions also could incorporate additional links to relevant documents, services, and metadata (Song & Bieber, 2008). For example, the links associated with the *i*-icon for an author could include the author's homepage and all articles, citations, blogs, and tweets written by or about this author. They also could permit users to add comments, ratings, or personal links regarding this author. These extensions assume that services to provide each of these links already exist or could be programmed (Catanio, Nnadi, Zhang, Bieber, & Galnares, 2004; Zhang, Bieber, Song, Oria, & Millard, 2010). Furthermore, by incorporating a recommendation engine, IntegraL could profile users in the context of their search results and provide context-specific recommendations (Im & Hars, 2007). IntegraL allows the various library systems to act both as *information requesters* (with a set of links embedded in display screens that widens user exploration of diverse, but relevant, resources) and *information providers* (of links to each system's relevant documents and services). For the current prototype, we have implemented a preliminary federated search, but our user study shows that even this basic service already yields better user-centric sense-making.

This article is organized as follows. In the next section, we review the literature concerning the rationale of users' information needs and seeking behavior as well as virtual integration and other infrastructure aspects. We then provide an overview of IntegraL's system architecture and its innovative way of focusing the use of multiple digital libraries, databases, and search engines. Next, we describe a user study evaluating IntegraL, along with the variables, measures, and our research hypotheses. Our research method is included in the subsequent section, where we present our experimental design, task assignments, rotation of conditions to avoid design bias, and strategies for data collection and analysis. Following this, we present the findings from the user study and detail how we tested our hypotheses. We then describe how we avoided threats to validity, exploring implications for information-seeking through IntegraL, and outlining limitations. We conclude with future research directions.

Related Work

The effectiveness of information seeking depends on an effective infrastructure that is based on users' information needs and information-seeking behavior as well as the state of the art in digital library virtual integration and search technology.

Information Needs

Based on information needs, a user may carry on several question-clarification processes while seeking information (Belkin, 1980; Belkin et al., 1982). A user may ask for help

DOI: 10.1002/asi

from a human reference source (e.g., a librarian) or attempt self-help (e.g., literature search or observations) (Taylor, 1968). During the process of information seeking, users define their own seeking strategies (Barry, 1994; Kuhlthau, 1991). In addition, the ease of access to information may be more significant than is the quality of information retrieved. Taylor (1968) identified four different levels of information needs. Users' information needs are often inexpressible and ambiguous in the beginning of an information search because they still need to determine (cognitively process) what they require to fill an information gap. Users' information needs may evolve from the first level (unconscious need for information) to the second level (conscious, but poorly described, need). At a third level, users may advance their ability to make a rational statement regarding their question. At this stage, users often include a librarian as part of the information-seeking process. At the fourth level, users can articulate specific documents to retrieve. During this process, the "form, quality, concreteness, and criteria" of information may change (Taylor, 1968, p. 8). But as more information is acquired, users can better formulate clear statements about what was really needed based on what information was available. Users will often satisfy their *information needs* with the information that is accessible. Although users' information needs may be compromised, their information behavior is highly rational and goal-oriented due to these needs (Case, 2006; Johnson, 2009; Wilson, 1999).

In reality, users' needs for information tend to shift dynamically according to available and accessible information, and their information-seeking strategies (Wilson, 1999; Xie, 2000, 2002). The faster information is obtained, the faster a user will seek more information. The dynamic nature of users' information needs has made information search and retrieval tasks more difficult to fulfill. Furthermore, contextual information is critical to users' information seeking and decision making. Contextual information can shift users' intentions and use of a specific type of information. Although contextual information can be repeatedly made available to users, the linkage between situational factors and users' information behavior may still be weak (Johnson, 2009; Weick, 1983). Information accessibility,

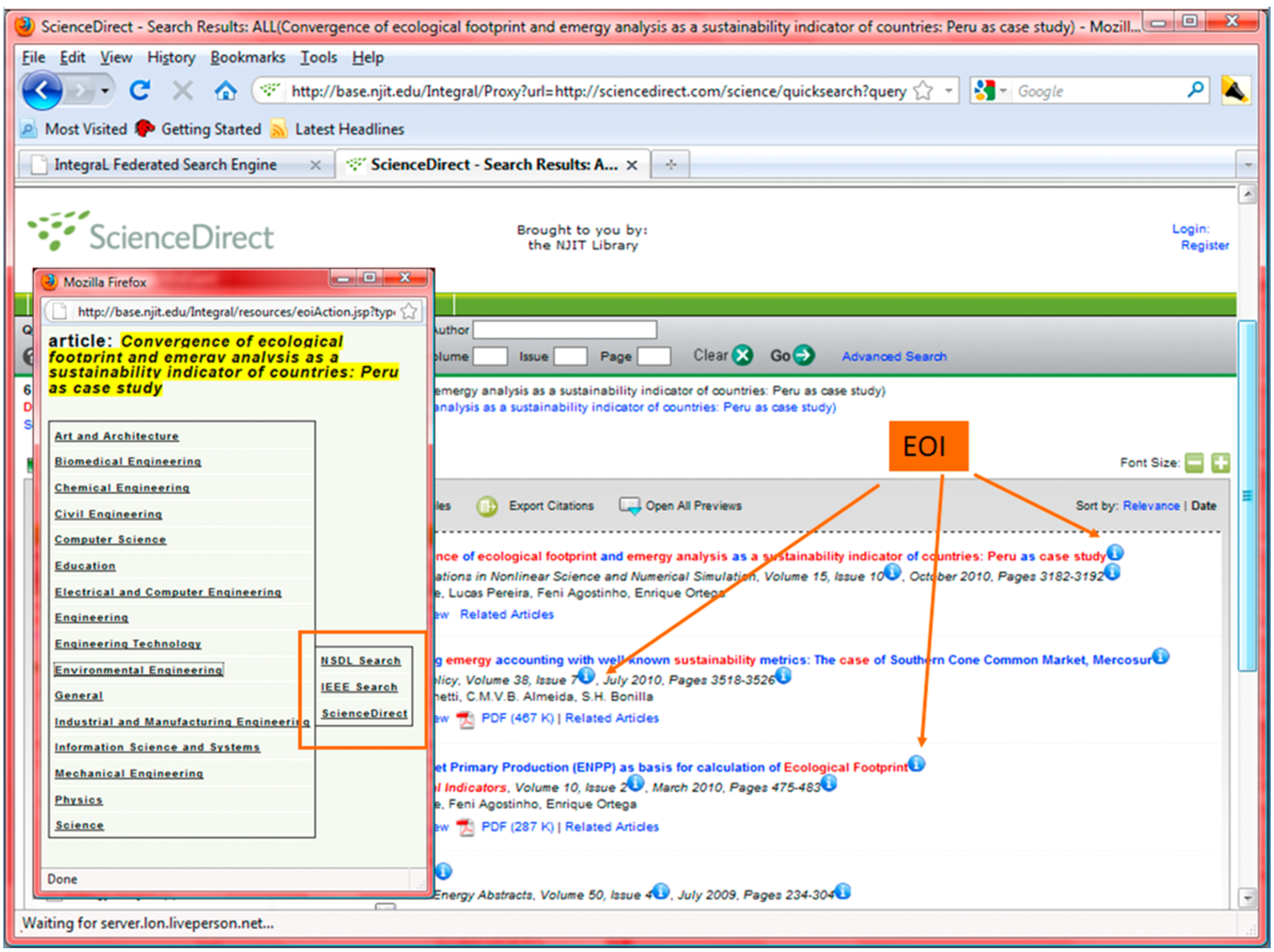

FIG. 1. IntegraL's interface showing link anchors added to the "element of interest" it identifies. Selecting the first anchor generates the list of relevant search engines for this element's domain. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

speed of information acquisition, relevance of information retrieved, and metadata of the retrieved information are all-important factors influencing users' information behavior (Johnson, 2009). As information is digitized, an effective system that facilitates users' information seeking (akin to of a digital librarian) can assist users to better articulate their informational needs while suggesting and delivering a pool of related files to address these needs.

Information Seeking Through Sense-Making

People are the ultimate *information requesters* or *information seekers*; they need and use information to bridge their knowledge gaps as they move through time and space. Time and space create situational and contextual conditions that may affect the observed information. Objective information is anchored in structures (e.g., sources and channels of information that are purposeful to a human's subjective needs; Case, 2006; Dervin & Nilan, 1986; Wilson, 2000). Whether through active or passive seeking, users' information behavior and decision making are constantly changing as a result of processing objective information. Objective information thus becomes somewhat subjective to *information requesters*. We may say that users' information-seeking behavior is part of human communication behavior through available channels, storage, and resources (Wilson, Ford, Ellis, Foster, & Spink, 2002). Information seeking is no longer viewed as a transmitting activity but as a *constructing* activity that is meaningful to the *information seeker*. By presenting users with more granular and increasingly relevant resources, systems can assist users in a series of constructing, reconstructing, and deconstructing activities until the users' information-seeking gap has been bridged (Dervin, 1983b; Savolainen, 2006).

Information seeking presents a challenging meta-theory because a user's information needs, seeking strategies, and information behaviors are constantly changing depending on the user's cognitive state and situational context (Vakkari, 1997). This meta-theory requires specific context and fixed social settings to identify how user's seeking behavior varies dynamically. The sense-making methodology requires situational context to be involved in building information-seeking support systems (Qu, 2003; Qu & Furnas, 2005). Solomon (1997a, 1997b, 1999a, 1999b) conducted a longitudinal study of users' information behavior in a sense-making context. In particular, the time aspect is essential in users' information seeking when they make sense of captured meaning from an uncertain and ambiguous context (Solomon, 1997a). Although sense-making takes time, the response rate from the information systems can assist in decision making and action-taking during the sense-making process. A user's social communication context also shapes seeking behavior (Solomon, 1999a). Users' communicative contexts (e.g., interactions with their close social groups, etc.) provide situations for and also constraints of their information behavior during ambiguous situations. Moreover, a user's cognition, personal habits, natural tendency, and sense-making styles all may influence information behavior (Solomon, 1999b). These personal attributes and ways of developing meaning of information are fundamentally embedded in our lifestyles.

Moreover, sense-making methodology can be adopted in a user's query strategies during the information-seeking process and the use of library systems. In addition to focusing on nouns and outcomes, sense-making methodology often focuses on verbing and other processes that are anchored and situated in time and space (Dervin, 1999). The verbs that an actor uses imply changes of state in an actor's intention and actions during the information-seeking process (Wilson, 1997; Xie, 2000). Xie's (2002) studies also showed that users' information-seeking behaviors tend to change along with their goals and search objectives. Xie (2000) stated that users tend to shift their intentions when accessing informational resources. Eight dimensions of intention, in verbing forms, were identified that facilitate users' information-seeking strategies. IntegraL facilitates users' information-seeking behavior by addressing several of these: learning, finding, accessing, and locating related digital resources across different situations and contexts. IntegraL also could integrate recommendation engines, which might support users by evaluating and indexing metadata.

