Dimensions and Elements of People's Mental Models of an Information-Rich Web Space

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Although considered proxies for people to interact with a system, mental models have produced limited practical implications for system design. This might be due to the lack of exploration of the elements of mental models resulting from the methodological challenge of measuring mental models. This study employed a new method, concept listing, to elicit people's mental models of an information-rich space, MedlinePlus, after they interacted with the system for 5 minutes. Thirty-eight undergraduate students participated in the study. The results showed that, in this short period of time, participants perceived MedlinePlus from many different aspects in relation to four components: the system as a whole, its content, information organization, and interface. Meanwhile, participants expressed evaluations of or emotions about the four components. In terms of the procedural knowledge, an integral part of people's mental models, only one participant identified a strategy more aligned to the capabilities of MedlinePlus to solve a hypothetical task; the rest planned to use general search and browse strategies. The composition of participants' mental models of MedlinePlus was consistent with that of their models of information-rich Web spaces in general.

Introduction

Mental models are knowledge structures that people employ to represent, make sense of, and interact with the external world (Gentner & Stevens, 1983; Johnson-Laird, 1983). Researchers in human computer interaction (HCI) and information retrieval (IR) postulate that people form mental models of a computer system that they interact with to understand "what the system contains, how it works, and why it works" (Carroll & Olson, 1988, p. 51; Sasse, 1991). Therefore, knowledge about mental models is expected to provide insights into the design of computer systems that are easy to use, intelligent in supporting users, and effective in reducing unnecessary human errors (Graham, Zheng, & Gonzalez, 2006; Kudikyala & Vaughn, 2005; Rode, Rosson, & Perez-Quiflones, 2004; Young, 2008).

After two decades of research, however, the impact of mental models research on system design and user training is still limited (Roger, 1992). One possible reason is the lack of empirical research on the elements, components, or dimensions of people's mental models of systems. Nevertheless, due to their inherent abstractness, eliciting and representing mental models has been a challenge (Borgman, 1986). Popular methods such as semistructured interviews, concept mapping, repertory grid technique, and pairwise rating tended to limit the emergence of new dimensions by imposing specific questions or concepts on users. Drawing, another widely used method, is limited in revealing people's understanding of implicit system processes, such as search mechanisms (Zhang, 2008a).

This study presents an attempt to elicit elements and dimensions of mental models using a bottom-up approach. Specifically, we explored people's mental models of an information-rich Web space, MedlinePlus, after they interacted with the system for 5 minutes. Information-rich Web spaces are hyperlink-based information systems that contain a large amount of information, often thousands or millions of Web pages, in a particular domain or across domains, such as Wikipedia and aclu.org. Information-rich spaces serve a wide range of audiences and the information could be in various forms, such as text, image, and videos (Shneiderman, 1997). As the Web keeps expanding, more and more government agencies, military organizations, and companies are looking to such hypermedia-based solutions for organizing and disseminating information (Farris, Jones, & Elgin, 2002).

Studies suggested that people often quickly made decisions whether they were going to stay on a Website (Sillence, Briggs, Harris, & Fishwick, 2007) and they tended to spend less than 5 minutes on a particular Website (Burk, Martin, Reilly, & Kuperman, 2003; Spink & Cole, 2006). Some software developers contended that if common-use software or Websites cannot make sense to the user in the first 5 minutes, they are losing customers. Thus, it is important to learn what kind of mental models people develop within such a

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short period of time. So in this study we limited participants' interaction with MedlinePlus to 5 minutes. MedlinePlus was selected as the platform for the study due to the fact that consumer health information-seeking has become one of the most popular activities online (Fox, 2005). Web-based consumer health information systems, like MedlinePlus, deserve more research.

Related Literature

Researchers in Information Science (IS) have examined people's mental models of various IR systems, including online library catalogs (Borgman, 1986; Dimitroff, 1992; Kerr, 1990; Slone, 2002), news databases (Katzeff, 1990), Web search engines (Efthimiadis & Hendry, 2005; Muramatsu & Pratt, 2001), digital libraries (Makri et al., 2007), experimental IR systems (Cool, Park, Belkin, Koenemann, & Ng, 1996; Savage-Knepshield, 2001), visualization interface (Chen & Czerwinski, 1997), 3D virtual environments (Billinghurst & Weghorst, 1995), the Internet or the Web (Bruce, 1999; Thatcher & Greyling, 1998), and college Websites (Otter & Johnson, 2000). Although information-rich Web spaces are an important type of Web-based IR system and have been gaining popularity in recent years (Shneiderman, 1997), few studies have examined people's mental models of such systems.