In contrast to a linear approach to studying the information-seeking process, A. Foster (2004) proposed a nonlinear model that users often adhere to in their information behavior. Some users would cognitively explore and browse their topics of interest, define and structure their problem by identifying keywords and search phrases, and then continue to redefine, shift, and consolidate knowledge and information throughout these core processes depending on their cognitive states, past experience, and efficacy of their prior knowledge as internal context and external, social environment. The information searched by users needs to be relevant and situated within their own perception and their social world.

User-Centric Design

The paradigm of information-systems studies has been shifting from system-centric to user-centric. Wilson (2000, p. 49) indicated a shift in information-behavior research from a "system-centered" approach toward a "person-centric" approach. Dervin (1999) emphasized that if the role of information systems is meant to help users make sense of knowledge gaps when moving through time and space, then considerations of social structure need to be designed and integrated into the use of information systems. Thus, the role of information systems should be to assist humans to dynamically articulate and translate unconscious goals into cognitive actions (Dervin, 1999). Information systems no longer exist to simply process data from input to output but should be designed in a way to assist people in their activities of information searching and being able to locate relevant information framed in users' specific social structure that helps to bridge the gaps (Vakkari, 2003).

DOI: 10.1002/asi

Virtual Integration of Resources

Rao (2004) described the progression of information-search functionality from the 1960s to the 1990s. Users' information-search capabilities have been greatly enhanced from simple query-in/result-out to information digests, indexing, extraction, categorization, and visualization, and further to federated searching. While the user's search capability has been enhanced, the design and development of digital libraries have become more sophisticated. Information retrieval was based on open and flexible infrastructures (Kazai & Doucet, 2008; Rao, 2004). Moreover, a scalable archival infrastructure can facilitate collaboration among heterogeneous digital libraries. Being able to accurately retrieve documents from distributed (sometimes uncooperative) digital libraries becomes critical. These studies have raised the awareness and importance of issues such as archival preservation of digital content, indexing collections, using representable query phrases, merging and transferring retrieved data, using metadata for searching, integrating search services and tools, and enabling user privacy and security considerations when accessing data for sensitive purposes.

Merging results from different databases and search engines requires acquisition of database resource descriptions, selecting from collections, and merging results into a single ranked list (Si & Callan, 2002). In merging high-volume data streams in a web-based infrastructure, Mazzucco, Ananthanarayan, Grossman, Levera, and Rao (2002) adopted data mining to process large streams of data and to extract patterns and anomalies.

IntegraL's "lightweight" virtual integration dynamically generates a list of links to related resources and services for elements of interest in a current document. A link is resolved dynamically only when actually selected by the user, thus minimizing processing time.

Federated Search Infrastructure

Federated search (i.e., distributed information retrieval) has been extensively studied and discussed. The Open Archival Initiative (OAI) is a framework that provides search services over aggregated metadata among federated digital libraries for both service providers and data providers (Lagoze & Van de Sompel, 2001). Maly, Zubair, Chilukamarri, and Kothari (2005) researched a grid-based architecture for parallel harvesting among large amounts of computing resources shared across organizational boundaries. This federated digital library architecture indexes and harvests hundreds of metadata tags from data providers. This type of architecture requires extensive load balancing, and may still suffer from insufficient service performance if low bandwidth of the data providers encounters high volume from the harvest nodes. On the other hand, a user modeling approach to full-text federated search focuses on collecting user behavior by analyzing users' long-term persistent interests based on past queries (Lu & Callan, 2006). Although this approach may enhance the robustness of the search, redundant documents from static search collections may lead to unnecessary processing costs from a federated search in an uncooperative environment.

Shokouhi and Zobel (2007) studied how different queries can reduce the overlap in search results from dynamic collections. When queries are federated, Shokouhi, Baillie, and Azzopardi (2007) suggested various policies in collection representation that impact retrieval accuracy in a dynamic federated search. Retrieval processes and algorithms that can enhance recall and precision are studied in uncooperative distributed search environments (Callan & Connel, 1999; Callan, Lu, & Croft, 1995; Paltoglou, Salampasis, & Satratzemi, 2007, 2008; Si & Callan, 2003, 2005).

The synchronous operations of the architecture among multiple harvesting nodes are important to a federated search, but the ability to harvest item-level metadata would also enhance the performance. The advent of the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) helps with the sharing and harvesting of item-level descriptive metadata for selected digital resources (Arms, Dushay, & Lagoze, 2003; Hagedorn, 2003; Simon & Bird, 2003). Foulonneau, Cole, Habing, and Shreeves (2005) stated that this granular collection-level descriptive metadata provides attributes for the retrieved documents, which would bring about more relevant documents in response to a query.

To classify searched results, Wu, Li, Bot, and Chen (2006) suggested using noun phrases as key phrases in automatic text extraction; these key phrases can be used as document metadata for web searching (Li, Wu, Bot, & Chen, 2004; Wu et al., 2006). Bot, Wu, Chen, and Li (2005) used these extracted key phrases as topical-oriented categories from the retrieved documents to correspond to different semantic aspects of the query. Highlight, as one example of a metadata search engine, performs document acquisition, document preclassification, and automatic concept-hierarchy generation. Document acquisition retrieves documents in response to a query. The document preclassification module classifies documents into predefined categories. Then, based on the extracted key phrases, the hierarchy module automatically generates individual concept hierarchies within each active category (Bot et al., 2005). As noted in the following section, IntegraL incorporates a preliminary form of federated search and will extend this in future versions.

System Architecture

IntegraL offers an open-source, scalable, web-based infrastructure that generates links among heterogeneous digital libraries. IntegraL is implemented as an open-source servlet container within a web-based proxy server, sitting on top of Tomcat. Figure 2 represents IntegraL's system architecture. When a user requests a URL to access a digital library resource or service, he or she is authenticated by a single sign-on (SSO) mechanism. We adopt an open-source authentication mechanism, Shibboleth, enabling seamless browsing across the many digital libraries that also have adopted Shibboleth. Once authenticated, this SSO

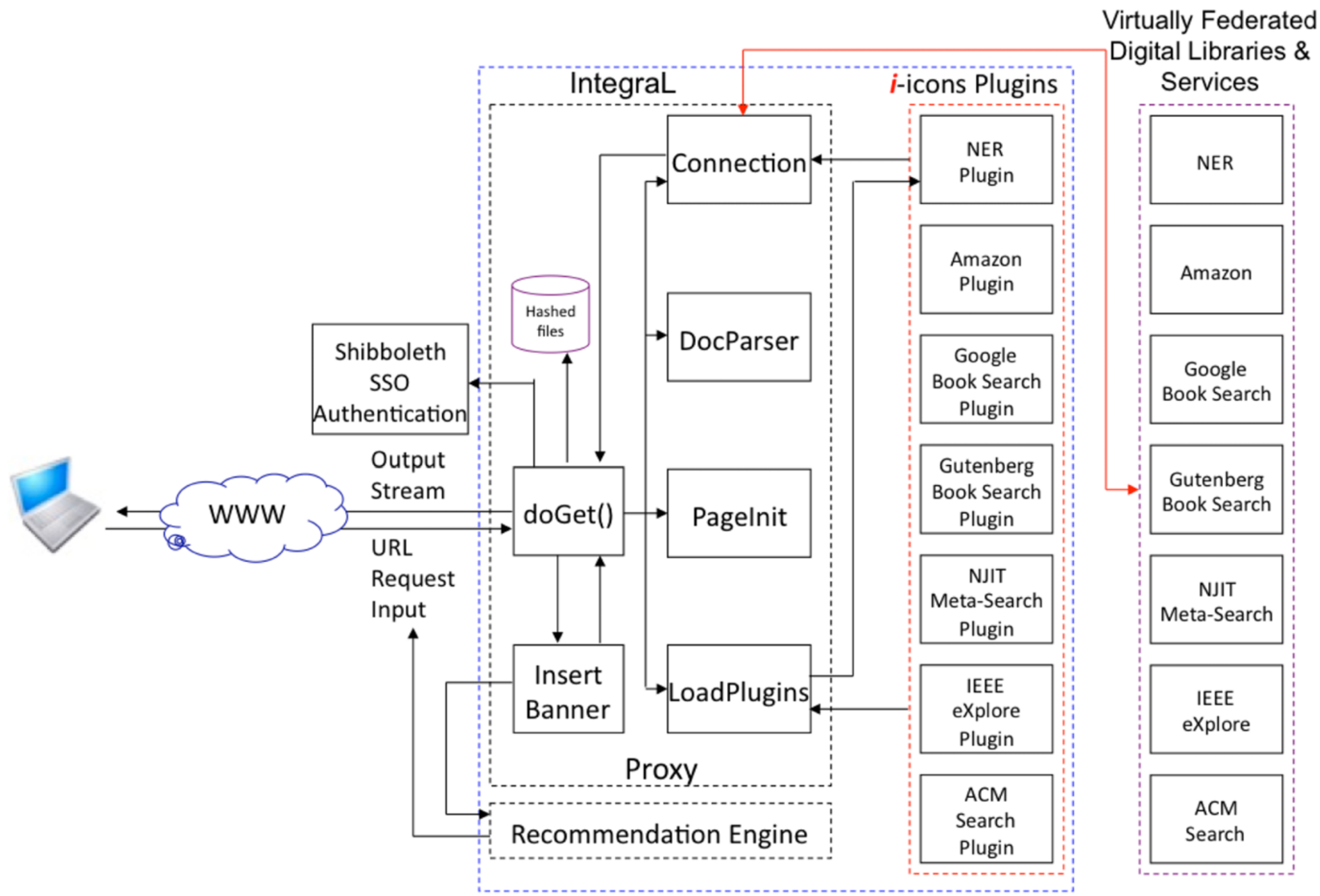

FIG. 2. IntegraL system architecture. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

mechanism allows the user to surf the various digital libraries without going through repetitious logins. User credentials are stored in hash files on the proxy.

The proxy handles all user requests. When a user browses any SSO-authorized subscribing digital library, the request to access the virtually federated digital libraries is handled by the proxy. When a user requests a URL, the IntegraL dialog box is inserted as a banner on the top of the screen (Figure 1). IntegraL converts all HTML pages returned into Document Object Model documents, and all relative URL paths to absolute URL paths.

Automatic Name Recognition With I-Icons

The *i*-icon plugins dynamically utilize name entity recognition (NER) to identify each element of interest (EOI) within a retrieved screen immediately before it is displayed. This is implemented using OpenCalais. This service annotates data with rich semantic metadata. Figure 3 illustrates this process. The NER plugin receives the screen (document) requested by the user through the proxy, analyzes the lexical meaning of recognized categories such as person, location, and so on, and then creates rich semantic metadata associated with each EOI's *i*-icon as a list of possible related links.

Locating EOIs within screens is the first step in virtual integration, facilitating independent, heterogeneous library databases and services. Figure 1 illustrates *i*-icons added at the end of each identified named entity. When a user clicks on the *i*-icon corresponding to the first article title, a dialog box with additional categorical information relevant to that name entity is provided. Illustrated on the right-hand side of Figure 2, plugins (developed using XPath) will parse screens (HTML documents) and insert *i*-icons wherever EOIs are located. EOIs are defined statically in templates utilized by these layout-based plugins. To identify any layout-related changes that would require updates to the static templates, IntegraL's web-based administrative interface periodically checks websites for which parsing plugins have been written.

Federated Search

IntegraL currently provides basic federated search across all relevant resources within a tabbed-browser display that groups query results by target resource. Figure 4 shows an example of the federated search results. This tabbed-browser display shows the search status and number of hits returned from each resource. This allows users to immediately access any resource and focus in on the most fruitful destinations for their search. The tabbed-browser display lets users move

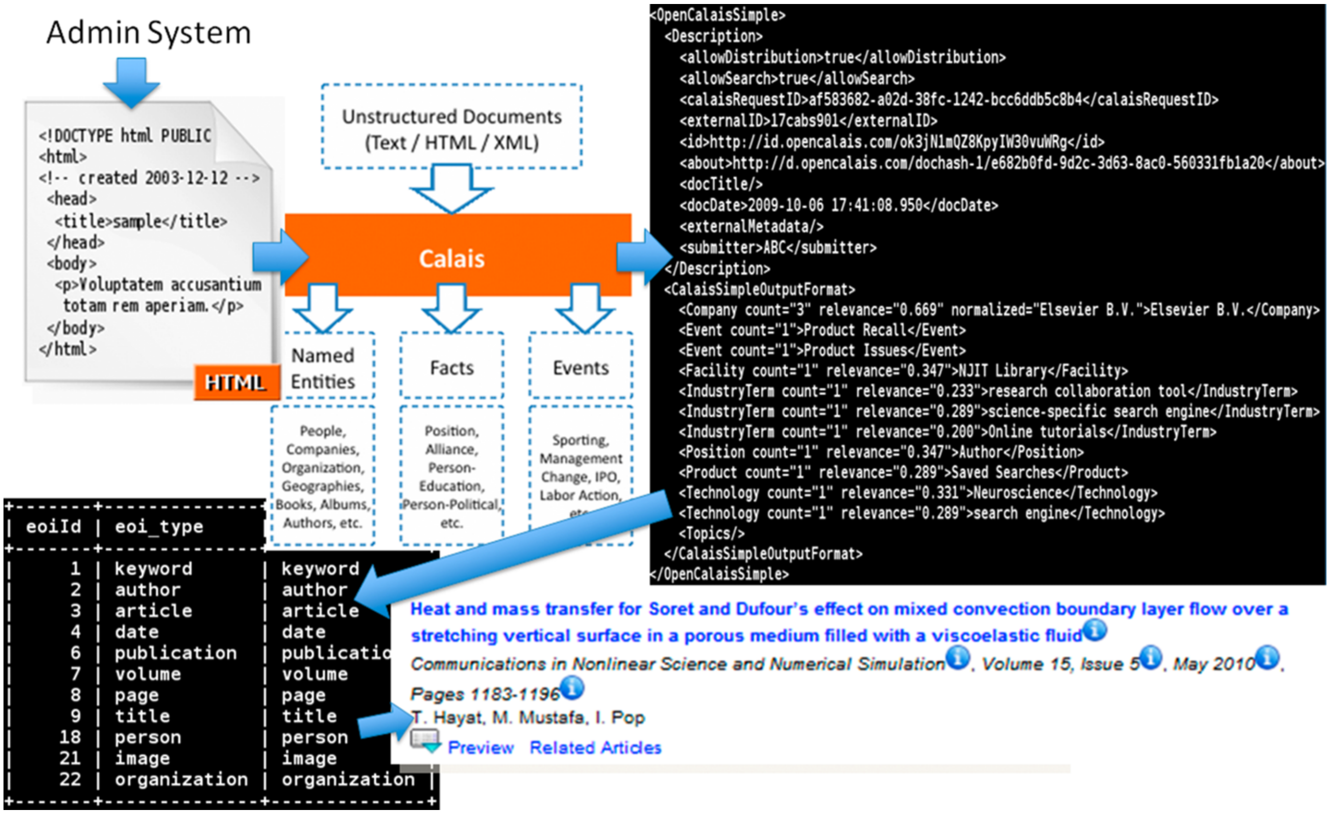

FIG. 3. Dataflow of the template-based webpage analysis: The library database sends an HTML document for display on the user screen. Calais is used to parse and do a name entity recognition analysis, producing the elements shown in the right-hand XML document. This in turn produces elements of interest (EOIs) shown in the bottom table that are reflected in the *i*-icons inserted into the bottom right-hand display screen segment (e.g., part of what we saw in Figure 1). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

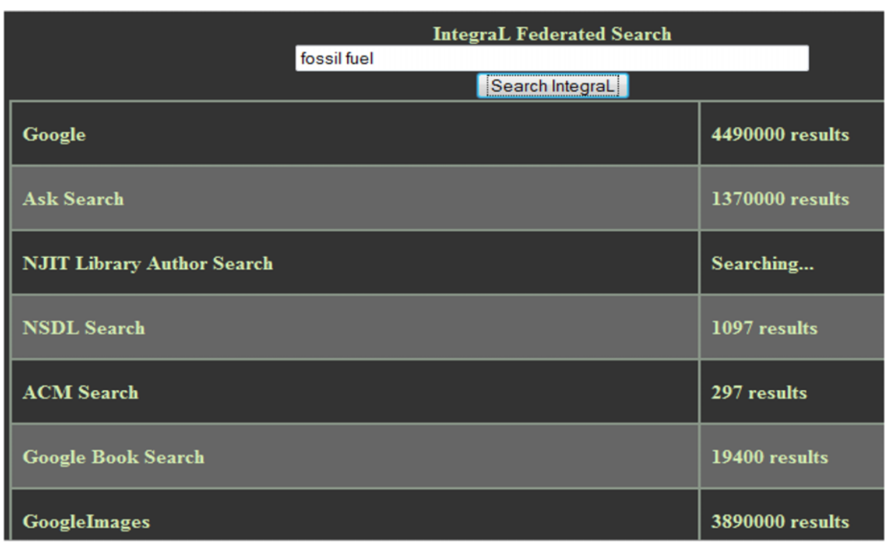

FIG. 4. An example of basic federated search results. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

between resources without losing their place in a set of search results. It also makes it easy for users to toggle between the tabbed display and an integrated list of search results. Future implementations will further merge search results in a single list without duplications, ranked in a personalized order for a user by a recommendation engine.

User Study

Based on our research questions, we formulated three hypotheses to understand users' experience concerning IntegraL's effectiveness and identified variables and measures, and conducted a user study. In this section, we

DOI: 10.1002/asi

describe the participant recruitment strategy, design of our experiments, users' experimental tasks, data-collection procedure, and data-analysis methods.

Variables and Measures

The first variable is the *system condition* under which each student participated. A baseline condition required participants to search academic digital libraries of their choice without IntegraL. Students had to find articles for the task scenarios assigned, determine the most relevant articles, rank order these, and explain the reasons justifying their ranking. The treatment condition required them to complete the same task with IntegraL and the federated search and *i*-icons it provides. Although each participant would experience both the baseline and treatment conditions in two different parts of the experiment, the order in which they experienced the conditions was randomized.

The second set of variables we incorporated concerned *task performance*. Participants' performance was measured objectively by graded scores on their results of the information-seeking tasks performed with each of the system conditions. The quality of search results, including the number and relevance of sources used, was judged by four expert graders. The *average score of the (expert) graders* was used as the measure of each participant's performance within each of the system conditions: IntegraL (treatment) and baseline, as described in the following subsections. The final score that each participant received was the sum of both.

We measured the number of digital library resources (e.g., websites, web pages, databases, etc.) accessed by each participant. One purpose of IntegraL is to enable users to access outside resources more readily than they would with a regular digital library. The *number of resources* accessed thus was chosen as another study variable. This variable was objectively measured by recording the number of unique resources and websites visited by users (from system logs).

In addition to the objective performance measures, participants' attitudes and perceptions about the IntegraL system were elicited in a posttask questionnaire as subjective measures (see Appendix B). These include satisfaction with, acceptance of, and effectiveness ratings for IntegraL. Participants' demographic information was captured in a pretask questionnaire (see Appendix A).

Hypotheses

We formulated three research hypotheses. The first two answer our first research question. The third hypothesis addresses the second research question.

> **H1:** Users perform better objectively when they use IntegraL than when they don't.

Our first hypothesis is an objective measure where users' performance was determined objectively by the four expert graders. Performance metrics included finding and making sense of information, and generally performing tasks more effectively.

> **H2:** Users perceive more effective performance subjectively when they use IntegraL than when they don't.

The second hypothesis is to understand from users' own perceptions whether IntegraL has helped to bridge gaps in their information-seeking steps. These are users' own subjective ratings.

> **H3:** Users utilize and access more library resources with IntegraL than without.

The third hypothesis determines whether users are motivated to access more resources when virtually integrated and made accessible due to the additional contextual information provided by anchor-based *i*-icons.

H3 has an inherently quantitative focus in that it assumes that accessing and utilizing more resources is desirable. Alternatively, one could argue for using fewer resources more effectively, and indeed, effective use is the focus of H1 and H2. Supporting H3, however, would be a persuasive argument for more digital libraries to adopt IntegraL-type support to increase the exposure of their resources to appropriate users.

Methods

The experiment[1] was designed and conducted in fall 2009. We recruited 139 participants from among physics freshman, with 78% males and 22% females older than 18 years of age attending the New Jersey Institute of Technology. A pilot study, which is not discussed in this article, was conducted in a prior semester (Ho, 2009).

Experimental Design

Vakkari (2003) suggested that users' tasks (in our case, information exploration) should be understood and taken into account when designing an information system. A within-subject experiment was designed with a step-by-step approach that helps users more deeply understand scholarly articles. The user task assignments and step-by-step approach are described next.

User task. The complexity of a user's task determines the performance of a user's information-seeking actions and consequent information needs (Vakkari, 1999). Most nontrivial uses of information systems involve multiple actions or steps to achieve a particular goal (Hackos & Redish, 1998; Hansen, 1999). In this study, all participants were given two moderately complex task assignments in random order to be performed individually (J. Foster, 2006). Search problems were structured with instructions and criteria (Appendix C). In principle, users were tasked to seek relevant articles based on topics and an author's works. Then, users were specifically asked to identify a different article

[1]IRB-approved E120-08, F94-08.

DOI: 10.1002/asi

based on the same or a different author's works and/or topics. As the last step, users are asked to rank their search results and then explain their rationale. Two task assignment examples are described next as well as in Appendix C.