Due to the abstractness of mental models, early research mainly focused on identifying characteristics of mental models, such as simple, unscientific, and parsimonious (e.g., Norman, 1983) or examining the impact of mental models on people's system use behavior and performance (e.g., Borgman, 1986; Halasz & Moran, 1983; Kieras & Bovair, 1984). Little effort was made to explore the elements, dimensions, or composition of mental models. As researchers in human factors, HCI, and IR seek means to apply mental models to the design of system and instructional materials, the importance of understanding the content of mental models is becoming paramount (Young, 2008).

In the existing literature, one of the main methods used to elicit people's mental models was interviews (Rutherford & Wilson, 1992; Sasse, 1991; Staggers & Norcio, 1993). In some studies, participants were asked to answer a set of questions concerning a system. For example, Zhang (2008a) investigated undergraduate students' mental models of the Web as an IR system by asking their perceptions of four main components of general IR systems: the information space, the information organization, search mechanism, and interface. Papastergiou (2005) examined subjects' mental models of the Internet by asking them to describe their perceptions regarding the Internet as an entity, a centralized or a distributed system, and the structure of the Internet.

Some interviews were less structured. For example, Dimitroff (1992) asked subjects to describe similarities and differences between card catalog and an OPAC system and describe how the OPAC system worked. Subjects' mental models were then evaluated against a predefined system conceptual model that included eight discrete components, such as data content, interactive nature of the system, existence of multiple files, and use of controlled vocabulary. It is apparent that both approaches could limit the emergence of new dimensions and elements (Wilson & Rutherford, 1989). The more structured interviews tend to scaffold subjects' mental models by limiting the aspects that they could talk about. The less structured interviews were less constraining; however, mental models were often reported in a predefined structure, rather than being allowed to emerge from the data naturally.

A second widely used method to elicit mental models was asking users to identify the type and/or strength of relationships between a set of concepts (e.g., Hanisch, Kramer, & Hulin, 1991), or draw a concept map of a set of concepts (Chang, 2007). For example, Langan-Fox, Platania-Phung, and Waycott (2006) used the pairwise ratings method to elicit subjects' mental models of a mobile phone network. The authors created a set of 15 concepts from the manual and asked participants to rate the relatedness of pairs of concepts concerning network services on a 7-point scale (1 = not at all related, 7 = highly related). The matrices generated by the ratings were then used to produce an associative network of the concepts to represent participants' mental models of the phone network. In such studies a limited number of concepts can be presented to users. Thus, these methods also tend to limit the emergence of new dimensions or elements of mental models (Royer, Cisero, & Carlo, 1993).

The other widely used method to represent mental models is drawing. In the drawings, participants were often asked to draw their perceptions about a system (e.g., Efthimiadis & Hendry, 2005; Zhang, 2008b). Drawings are illustrative in demonstrating the elements included in mental models. For example, based on the elements presented in drawings, Thatcher and Greyling (1998) identified people's mental models of the Internet into six categories: (1) interface and utilitarian functionality, (2) central database, (3) user to the world, (4) simple connectivity, (5) simple modularity, and (6) modularity and networking. Papastergiou (2005) identified eight categories of high school students' mental models of the Internet: (1) nondigital entity, such as information and users without computers involved, (2) services and content, (3) users' computers, (4) servers, (5) connection between two computers, (6) few computers linked through a connection point, (7) computer network, and (8) network of computer networks. However, drawings fall short in representing invisible or implicit system processes, such as query processing and relevance ranking mechanisms (Papastergiou, 2005; Thatcher & Greyling, 1998; Zhang, 2008a,b).

To better inform system design and user instruction, it is necessary to understand mental models from the end user's perspective. Given the limitations of the current methods, new methods are needed to allow the elements and dimension of people's mental models to emerge without any preimposed structure. It is also necessary to be able to elicit and represent people's procedural knowledge of using the system, because such knowledge is an integral part of mental models (Brandt & Uden, 2003; Carroll & Olson, 1988;

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deKleer & Brown, 1988; diSessa, 1986; Gott, Benett, & Gillet, 1988; Nielsen, 1990).