User Task 1 (T1): Nonrenewable energy consumption will cause carbon dioxide to be trapped in the atmosphere. Please search and find relevant articles about the nonrenewable energy consumption of fossil fuel, and how to reduce the "carbon footprint" from human social activities.

User Task 2 (T2): To generate energy in a *renewable* manner, you must utilize resources that are naturally replenished or available in a natural, unlimited supply. Please consider renewable solar energy. Study and describe how solar renewable sources of energy can be generated.

Participants took about 20 to 25 min to work on each task. The amount of time for the completion of these two tasks totaled 45 to 50 min maximum. We scheduled a 5-min orientation session before the experiment started. Because this was conducted during a physics class, students were free to choose either to participate in the study or work on a different, independent assignment that was not part of this study.

Step-by-step approach. Xie (2000, 2002) controlled users' seeking activities using a step-by-step approach with information-seeking episodes to understand how users shifted their intention during information seeking. Likewise, we adopted this sense-making micromoment timeline survey approach to capture and measure participants' decisions on choosing relevant articles (Dervin, 1983b). For each step users took toward completing their goals in the assigned tasks, participants were asked to rank the relevancy of the information or article they found (Spink, 1996, 1998) (see Appendix C).

Data-Collection Instruments

We used five data-collection instruments. Five different mechanisms were designed to capture data before, during, and after the tasks.

1. Participants' demographics and prior experience were surveyed in a pretask survey (Appendix A).
2. Participants' utilization of resources (e.g., click-streams) was objectively logged.
3. Participants' subjective performance measured the quality of their own search and synthesis, including relevance of references and citations, use of scholarly database, participants' own judgment of the relevance of the articles found, and participants' own reasons for ranking the reference lists.
4. Participants' perceived satisfaction and effectiveness of their performance ratings were collected in the posttask survey. A 7-point (from *Very strongly disagree* to *Very strongly agree*) Likert scale survey instrument was used (Table 1).
5. Four experts were recruited to grade objective measures of participants' performance. All grading rubrics were provided in advance.

TABLE 1. Rotation of conditions and tasks. Participants were randomly assigned to one of these combinations.

Task 1	System Condition 1	Task 2	System Condition 2
T1	Baseline	T2	IntegraL (Treatment)
T1	IntegraL (Treatment)	T2	Baseline
T2	Baseline	T1	IntegraL (Treatment)
T2	IntegraL (Treatment)	T1	Baseline

Rotation of Conditions and Tasks

For this experiment, we use four combinations of two tasks (T1, T2) rotated between one treatment condition with IntegraL and one baseline condition. In the treatment condition, federated search and NER plugins were both enabled. *i*-icons were inserted on elements of interest to provide additional context-based access. In the baseline condition, users instead experienced the regular interface for each digital library. Table 1 illustrates the four combinations. Because of the within-subject experimental design, each participant worked on one task in the treatment condition (using IntegraL) and the other task in the baseline condition (without using IntegraL). To evenly distribute task assignments with different combinations of systems conditions, the system conditions were controlled centrally at the proxy server. Participants logged in with a randomly assigned user ID that gave them system access using one of the four combinations. With this rotation design of users' tasks and system conditions, the threats to validity occurring within subjects were eliminated.

Procedures

Participants were invited (with consent) to perform the tasks and to complete the questionnaires in the computer laboratory. Before the tasks were given, participants were briefed about the two user tasks, and then tasks were assigned. After completing the tasks, participants were asked to fill out the posttask questionnaire.

Data Analysis

Data were aggregated and cleaned based on whether participants completed the first four mechanisms listed earlier. Data were reorganized based on a unique identifier. Descriptive statistics were conducted to analyze demographics, users' perceptions, and objective measures. We used open-source R and SPSS statistics tools to run our analysis.

Results

In this section, we discuss our participants' demographic information and prior experience, and summarize the objective measurements of users' performance over task assignments in different conditions, the subjective assessment

DOI: 10.1002/asi

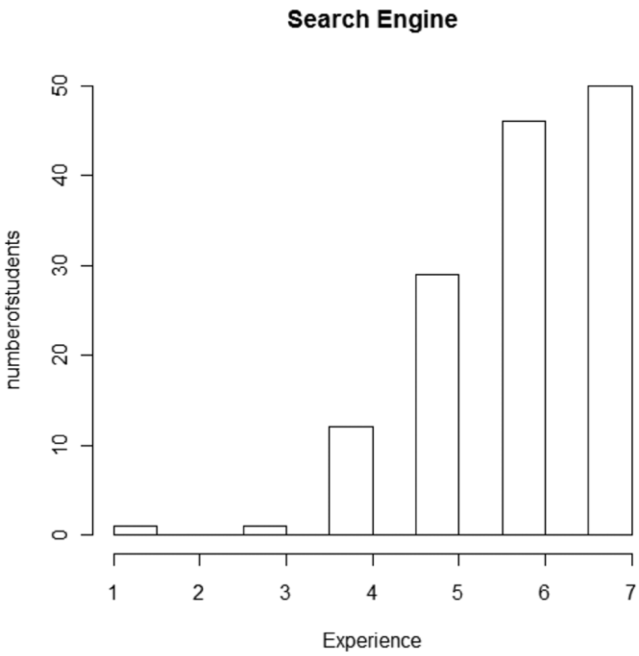

FIG. 5. Participants' prior search engine experience on a Likert scale of 1 (*least experienced*) to 7 (*most experienced*).

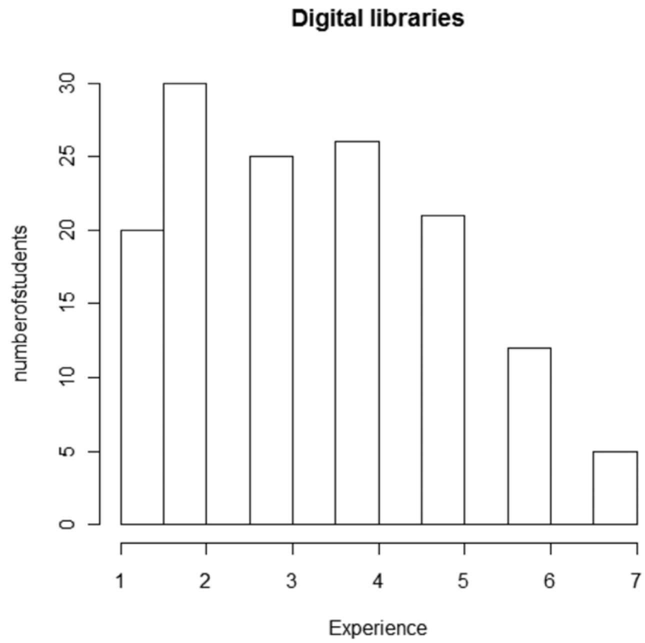

FIG. 6. Participants' prior digital library experience and proficiency on a Likert scale of 1 (*least experienced*) to 7 (*most experienced*).

of their performance, and their perception of IntegraL. In addition, we present objective measures of users' system utilization.

Participants' Existing Digital Library Experience

On a Likert scale of 1 (*least experienced*) to 7 (*most experienced*), most of the 139 participants were very experienced ($M = 5.94$) in using search engines such as Google, Yahoo, and so on (Figure 5).

However, their experience of using a digital library such as NSDL, ACM, IEEE, and Science Direct was very slim ($M = 3.45$) (Figure 6). This means that users tend to use the search engine Google to do academic research and were not generally accustomed to searching for scholarly articles from digital libraries.

Objective Assessment of Users' Performance

During the objective performance assessment, four expert graders were recruited to independently assess the quality of users' search results using the same grading rubrics. These performance measures were objective judgments about the quality of participants' search results, with a mean of bivariate correlations R of 0.839 ($p = 0$) and a Cronbach's α of 0.965. Thus, the experts' grading results (see Figure 7) reveal a high level of agreement and accurately and objectively represent participants' performance.

In Figure 7, the full score of 50 points is represented on the y axis, and each student is represented individually on the x axis. Each student's performance is represented by (a) the color of the line, indicating which condition's task had a higher score (red indicates the treatment condition [with IntegraL] and blue indicates the baseline condition); (b) line height representing the task score of the condition with the higher score; and (c) a dot marking the lower task score corresponding to the other condition. Thus, if the student has a higher score in the baseline-condition task, a blue line will be displayed, and its embedded dot represents the lower score from that student's treatment-condition task. Likewise, if the student has a higher score in the treatment condition, a red line will be displayed, and its embedded dot represents the lower score from that student's baseline condition.

We compared the objective performance between the two tasks for all students. The result shows predominantly red lines. This means that students overall had higher task scores in the treatment condition (with IntegraL) than they did with the baseline condition (blue). Thus, the dots predominantly show lower task scores for the baseline condition. These objective results indicate that those who used IntegraL's virtual integration generally had higher quality search results, rankings, and the justifications that make sense of them (higher performance scores) than did users in the baseline condition. Therefore, H1 is supported.

Users' Attitude and Perceived Acceptance

We conducted a posttask survey (Appendix B) with three measures of users' general attitudes toward technologies (AUTQ): (a) Using IntegraL is a good idea (autq1), (b) IntegraL makes searching interesting and fun

DOI: 10.1002/asi

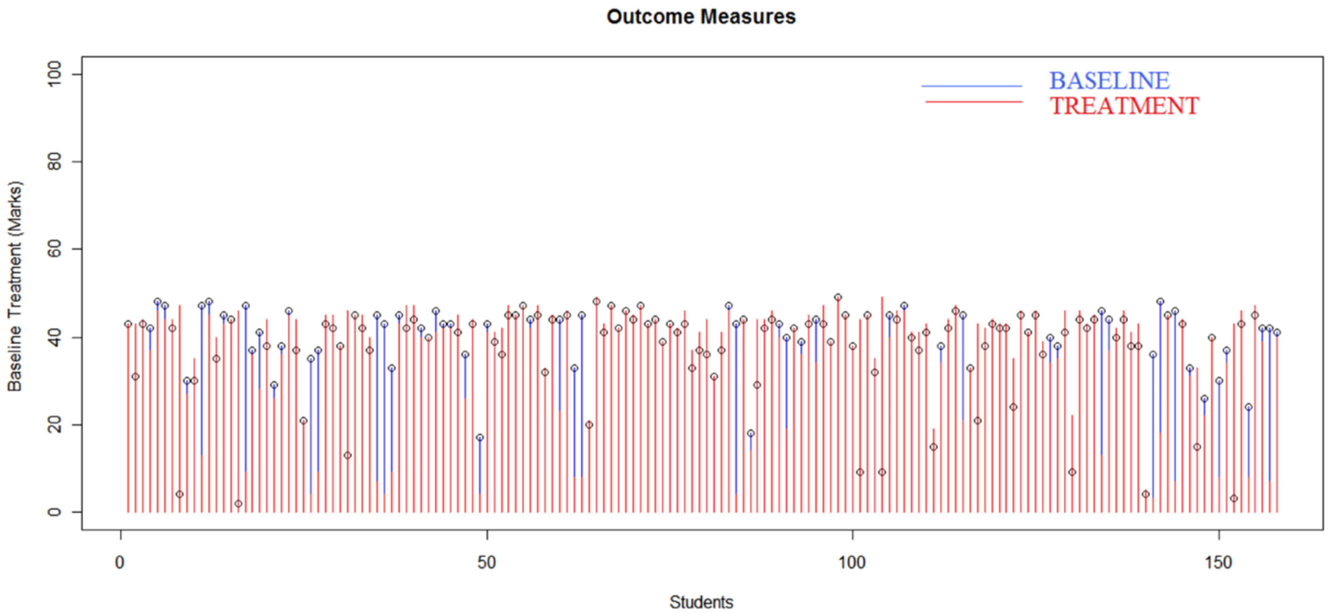

FIG. 7. Objective measurements of users' performance. Line color indicates the condition with the higher task score for that participant. Line height represents that higher score (of 50). Dots represent that participant's score for the other condition. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

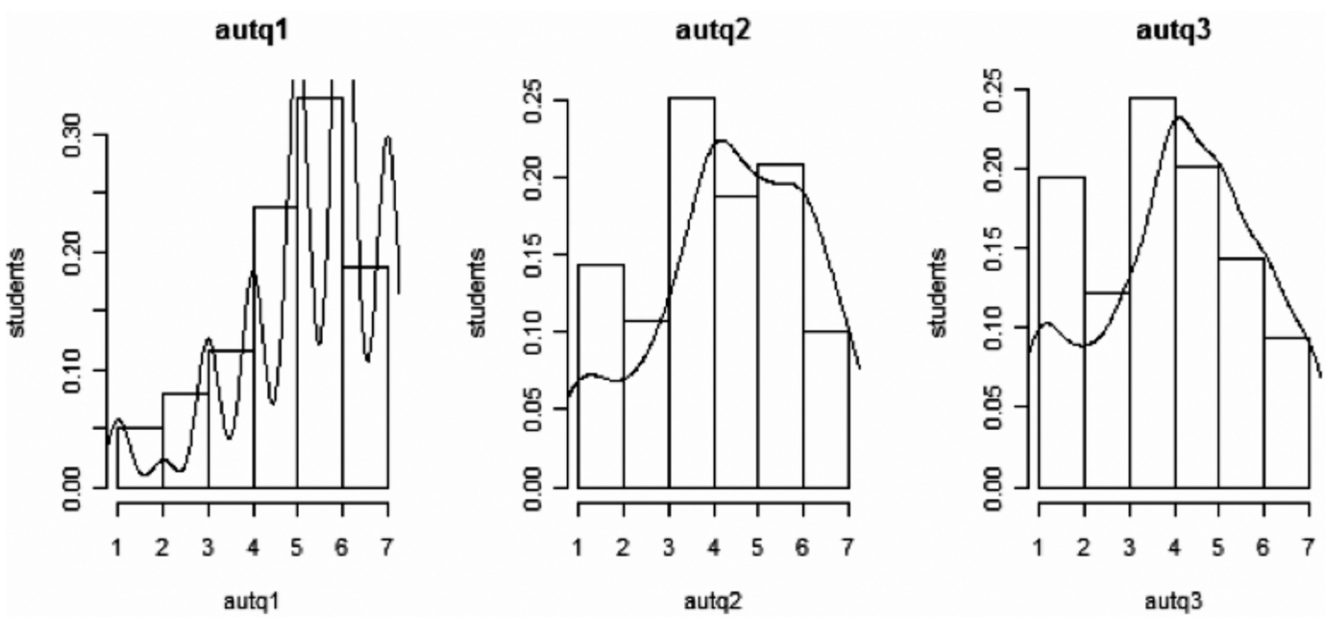

FIG. 8. Subjective measures of IntegraL, that is, users' attitude toward using technology (AUTQ) on a 7-point Likert scale of 1 (*least experienced*) to 7 (*most experienced*). These correspond to the three questions for this category in our posttask questionnaire shown in Appendix B: (a) Using IntegraL is a good idea (autq1), (b) IntegraL makes searching interesting and fun (autq2), and (c) I love searching with IntegraL (autq3). Each measure is skewed positive (>4).

(autq2), and (c) I love searching with IntegraL (autq3) (Figure 8).

The fact that the three measures all skewed to the right shows that users are confident of IntegraL's ability to provide satisfactory task performance (see Figure 9). Based on users' perceptions, when comparing IntegraL-enabled search systems with conventional search environments (e.g., using Google) as designed in our baseline condition, most users perceive IntegraL to provide more accurate results (see Figure 10).

To ascertain whether participants' attitude and perceptions had affected their performance with the use of IntegraL, a general linear model (GLM) analysis was conducted, with the performance score for using IntegraL as the

DOI: 10.1002/asi

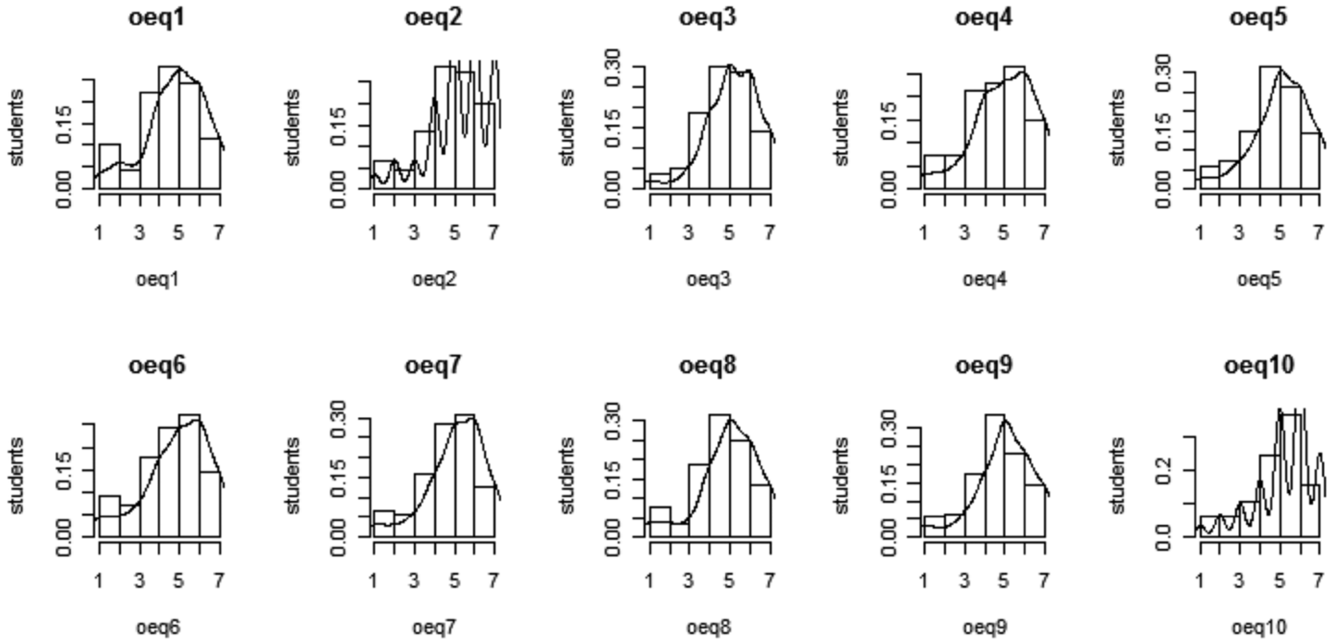

FIG. 9. Subjective measures of IntegraL, that is, users' overall satisfaction (OEQ) on a 7-point Likert scale of 1 (*least experienced*) to 7 (*most experienced*). These correspond to the 10 questions for this category in our posttask questionnaire shown in Appendix B. Each measure is skewed positive (>4).

dependent variable. Before conducting this GLM analysis, a factor analysis was conducted on the sets of attitude and perception variables and questions summarizing the posttask questionnaire data. For each category of question, a single factor was extracted, and the factor scores for all factors were used in the GLM analysis to replace the original question ratings. These factors—as well as the percentage of the variation that each explains in the original data—are listed in Table 2. In each case, the single factor extracted represented all original variables. In general, the factor loadings from original variables were above 0.5.

The result of the GLM analysis did not find any significant effect by any of the attitude and perception factors listed in Table 2. This probably was due to the characteristics of the user sample used in the study: These students were actually very familiar with using web search engines, and in their prior experience were particularly biased toward Google.

Nevertheless, results showed that IntegraL was perceived to support users' information-seeking needs. The eigenvalue for their performance expectancy ($\lambda = 4.871$) was higher than the social influence, effort expectancy, and so on. Users, on average, were satisfied with IntegraL ($\lambda = 7.027$).

Moreover, in the posttask questionnaire, students gave positive feedback about their experience with IntegraL's virtual integration. Participants found IntegraL easy to use and helpful in satisfying their information needs during their information-seeking process:

> "I really enjoyed using IntegraL because other search engines I have used never gave me relevant references I was looking for. It takes longer to search for your topic using Google, Ask.com, etc. whereas IntegraL makes it easier, faster, and really beneficial."
>
> "I liked using this method because it is easier to find similar topics."
>
> "IntegraL was easier to use than that of Google or yahoo. I was happy with the I-icon and the availability of other resources at one time."
>
> "The Integral system is very useful. It compiles many different search engines in one site so that you do not have to go about looking separately for them. They also give articles from credited sources so that you know they are professional journal entries."
>
> "IntegraL was a very helpful system, it definitely cut my searching time in half and it allowed me to find precise articles pertaining to my article."

Thus, the findings in this section support H2.

Users' Effective Utilization of Virtual Integration

According to H3, to learn whether users more frequently access and utilize resources when they are virtually integrated, we compared the number of unique digital library resources accessed and the amount of time spent for the baseline and treatment conditions. Due to a technology glitch, we only captured the logs for 65 of the 139 students and therefore could only use 65 records to perform descriptive analysis ($df = 3$). These log records showed the number of unique pages accessed, time spent, and the total number of resources accessed. The descriptive data are presented in Table 3.