Research Questions

Mental models do not have firm boundaries (Norman, 1983). Users often come to an IR system with a set of knowledge or assumptions (Bruce, 1999). Thus, we are also interested in participants' initial model of information-rich Web spaces in general. In the study, two research questions are explored:

1. What is participants' mental model of information-rich Web spaces before they interact with MedlinePlus?
2. What is their mental model of MedlinePlus, a typical information-rich Web space, after they interact with the system for 5 minutes?

Methods

Participants

A total of 39 (19 males, 20 females) undergraduate students at the University of North Carolina (UNC) participated in the study. The participants had never used MedlinePlus before the study. Because spatial ability was related to people's navigation in hyperlink-based systems (e.g., Campagnoni & Ehrlich, 1989), one participant was excluded from the data analysis due to his extremely low spatial ability. The ages of the subsequent 38 participants (18 males, 20 females) ranged from 18 to 22, with an average age of 21 years old (SD = 1.07).

To control the impact of domain knowledge on mental model construction, students who majored in medical-related fields, such as nursing, medicine, pharmacy, public health, and biology, were excluded from the recruitment. As a result, participants in the study were from 22 different nonmedical-related majors, such as art history, business, English, Spanish, communication studies, political science, physics, geography, and math. One subject had not decided on a major area of study.

The Platform: MedlinePlus

MedlinePlus (www.medlineplus.gov) provides authoritative medical and health information for the general public. It was launched in 1998 by the National Library of Medicine (NLM) in response to the intensive use of the MEDLINE database by general consumers via the Web. Two sources contribute to the collection of MedlinePlus: National Institutes of Health's (NIH) publications of consumer health information based on the medical research that NIH sponsors, and publications of professional medical societies and voluntary health agencies without commercial or business motives (Lindberg, 2000; Marill, Miller, & Kitendaugh, 2006). MedlinePlus also licenses information sources, such as medical dictionaries, encyclopedia, information about prescription drugs, directories of health professionals and hospitals, news feeds, and tutorials. In MedlinePlus, users can access information by browsing subject hierarchies or alphabetical lists. Search was supported, but the search function was rather simple. There was no advanced search option and users cannot limit the search to certain fields.

Measuring Mental Models

Students' initial model of information-rich Web spaces was elicited in the demographic questionnaire by two requests: (1) "Please describe characteristics of information-rich Web spaces based on their experience and understanding," and (2) "Please describe your general approaches to use this type of Web spaces."

Students' mental models of MedlinePlus were measured by three methods, a concept listing protocol, a semistructured interview, and a drawing task. In the concept listing protocol, participants were asked to list concepts related to MedlinePlus in the order that the concepts appeared in their mind. The concept listing lasted for 5 minutes. Every list of concepts was viewed as the result of a participant's cognitive process of making sense of the system. By this means, no predefined structure was imposed and participants' mental models of MedlinePlus were allowed to emerge from the data. A Web-based graphic interface was designed to assist participants in inputting concepts. The submitted concepts were stored in a MySQL database.

Mental model theory suggests that people's mental models of a system also encompass procedural knowledge of using the system (e.g., Fein, Olson, & Olson, 1993; Mayer, 2002). It was foreseen that the concept listing protocol might have a limited capacity to elicit the procedure knowledge. Therefore, semistructured interviews were performed. In the interviews, participants were presented with a hypothetical task, as shown below, and asked to describe steps that they would follow to solve the task.

> Imagine that you are required to write a paper about hepatitis to arouse public attention to the seriousness of this disease. In the paper, you want to include, but are not limited to, aspects such as what is the difference between chronic and nonchronic hepatitis? What determines this? What are the differences between hepatitis A, B, and C, and what are the treatments for each of them, and can we prevent the development of liver cirrhosis among patients with chronic hepatitis? You decide to use MedlinePlus to collect information for your paper.

They were also asked to describe their impressions of MedlinePlus concerning its collection, search mechanisms, information organization, and the interface. Two examples of the interview questions are: "What information is provided by MedlinePlus," and "How do you think information in MedlinePlus is organized?" The interviews were audiorecorded. After the interviews, subjects were asked to draw their perceptions of MedlinePlus. The drawings will not be analyzed and reported here.