DOI: 10.1002/asi

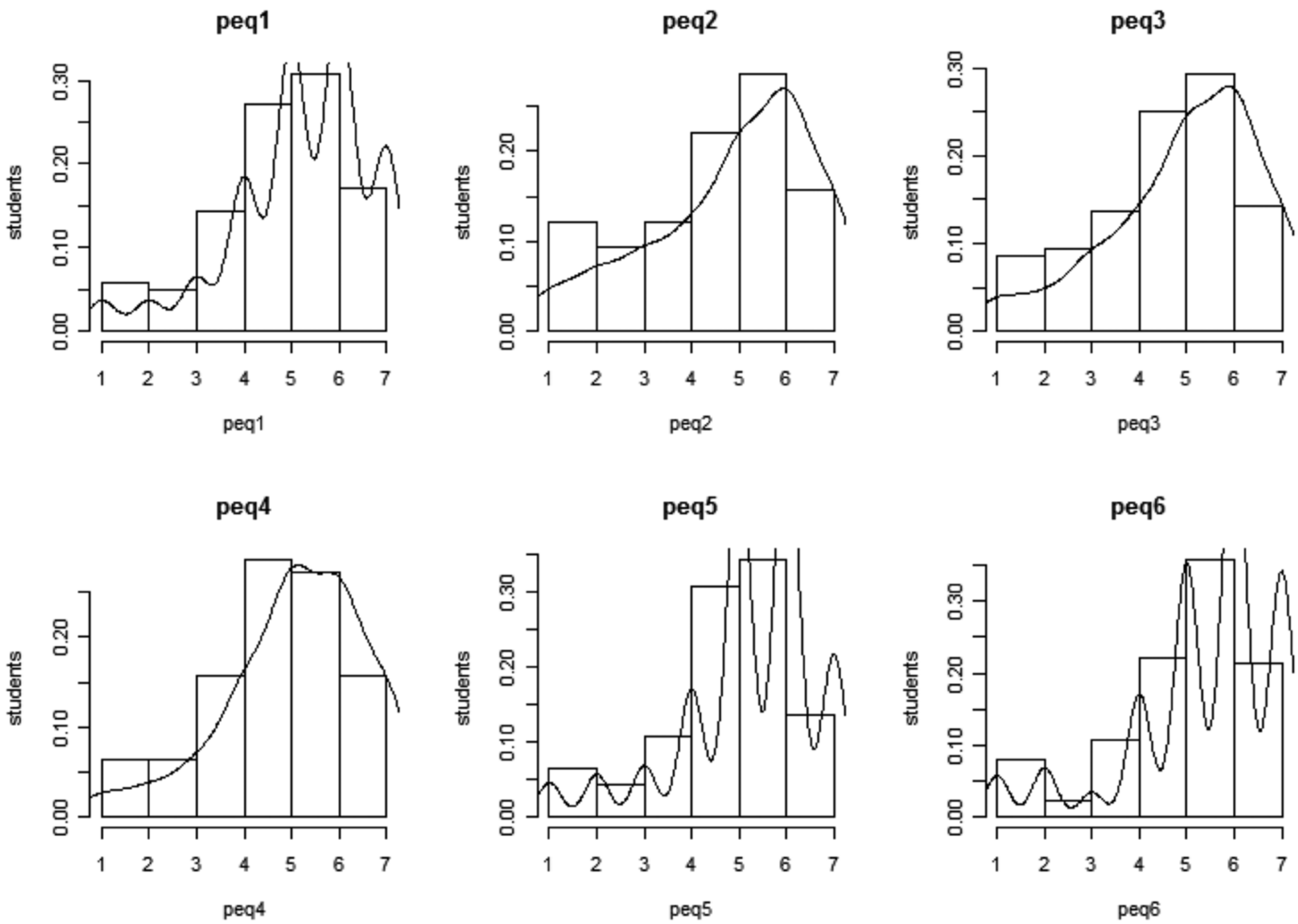

FIG. 10. Subjective measures of IntegraL, that is, users' subjective performance evaluation (PEQ) on a 7-point Likert scale. These correspond to the six questions for this category labeled "performance expectancy" in our posttask questionnaire shown in Appendix B. Each measure is skewed positive (>4).

TABLE 2. Results of principal factorial analysis.

Extracted factors	Original variables	Total variance explained: Eigenvalues	% of variance	Cumulative %
1	Performance expectancy	4.871	81.178	81.178
2	Effort expectancy	3.283	82.082	82.082
3	Social influence	2.983	74.582	74.582
4	Facilitating conditions	2.370	59.260	59.260
5	Overall satisfaction	7.027	70.274	70.274
6	Attitude toward using technology	2.307	76.904	76.904
7	Intention to use the technology	2.623	87.426	87.426
8	Perceived risk	4.492	74.863	74.863

As observed in Table 3, under the IntegraL condition where virtual integration provided additional links for elements of interest, the number of websites/pages accessed ($\mu = 59.88$, $\sigma = 38.78$) is more than was found with the baseline system ($\mu = 46.76$, $\sigma = 45.06$). A two-tailed t test for independent means of the two groups (based on the number of clicks) found a significant difference ($p < .001$).

TABLE 3. Effective use of the digital library resources.

	N	Variables	*M*	*SD*
IntegraL	62	No. of unique web pages accessed	59.88	38.78
		Time (min)	50.03	49.93
Baseline	62	No. of access	46.76	45.06
		Time (min)	26.25	20.71

DOI: 10.1002/asi

Correspondingly, we also logged how many times users took advantage of *i*-icons, and then ran a two-tailed *t* test for independent means of the two groups on the amount of time spent. The time users spent on the digital library resources through IntegraL ($\mu = 50.03$, $\sigma = 49.93$) was greater than the time spent on the baseline condition without IntegraL ($\mu = 26.25$, $\sigma = 20.71$); the difference also was significant ($p < .001$). Therefore, we reject the null hypothesis; H3 is supported: Users tend to utilize more virtually integrated resources when searching with IntegraL.

Results of Hypotheses Testing

Our study showed that participants *perceive more effective performance subjectively with IntegraL* (H2). This answered our first research question that virtual integration would help users more effectively find and make sense of information. Our study showed that participants *objectively perform better with IntegraL* (H1). This also demonstrates that IntegraL helps users to more effectively perform tasks involving library resources. We answered our second research question that IntegraL virtual integration helped users to *utilize more resources* (H3).

Discussion

In this section, we discuss how we eliminated threats to the validity of this user study, summarize the results of our hypothesis testing, and explore implications of IntegraL research for users' information seeking and sense-making.

Threats to Validity

This experiment originally contained some threats to validity; however, we were able to manipulate our research design to reduce these foreseeable threats.

- The design of systematically rotating tasks and conditions eliminates threats to internal validity.
- The grading rubric guided judging of user search performance. This interrater reliability eliminates threats to criterion validity regarding a user's objective search quality and search performance.
- Participants usually have a good deal of experience with multiple search engines. This preexisting experience creates biases on how users approach a new or different search environment. This threat was accounted for in the phrasing of our research question. We choose to use objective outcome measures on users' quality of task output (resources selected, ranking, and justification) rather than objective clickstream data and the amount of time spent on completing one task. These latter measures would have evaluated actual usage statistics instead of the quality of the activity conducted with the infrastructure.

Implications

IntegraL's approach to providing access to online information resources is based on the information-seeking theory that cognitive structure (i.e., the way people think about and do things) needs to be designed and integrated into the use of information systems (Dervin, 1999). By design, IntegraL takes into account a person's step-by-step information seeking needs by offering an *i*-icon feature that acts as a unique way to refine one's search. *I*-icons dynamically present contextual, categorical information, as representation of cognitive structure, to assist during users' decision-making regarding information use.

Our user study provides evidence that users accepted and appreciated IntegraL for information seeking. Given a group of users who were strongly biased in favor of web search engines such as Google (Figure 5), the majority of users positively acknowledged IntegraL's key features, and their task performance using IntegraL (treatment) was more efficient than when using conventional tools (baseline). When given the chance to use IntegraL, users did access more resources across virtually integrated digital libraries. The evaluation results imply that users' seeking behaviors were shaped by IntegraL's design for step-by-step search, meaning IntegraL's design addresses users' information needs.

Limitations

The current implementation of IntegraL incorporates only a basic level of virtual integration, which provides relevant links to search facilities within the digital libraries to which the New Jersey Institute of Technology subscribes. Our participants were all enrolled in the same freshman college course. Due to technical difficulties, we were able to log click streams of only 65 users for the overall objective measures. The small sampled data set in this collection may not fully represent the entire digital library user population. Yet, within these limitations we were able to prove that IntegraL's virtual integration successfully enabled these students to access more diverse library resources and make better sense of them.

Conclusions and Future Research

IntegraL was designed and developed as a user-centric information-seeking and sense-making system to provide users with contextual information based on their information needs in a way that both makes sense to them and shapes their information seeking. Without the rigidity and complexity of complete system integration, IntegraL adopts a lightweight approach that dynamically generates context-focused anchors over elements of interest, which in turn dynamically generate lists of links to relevant heterogeneous digital libraries, services, and search engines. It allows interoperability among different services, search results, search engines, and digital libraries. IntegraL's dynamic, lightweight integration virtually federates digital library resources (horizontally) while the virtual link anchors foster deeper search and exploration (vertically). The system itself is mostly built on open-source software, which can be reliable and cost-effective.

DOI: 10.1002/asi

We plan to implement a fully federated search engine within IntegraL that would merge search results and remove duplicates. Single sign-on authentication could provide seamless movement among all virtually integrated library resources. IntegraL also should virtually integrate public resources beyond digital libraries.

Dervin's (2003) sense-making theory evolved from the "mental gap" of information seekers to a model that encompasses language used in complex, real-life interactions and social context. Although this study does not fully provide such richness, it does take a major first step. Future versions of IntegraL will strive to increase the meaningfulness of the set of anchors and links dynamically generated and how they are labeled or otherwise conveyed to the user, based in part on the user's context, current task, and desired knowledge.

We intend to add many more services as links for elements of interest. We gave several examples of the novel features of IntegraL for information-seekers. Although many of these services exist, IntegraL-style integration could encourage people to develop new services that others would find useful. We plan to filter and rank order the list of links (services and resources) using a recommendation engine encompassing the user's context—background, characteristics, tasks, and current and desired knowledge. Text and image analysis could suggest related documents that would be recommended as part of the list of links. Customized terms could further enhance personalized exploration. Such a personalized environment would utilize collective intelligence to fulfill the user's information needs during information seeking and exploration. To prove that IntegraL is beneficial on a large scale, further experiments should include broad groups of users and experimental tasks. We look forward to a time when IntegraL-style features are a standard part of all web-based and mobile systems.

Acknowledgments

Partial support for this research was provided by the National Science Digital Library (NSDL) under Grant LG-02-04-0002, by the National Science Foundation under grants DUE-0434581 and DUE-0434998, and by the New Jersey Institute of Technology.

References

Arms, W.Y., Dushay, N.D.F., & Lagoze, C. (2003). A case study in metadata harvesting: The NSDL. Library High Tech, 21(2), 228–237.

Barry, C. (1994). User-defined relevance criteria: An exploratory study. Journal of the American Society for Information Science, 45, 149–159.

Belkin, N.J. (Ed.). (1980). The problem of "matching" in information retrieval. London, England: Mansell.

Belkin, N.J., Oddy, R.N., & Brooks, H.M. (1982). ASK for information retrieval. Journal of Documentation, 38, 145–164.

Bot, R.S., Wu, Y.B., Chen, X., & Li, Q. (2005, October–November). Generating better concept hierarchies using automatic document classification. Paper presented at the 14th International Conference on Information and Knowledge Management, Bremen, Germany.

Callan, J.P., & Connel, M. (1999). Query-based sampling of text databases. ACM Transactions of Information Systems, 19(2), 97–130.

Callan, J.P., Lu, Z., & Croft, W.B. (1995, July). Searching distributed collections with inference networks. Paper presented at the 18th International Conference on Research Development in Information Retrieval, New York, NY.

Case, D. (2006). Information behavior. Annual Review of Information Science and Technology, 40, 293–327.

Catanio, J., Nnadi, N., Zhang, L., Bieber, M., & Galnares, R. (2004). Ubiquitous meta-information and the WYWWYWI* principle. Journal of Digital Information, 5(1), April.

Courtright, C. (2007). Context in information behavior research. Annual Review of Information Science and Technology, 41(1), 273–306.

Dervin, B. (Ed.). (1983a). Information as a user construct: The relevance of perceived information needs to synthesis and interpretation (Vol. 1983). Philadelphia, PA: Temple University Press.

Dervin, B. (1983b, May). An overview of sense-making: Concepts, methods, and results to date. Paper presented at the annual meeting of the International Communication Association, Dallas, TX.

Dervin, B. (1999). On studying information seeking methodologically: Ihe implications of connecting metatheory to method. Information Processing & Management, 35, 727–750.

Dervin, B. (2003). Human studies and user studies: Call for methodological inter-disciplinarity. Information Research, 9(1), 33.

Dervin, B., & Nilan, M. (1986). Information needs and uses. Annual Review of Information Science and Technology, 21, 3–33.

Foster, A. (2004). A nonlinear model of information-seeking behavior. Journal of the American Society for Information Science and Technology, 55(3), 228–237.

Foster, J. (2006). Collaborative information seeking and retrieval. Annual Review of Information Science and Technology, 40, 329–356.

Foulonneau, M., Cole, T.W., Habing, T.G., & Shreeves, S.L. (2005, June). Using collection descriptions to enhance an aggregation of harvested item-level metadata. Paper presented at the 5th ACM/IEEE-CS Joint Conference on Digital Libraries, Denver, CO.

Hackos, J., & Redish, J. (1998). User and task analysis for interface design. New York, NY: Wiley.

Hagedorn, K. (2003). OAIster: A "no dead ends" OAI service provider. Library High Tech, 21(2), 170–181.

Hansen, P. (1999). User interface design for IR interaction. A task-oriented approach. In Proceedings of the Third International Conference on the Conceptions of the Library and Information Science (CoLIS 3; pp. 23–26), Lokve, Croatia.

Ho, S.M. (2009). [IntegraL usability pilot study with NJIT physics student]. Unpublished raw data.

Im, I., & Hars, A. (2007). Does a one-size recommendation system fit all? The effectiveness of collaborative filtering based recommendation systems across different domains and search modes. ACM Transactions on Information Systems, 26(1), 4:1–4:30.

Johnson, J.D. (2009). An impressionistic mapping of information behavior with special attention to contexts, rationality and ignorance. Information Processing & Management, 45(5), 593–604.

Kazai, G., & Doucet, A. (2008). Overview of the INEX 2007 book search track: BookSearch '07. ACM SIGIR Forum, 42, 2–15.

Kuhlthau, C.C. (1991). Inside the search process: Information seeking from the user's perspective. Journal of the American Society for Information Science, 42(5), 361–371.

Lagoze, C., & Van de Sompel, H. (2001). The open archives initiative: Building a low-barrier interoperability framework. In Proceedings of the First Association for Computing Machinery/Institute of Electrical and Electronics Engineers (ACM/EEE) Joint Conference on Digital Libraries (pp. 54–62), Roanoke, VA.

Li, Q., Wu, Y.B., Bot, R.S., & Chen, X. (2004, August). Incorporating document keyphrases in search results. Paper presented at the the 10th Americas Conference on Information Systems, New York, NY.

Lu, J., & Callan, J.P. (2006, August). User modeling for full-text federated search in peer-to-peer networks. Paper presented at the annual

International ACM SIGIR Conference on Research and Development in Information Retrieval, Seattle, WA.
Maly, K., Zubair, M., Chilukamarri, V., & Kothari, P. (2005, May). GRID based federated digital library. Paper presented at the annual meeting of the Computer Frontiers, Ischia, Italy.
Mazzucco, M., Ananthanarayan, A., Grossman, R.L., Levera, J., & Rao, G.B. (2002). Merging multiple data streams on common keys over high performance networks. In Proceedings of the 2002 Association for Computing Machinery/Institute of Electrical and Electronics Engineers (ACM/EEE) Conference on Supercomputing (pp. 1–12), Baltimore, MD.
Meyers, E.M., Fisher, K.E., & Marcoux, E. (2009). Making sense of an information world: The everyday-life information behavior of preteens. Library Quarterly, 79(3), 301–341.
Mizzaro, S. (1997). Relevance: The whole history. Journal of the American Society for Information Science, 48(9), 810–832.
Paltoglou, G., Salampasis, M., & Satratzemi, M. (2007, November). Hybrid results merging. Paper presented at the 16th ACM Conference on Information and Knowledge Management, New York, NY.
Paltoglou, G., Salampasis, M., & Satratzemi, M. (2008, October). Integral based source selection for uncooperative distributed information retrieval environments. Paper presented at the 2008 ACM Workshop on Large-Scale Distributed Systems for Information Retrieval, Napa Valley, CA.
Qu, Y. (2003, April). A sensemaking-supporting information gathering system. Paper presented at the CHI 2003 Conference on Human Factors in Computing Systems, Ft. Lauderdale, FL.
Qu, Y., & Furnas, G.W. (2005, April). Sources of structure in sensemaking. Paper presented at the CHI 2005 Conference on Human Factors in Computing Systems, Portland, OR.
Rao, R. (2004). From IR to search, and beyond. Queue: Open Source Grows Up, 2(3), 66–73.
Savolainen, R. (2006). Information use as gap-bridging: The viewpoint of sense-making methodology. Journal of the American Society for Information Science and Technology, 57(8), 1116–1125.
Shokouhi, M., Baillie, M., & Azzopardi, L. (2007, July). Updating collection representations for federated search. Paper presented at the 30th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Amsterdam, The Netherlands.
Shokouhi, M., & Zobel, J. (2007, July). Federated text retrieval from uncooperative overlapped collections. Paper presented at the 30th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Amsterdam, The Netherlands.
Si, L., & Callan, J.P. (2002, August). Using sampled data and regression to merge search engine results. Paper presented at the 25th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Tempere, Finland.
Si, L., & Callan, J.P. (2003). A semisupervised learning method to merge search engine results. ACM Transaction of Information Systems, 21(4), 457–491.
Si, L., & Callan, J.P. (2005, August). Modeling search engine effectiveness for federated search. Paper presented at the 28th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Salvador, Brazil.
Simon, G., & Bird, S. (2003). Building an open language archives community on the OAI foundation. Library High Tech, 21(2), 210–218.
Solomon, P. (1997a). Discovering information behavior in sense making: I. Time and timing. Journal of the American Society for Information Science, 48(12), 1097–1108.
Solomon, P. (Ed.). (1997b). Information behavior in sense making: A three-year case study of work planning. London, England: Taylor Graham.
Solomon, P. (1999a). Discovering information behavior in sense making: II The social. Journal of the American Society for Information Science, 48(12), 1109–1126.
Solomon, P. (1999b). Discovering information behavior in sense making: III. The person. Journal of the American Society for Information Science, 48(12), 1127–1138.
Song, M., & Bieber, M. (2008, July). IntegraL: Lightweight link-based integration of heterogeneous digital library collections and services in the deep web. Paper presented at the 10th Institute of Electrical and Electronics Engineers (IEEE) Conference on E-Commerce Technology and the 5th Institute of Electrical and Electronics Engineers (IEEE) Conference on Enterprise Computing, E-Commerce and E-Services.
Spink, A. (1996). Multiple search sessions model of end-user behavior: An exploratory study. Journal of the American Society for Information Science and Technology, 47, 603–609.
Spink, A. (1998). From highly relevant to non-relevant: Examining different regions of relevance. Information Processing & Management, 34, 599–622.
Taija, S. (1996). Constituting "information" and "user" as research objects: A theory of knowledge formations as an alternative to the information man-theory. Paper presented at the International Conference on Research in Information Needs, Seeking and Use in Different Contexts, Tampere, Finland.
Taylor, R.S. (1962). The process of asking qestions. American Documentation, 13, 391–396.
Taylor, R.S. (1968). Question-negotiation and information seeking in libraries. College & Research Libraries, 28, 178–194.
Taylor, R.S. (1985). Information values in decision contexts. Information Management Review, 1, 47–55.
Taylor, R.S. (1988). Value-added processes in information systems. Norwood, NJ: Ablex.
Vakkari, P. (Ed.). (1997). Information seeking in context: A changing and challenging metatheory. London, England: Graham Taylor.
Vakkari, P. (1999). Task complexity, problem structure and information actions: Integrating studies on information seeking and retrieval. Information Processing & Management, 35(6), 819–837.
Vakkari, P. (2003). Task-based information searching. Annual Review of Information Science and Technology, 37, 413–464.
Weick, K.E. (Ed.). (1983). Organizational communication: Toward a research agenda. Beverly Hills, CA: Sage.
Wilson, T.D. (1997). Information behaviour: An interdisciplinary perspective. Information Processing & Management, 33(4), 551–572.
Wilson, T.D. (1999). Models in information behavior research. Journal of Documentation, 55(3), 249–270.
Wilson, T.D. (2000). Human information behavior. Information Science, 3(2), 49–55.
Wilson, T.D., Ford, N., Ellis, D., Foster, A., & Spink, A. (2002). Information seeking and mediated searching (Part 2): Uncertainty and its correlates. Journal of the American Society for Information Science and Technology, 53, 704–715.
Wu, Y.B., Li, Q., Bot, R.S., & Chen, X. (2006). Finding nuggets in documents: A machine learning approach. Journal of the American Society for Information Science and Technology, 57(6), 740–752.
Xie, H.I. (2000). Shifts of interactive intentions and information-seeking strategies in interactive information retrieval. Journal of the American Society for Information Science and Technology, 51(9), 841–857.
Xie, H.I. (2002). Patterns between interactive intentions and information-seeking strategies. Information Processing & Management, 38, 55–77.
Zhang, L., Bieber, M., Song, M., Oria, V., & Millard, D.E. (2010). Supplementing virtual documents with just-in-time hypermedia functionality. International Journal of Digital Library, 11, 155–168.

DOI: 10.1002/asi

Appendix A

Questionnaire for demographic information.