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Procedure

Participants were scheduled to take part in the study at their convenience. Upon arrival, they were welcomed and were provided a brief introduction to the study. After signing a consent form, participants were asked to finish a 2-page 20-item ETS VZ-2 test (Eckstrom, French, Harman, & Derman, 1976); each page was limited to 3 minutes. Participants then finished a demographic questionnaire, reporting their age, major field of study, computer experience, experience with health and medical information searching online, and their perceptions of information-rich Web spaces. Upon the completion of the questionnaire, instead of watching a prerecorded video introduction to the system, the participants were instructed to spend 5 minutes to explore MedlinePlus in the way that they normally do when freely exploring a new information system. After the exploration, participants finished the set of protocols measuring their mental models of the system, including a concept listing, a semistructured interview, and a drawing task.

Data Analysis

The demographic data were analyzed using descriptive statistics. Descriptions that participants provided in the demographic questionnaire about their perceptions of information-rich Web spaces were imported into QSR N6 software. Open coding was employed to code the data. Whenever an element, such as videos, Q&A, and database or a strategy of using the spaces, such as search, browse, and Google to research the site appeared, it was coded into a category. The subsequent categories were organized from bottom-up based on what component of the systems the categories referred to. A second coder coded the descriptions and the intercoder agreement was 91.6%.

The concepts that participants contributed in the concept listing protocol was exported to an Excel sheet. Open coding was employed to code the data. The coding unit was a concept. When multiple concepts were involved in an entry, multiple codes were assigned to the entry. A coding schema was developed by coding a subset of the concepts. The schema contained the names of categories emerging from the coding, definitions of the categories, and examples for each category. The scheme was then applied to code the rest of the concepts. Several coding examples are provided in Table 1. The first level of the code refers to major components of the MedlinePlus system and the second level of code refers to a particular aspect of a component. For example, the code for "well organized" indicates that it is an evaluation of the information organization in MedlinePlus. The author coded all the concepts and a second coder coded 10% of the data. The intercoder agreement (Krippendorff's α) was 78.4% in the first round of coding (Krippendorff, 2004). A review session between the two coders revealed that the majority of the disagreements appeared at the second level of the code. For example, the second coder initially coded "NIH" as "system: similar sites." After the discussion, she agreed with the author and coded it as "system: agencies involved." After the review, the intercoder reliability reached 95.7%.

The audiotaped semistructured interviews were transcribed. The transcripts were imported into QSR N6 software. Distinct strategies of solving problems using MedlinePlus were identified by reading participants' descriptions of the steps that they planned to take to solve the hypothetic task. The rest of the transcripts were mainly used as a source to assist the interpretation and verification of certain concepts in the concept listing protocol.

Results

Experience With Health Information Searching

The 38 participants had used the Web for 6 to 13 years (mean = 9.9; SD = 1.83). Among them, 35 (92.1%) had used the Web for health information. Table 2 lists the resources that participants used. As shown in the table, there were three main resources for health information: people, Websites, and books. About 79% of the participants reported that they sought medical information from family, friends, and doctors. One mentioned that she asked for medical advice from her athletic trainer. The most popular online sources for health information were general search engines, WebMD, and Wikipedia. About 29% of the participants had also used the online health sources provided by UNC (i.e., health information under the unc.edu domain). Only 13.2% used books for health information. Other resources used by only a couple of participants included Yahoo Health, PubMed, and the People's Pharmacy.

Participants' Initial Model of Information-Rich Web Spaces

Participants' initial model of information-rich Web spaces was induced from their descriptions of their general

TABLE 1. Coding examples.

Concepts contributed by subjects	Assigned codes
Lung cancer	Content: specific
Alphabetical	Information organization: schema
Well organized	Information organization: evaluation
Tabs	Interface: element
Search	Interface: function
CDC	System: agencies involved

TABLE 2. Information sources for health and medical information.

Information sources	Total
General search engines	32 (84.2%)
Family & friends	30 (78.9%)
Doctors	30 (78.9%)
WebMD	24 (63.2%)
Wikipedia	18 (47.4%)
UNC online health sources	11 (28.9%)
Books	5 (13.2%)

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perceptions about and strategies of using these spaces. The analysis showed that participants represented information-rich Web spaces in relation to four system components: system, content, information organization, and interface. The system component was participants' representation of the overall systems, rather than any individual part of them. This component was represented in relation to two aspects: the structure of and the audience for the systems. For example, in talking about the structure, one subject suggested that:

> Based on my own experience and understanding, information-rich Websites are defined as those that compile any amount of databases into what could be considered a data warehouse. Utilizing the warehouse search capabilities, users are directed to the individual databases, which are hyperlinked onto the site.

In talking about the audience, participants thought that some information-rich Web spaces served novices in the field of their interest and some were directed more toward experts. A couple of participants suggested that such spaces were useful for a wide variety of people.

The content component was participants' representation of the information contained in information-rich Web spaces. This component was perceived in relation to three aspects: subject, type, and format. For the subject, some participants described information-rich Web spaces as covering one particular topic, while some said that they covered various topics. For the type of information, participants mentioned Q&A, help, and advertisements. For the format, participants expected to see images, graphics, text, videos, multimedia, and audios.

The information organization component was participants' understanding of the ways in which information is organized. Generally, they recognized that, in information-rich Web spaces, information was interlinked; some links led to outside sources. Instead of having a specific information organization schema, such as alphabetical or hierarchical organization, participants tended to have only a very general idea that information was categorized in some way. For example, one participant commented that:

> Information is usually organized into categories of some kind on these Websites, to make it more accessible for users . . . . The categories can be manually looked through usually.

The interface component was participants' representation of the interface of information-rich Web spaces. In representing this component, participants thought about navigational elements, including menus, side bars, tabs, hyperlinks, subheadings, and bold font. They also mentioned functionalities made available through the interface, including search, advanced search, suggesting other pages of interest, and frequently searched links and topics.

When representing information-rich Web spaces in relation to the four components, participants simultaneously expressed their evaluations of or emotions about each component. For example:

- System: convenient, accessible
- Content: a lot of info, useful, helpful, reliable, readable, updated frequently, clear, informative, unreliable, overwhelming
- Information organization: rigid organization
- Interface: easy to navigate, cluttered, distracting

In describing their approaches of using information-rich Web spaces, the participants listed the following strategies:

- Google to reach the site
- Search
- Browse
- Read citation pages
- Click random links
- Avoid watching videos
- Glance for graphs, pictures, and headings

In summary, participants had an initial model of information-rich Web spaces. In the initial model, two distinct but closely related dimensions emerged: (1) representations: participants represented information-rich Web spaces in relation to four components: system, content, information organization, and interface; and (2) evaluations: participants simultaneously expressed evaluations of or emotions about the four components. They also had a set of general strategies or heuristics of using such spaces.

An Overview of Participants' Mental Model of MedlinePlus

Participants' mental model of MedlinePlus was derived from the analysis of the concepts that they contributed in the concept listing protocol. The result suggests that their mental model of MedlinePlus shared a similar composition to that of their initial model of information-rich Web spaces. They represented and evaluated MedlinePlus in terms of four components:

- System: the overall MedlinePlus rather than any part of it
- Content: the content included in MedlinePlus
- Information organization: how information is organized in MedlinePlus
- Interface: the interface of MedlinePlus

Table 3a,b, respectively, summarizes the aspects from which each component was represented or evaluated in the two dimensions.

Informed by the mental model theory, participants' mental model of MedlinePlus also encompasses procedural knowledge of solving problems using the system. The procedural knowledge was elicited from their descriptions of steps that they would employ to solve the hypothetical task in the semistructured interview. Three distinct strategies were proposed. Strategy A is a general searching strategy: participants submit a search query to the system and review the search results. Strategy C is a general browsing strategy: participants follow links from the homepage to the page where the

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answer is located. Strategy B is a combination of searching and browsing, where participants search a disease or conditions, click on the first result to reach the health topic page pertaining to the disease or condition, and browse the links on the health topic page to find relevant information. Strategy B is more closely aligned to the capabilities of MedlinePlus and requires fewer clicks to reach the desired information.

TABLE 3a. Representations dimension of participants' mental models of MedlinePlus.