Q#	Item	Questions
1	Gender	• Gender ☐ Male ☐ Female
2	Age	• Age ☐ Under 18 ☐ 18–26 ☐ 27–35 ☐ 36–44 ☐ 45–53 ☐ 54 and Over
3	Role	• What is your current academic standing? ☐ Freshman ☐ Sophomore ☐ Junior ☐ Senior ☐ Master's ☐ PhD • What's your major?
4	Library Database Experience	• How much experience do you have with using Internet search engines (Yahoo, Google, Ask.com)? None 1 : 2 : 3 : 4 : 5 : 6 : 7 Very Experienced • How much experience do you have using the databases to which your school Library subscribes (e.g., Scopus, IEEE, ACM, ScienceDirect)? None 1 : 2 : 3 : 4 : 5 : 6 : 7 Very Experienced • How familiar are you with sites that provide recommendations (e.g., Amazon.com book recommendations, Netflix movie recommendations)? Not at all Familiar 1 : 2 : 3 : 4 : 5 : 6 : 7 Very Familiar
5	Frequency of Library Database Use	• How often do you use one or more of the NJIT Library databases for job/class related activities? ☐ Daily (At least once a day) ☐ Weekly (At least once a week) ☐ Monthly (At least once a month) ☐ Occasionally (<12 times a year) ☐ Never
6	Current User Task	• For which of the following tasks are you **currently** searching for information? (For Students) ☐ Class Assignments problem-solving (e.g., math homework, programming) ☐ Class Assignment Papers (e.g., essays, case study, research paper) ☐ Thesis/Dissertation ☐ Conference Paper/Journal Paper ☐ Other, please specify • For each of the tasks you have performed, indicate your preferred source of finding information (check all that apply): ☐ Internet Search Engines ☐ NJIT Library databases (Digital Libraries) ☐ NJIT Library book catalog ☐ Print journals ☐ Magazines, Newspapers or Other periodical publications ☐ Other personal-subscribed digital libraries ☐ Other, please specify
7. How difficult do you think about learning energy conservation to be? Please evaluate the task based on your current knowledge. There is no right or wrong answer.		Very Very Difficult ←1—2—3—4—5—6—7→ Easy

DOI: 10.1002/asi

Appendix B

Posttask questionnaire.

I. Please answer the following questions regarding IntegraL usefulness. There is no right or wrong answer.

Performance Expectancy

1. I find IntegraL useful to find ***relevant*** documents (search results).	VSD ← 1—2—3—4—5—6—7 → VSA
2. Using IntegraL enables me to accomplish tasks more quickly.	VSD ← 1—2—3—4—5—6—7 → VSA
3. Using IntegraL increases my productivity.	VSD ← 1—2—3—4—5—6—7 → VSA
4. If I use IntegraL, I will increase my chances of getting a good grade (or, a raise in my job).	VSD ← 1—2—3—4—5—6—7 → VSA
5. Using IntegraL would help me to expand relevant search results in my study (or, at work).	VSD ← 1—2—3—4—5—6—7 → VSA
6. Using IntegraL would benefit me.	VSD ← 1—2—3—4—5—6—7 → VSA

Effort Expectancy

1. My interaction with IntegraL is clear and understandable.	VSD ← 1—2—3—4—5—6—7 → VSA
2. It would be easy for me to become skillful at using IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
3. I find IntegraL easy to use.	VSD ← 1—2—3—4—5—6—7 → VSA
4. Learning to operate IntegraL is easy for me.	VSD ← 1—2—3—4—5—6—7 → VSA

Social Influence

1. People who influence my behavior (e.g. my friends or my professors) would think that I should use IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
2. People who are important to me would think that I should use IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
3. The senior people (e.g. professors or administrators) in this school would be helpful in the use of IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
4. In general, the school (or organization) would support the use of IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA

Facilitating Conditions

1. I have the resources necessary to use IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
2. I have the knowledge necessary to use IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
3. IntegraL is compatible with other systems I use.	VSD ← 1—2—3—4—5—6—7 → VSA
4. A specific person (or group) would be available for assistance with difficulties related to using IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA

Overall Evaluation of Users' Satisfaction

1. I am very satisfied with the search results provided by IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
2. IntegraL would suggest information or articles previously unknown to me.	VSD ← 1—2—3—4—5—6—7 → VSA
3. I find that IntegraL allows me to locate *relevant* information I need for my task.	VSD ← 1—2—3—4—5—6—7 → VSA
4. I was able to answer the task question, resolve my problem, and complete my task using IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
5. I am satisfied with the *relevant* information on the search results presented by IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
6. The information presented by the *i*-icon allowed me to find *relevant* information quickly.	VSD ← 1—2—3—4—5—6—7 → VSA
7. I was able to complete all tasks presented to me through the use of IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
8. IntegraL provided me with new perspectives on the information I needed.	VSD ← 1—2—3—4—5—6—7 → VSA
9. I was satisfied with the additional links provided by IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA
10. Overall how would you rate this system?	Not Useful Useful ← 1—2—3—4—5—6—7 →

II. Please check what you think. Please note that there is no right or wrong answer.

Attitude toward using technology

1. Using IntegraL is a good idea.	VSD ← 1—2—3—4—5—6—7 → VSA
2. IntegraL makes *searching* more interesting and fun.	VSD ← 1—2—3—4—5—6—7 → VSA
3. I love searching with IntegraL.	VSD ← 1—2—3—4—5—6—7 → VSA

Intention to Use the Technology

1. I intend to use IntegraL if I must.	VSD ← 1—2—3—4—5—6—7 → VSA
2. I predict that I will use IntegraL if it is available.	VSD ← 1—2—3—4—5—6—7 → VSA
3. I definitely plan to use IntegraL because of its excellent features.	VSD ← 1—2—3—4—5—6—7 → VSA

Perceived Risk

1. How do you perceive IntegraL as a search tool in getting precisely what you are looking for?	Significant Insignificant Risk ← 1—2—3—4—5—6—7 → Risk
2. How confident are you about IntegraL's ability to perform (e.g. search) satisfactorily?	Not sure Very sure ← 1—2—3—4—5—6—7 →
3. Does IntegraL help you to get situated in your search needs?	Negative situation Positive Situation ← 1—2—3—4—5—6—7 →
4. In your opinion, do you feel that IntegraL, if introduced, would perform as well as other similar search systems now on the market?	Would not Would perform ← 1—2—3—4—5—6—7 → perform as well as well
5. How do you perceive the use of IntegraL in relation to contributing to the search results?	High potential for High potential for Loss ← 1—2—3—4—5—6—7 → Gain
6. Do you feel that IntegraL will perform the functions that were described in the introduction?	Do not feel so Do feel so ← 1—2—3—4—5—6—7 →

III. Please tell us how you feel about IntegraL. How would you think about this IntegraL system? There is no right or wrong answer.

IV. How much familiarity, knowledge and expertise have you gained with the subject about energy conservation when using IntegraL? There is no right or wrong answer.

V. How difficult do you think about learning energyconservation to be? Please re-evaluate the tasks you have done in these exercises. There is no right or wrong answer. Very Very Difficult ← 1—2—3—4—5—6—7 → Easy

VI. Did your expertise help you accomplish the task after using IntegraL? There is no right or wrong answer.

VII. Did you feel that you have learned something about the energy conservation? There is no right or wrong answer.

Thank you for your time and participation in this study. Your comments and responses will be used to enhance the system in future studies.

Note. VSD: Very strongly disagree; VSA: Very strongly agree.

DOI: 10.1002/asi

Appendix C

One example of a user task assignment.

OPTION 1: Learning the New Library System
[Task Code]: 4-GN-ConBas

Assuming you are writing a research paper, finding relevant documents and articles is the first step to help you to understand the research topic. In this assignment, you need to compile a list of 5 relevant documents or articles that address each task assigned below. Following the steps given in the instruction, you will then rank how relevant they are to the research task according to your own judgment. You will be instructed to use different library systems and infrastructure in order to work on your tasks.

[Additional administrative information and examples of APA citation format omitted here.]

Note:

a) Please limit your sources of information to the materials you get from the system. External sources such as google.com are not allowed, though you **CAN** use google.com through IntegraL.
b) Please make sure that you indicate the references and databases wherever applicable.
c) When determining the *relevancy* of the articles to each research topic or task, we suggest you to study the abstract, introduction and conclusion of the article carefully. You may browse through the remaining of the articles such as methods, data analysis, etc.
d) Your report includes your answers for 2 tasks. Your report includes *relevant* documents that support your understanding for the task assignment, your ranking judgment regarding the relevancy for each document, and your reasons (and, arguments) that back up your ranking judgments.
e) There is no single correct answer for this assignment. Your report will be graded based on the quality of your report such as how *adequate* and *relevant citations* are used and cited.
f) You may use key-phrase suggested below to search. You may also apply recommended terms suggested by IntegraL. The key phrase function is popped up in a black box when you click *i*-icon.

Ready? Let's start our assignments! Please flip to the next page and begin!

[Controlled Condition] *Start your search with the IntegraL library system, and answer the following questions.*

[Baseline Condition] *Start your search with your preferred digital library or search engine, and answer the following questions.*

Task NREC: [Non-Renewable Energy Consumption] The non-renewable energy consumption will cause the carbon dioxide trapped in the atmosphere. Please search and find out the relevant articles about the non-renewable energy consumption of fossil fuel, and how to reduce "carbon footprint" from human social activities.

In order to study this above research topic, you will need to compile a list of 5 ***relevant*** articles. After 5 ***relevant*** articles are found, you will rank them according to their relevancy to the above research topic based on your own judgment. Then, tell us your reasons why each article is ranked the level you assign them to.

It will take you 20-minutes to complete this task. Please follow steps below.

1) Please search ***relevant*** articles based on the following search criteria. Remember to save all articles and papers that you have referenced in every step below (5 references in total). Your reference shall be recorded on the template in APA-compliant format.

An APA reference looks like this:

○ Author (Year). Article Title, ***Journal***, Volume (Issue), Issuing Month Year, pages.

   1. Use a database to search a relevant article, and provide the reference for that article.
   2. Based on the same author's work, please use another search engine (or, another different database) to locate 1 different article (or, book) written by the same author.
   3. Based on what you found in the first article, find 1 other article (or, book) of the same type of topic.
   4. Based on what you found in the previous step, find 1 other article (or, book) of a different author but based on the same type of topic (or the same area of expertise) about the energy waste of fossil fuel as a result of human social activities.
   5. Then, use a different source or database to find 1 other article (or, a book) of a different author but based on the same type of topic that discusses the strategies of using biofuel and monitoring human's "carbon footprint" to reduce the carbon dioxide trapped in the atmosphere.

2) Rank all found articles according to your own judgment of how they relate to the topic of this task.
3) Explain your reasons why they are ranked the level they are, and how your ranking decisions were made.

[Additional administrative information omitted here.]

DOI: 10.1002/asi