System (76)	Content (413)	Info. org. (35)	Interface (102)
– Structure – System behavior – Agencies involved – Audience – Usage of the system – Similar sites	– Subject – Type – Presentation – Format	– Information organization schemas	– Elements – Functions – Results

The number in parentheses is the number of concepts that the participants dedicated to each component.

TABLE 3b. Evaluations/emotions dimension of participants' mental models of MedlinePlus.

System (47)	Content (89)	Info. org. (15)	Interface (52)
– Usefulness – Attributes – Usability	– Quality – Utility – Attributes – Quantity – Specific sections	– Information organization	– Look & feel – Search – Navigation – Results

The number in parentheses is the number of concepts that the participants dedicated to each component.

Participants' Mental Model of MedlinePlus

In this section, participants' mental model of MedlinePlus after they used the system for 5 minutes is reported in detail.

Representations and evaluations of the system component. After a 5-minute interaction, participants represented MedlinePlus as an integrated system from six aspects. Table 4a lists the concepts and the number of concepts associated with each aspect.

In representing the structure of MedlinePlus, participants thought that MedlinePlus was a large database and storage tank. It had its own information, but also linked to external resources. The system worked primarily based on links rather than search features. In representing the system's behavior, participants speculated that MedlinePlus aggregated, pooled, and filtered information from other medical Websites and it was frequently updated. They noticed that MedlinePlus was associated with government agencies and some medical associations. The audience for system could be both general people (e.g., everyday users, lay people, novices, parents, adults, and juveniles) and medical professionals.

After the brief interaction, participants also started thinking about the potential usage of the site. Some suggested that the system was a starting point for research and could be used to gather information about particular conditions. Some thought that the system was a good counseling tool for people to learn to be healthy and to self-diagnose conditions. Nevertheless, some participants pointed out that they would

TABLE 4a. Participants' representations of MedlinePlus as an integrated system.

Aspects	Concepts	
System structure (22)	– Database; Storage tank – Links to outside info; links to other medical sites – Linked pages	– The site seems to work primarily based on links rather than search features. – Inside information
System behavior (13)	– Pop-up windows – Redirection – Updated daily	– Pooling information – Filter – Aggregate
Agencies involved (11)	– General: government agencies, partners, – medical associations	– Specific: NIH
Audience (17)	– All genders/ages – Laypeople – Everyday users – Juvenile – Someone with an interest in a particular condition	– Professionals – Patients – Parents – Novices – Older adults – Adults
Usage of the system (11)	– Learning how to be healthy – Starting point – Information gathering – Explore – Useful to research minor twinges	– Counseling, consult – Self-diagnosing – Used to see if any major health issues – Would also seek info from doc
Similar systems (2)	– WebMD	– PubMed

When similar expressions were used to describe one concept, only one expression is listed in the table.

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TABLE 4b. Participants' evaluations of MedlinePlus as an integrated system.

Aspects	Concepts	
Attributes of the system (12)	– Search oriented; searchable – Similar to other information-rich sites	– Large database; quite large in scope – Data-rich, Resourceful – Free
Usefulness (10)	– Helpful – Wide array of use – Less need for doctors	– Good place to seek initial advice – Good for avoiding doctor – Not self sufficient
Usability of the system (24)	– Accessible – Quick access; fast; prompt – Easy to use – User friendly	– Fast paced – No glitches – Not reactive – Not clear how they pick links
Public awareness (1)	– Not well known to the public	

When similar expressions were used to describe one concept, only one expression is listed in the table.

still need to consult and seek information from doctors. It is worth noting that several participants thought of two systems that they were more familiar with, WebMD and PubMed.

The evaluations or emotions about the system component were in relation to four aspects: attributes of the system, usefulness, usability of the system, and public awareness, as shown in Table 4b.

Attributes of the system refer to participants' understanding of the characteristics of MedlinePlus as an integrated system. In the study, participants described MedlinePlus as a large and resourceful search-oriented system. It was similar to other information-rich Web sites and it was free. Concerning the usefulness of the system, participants felt that MedlinePlus was helpful. It was a good place for initial medical advice and could help people avoid seeing the doctor. Only one participant pointed out that the system was not self-sufficient.

As shown in the table, about half of the evaluations of the system component were about the usability of MedlinePlus. Participants generally agreed that the system was user-friendly, fast to access, easy to use, and without noticeable glitches. Only a couple of them pointed out that it was not reactive and it was not clear how the links were selected. One participant commented that MedlinePlus was not well known to the public.

Representations and evaluations of the content component. Participants represented the content of MedlinePlus in relation to four aspects: subject, type, format, and presentation of information. The subject of the information in MedlinePlus was represented at three different levels: general, topical, and specific. Concepts at the general level (55 concepts) do not reveal the subject matter of the site and do not differentiate MedlinePlus from other sites. Examples included information, data, advice, articles, literature, and sources. Concepts at the topical level (146 concepts) described the topicality of the information in the system. Examples included medical information, diseases, symptoms, treatments, health information, diagnosis, supplements, and drugs. Concepts at the specific level (123 concepts) described specific diseases, treatments, supplements, or drugs and were more specific than the ones at the topical level. Examples included diabetes, exercise routines, cardiology, endocrine system, ear infection, tuberculosis, x-rays, and insulin.

TABLE 5a. Participants' representations of the type, format, and presentation of information in MedlinePlus.

Aspects	Concepts	
Type (50)	– Dictionary – Directories – Encyclopedia – FAQs – Glossary – Journals – News	– References for medicine – Tutorials – Presentations – Scholarly articles – Medical sites – Magazine – Q&A
Format (24)	– Text – Videos/Movies – Images/Photos/Pictures	– Flash – Multimedia – PDF
Presentation (15)	– Demonstrations – Details – Overview – Diagrams	– Short articles – Several sections – Summaries

When similar expressions were used to describe one concept, only one expression is listed in the table.

Concepts that participants contributed to represent the type, format, and presentation of information in MedlinePlus are listed in Table 5a. As shown in the table, participants recognized various types of medical and health information in MedlinePlus, including a dictionary, directories, an encyclopedia, FAQs, a glossary of diseases, journals, medical news, Q&A, references for medicine, and tutorials. The information was in different formats, such as text, image, video, flash, and multimedia. At the same time, participants paid attention to different ways in which information was presented in the system. They found that some articles were divided into several sections; some information was presented as overviews, summaries, diagrams, demonstrations, or short articles, and sometimes details were provided.

When representing the content in MedlinePlus, participants also expressed their evaluations of or emotions about

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TABLE 5b. Participants' evaluations and emotions concerning the content of MedlinePlus.

Aspects	Concepts	
Quantity of information (11)	– Information on a large number of topics, including lesser-known conditions – Overwhelming amounts of information; Lots of information	– Not many articles – Limited – Additional content is needed
Quality of information (13)	– Academic, Scientific; Well-researched – Clear – Consistent – Thorough	– Reputable – Reliable, trustworthy – Authoritative – Question of credibility
Utility of information (21)	– Helpful – Useful – Interesting – Relevant – Informative – Easy to read – Self-explanatory	– Understandable – No information on brown recluse bite – Additional content other than medical data might make it more interesting, such as an article about health insurance
Attributes of information (42)	*Comprehensiveness* – Comprehensive – Diverse – Not restrictive to one area of medicine – National and local information *Currency* – Current; Contemporary – Recent; Up-to-date *Objectivity* – Facts	*Depth of information* – Basic; General – Common – Quick information – Broad; Breadth not depth – Specific *Language* – Available in different languages – Words were mostly monochromatic *Others* – Popular topics – Concise
Evaluation of specific sections of content (2)	– The general information on bodily systems and functions supplements and provides a foundation for the information on diseases.	– More description on black widow bite

When similar expressions were used to describe one concept, only one expression is listed in the table.

the quantity, quality, utility, attributes, and specific sections of the content, as shown in Table 5b.

Concerning the quantity of information, some participants thought that MedlinePlus contained a good amount of information, while others thought that there were not many articles and additional content, such as information about health insurance and more descriptions on certain topics. Concerning the quality of information, participants had mostly positive feelings. They felt that the content of MedlinePlus was not only thorough and clear, but also consistent, reputable, and reliable. Only one participant questioned the credibility of the information. Concerning the utility of information, participants felt that the information in MedlinePlus was not only useful (e.g., relevant, useful, and informative), but also usable (e.g., self-explanatory and easy to read).

At the same time, participants developed opinions concerning various attributes of the content, such as comprehensiveness, currency, objectivity, and depth. They commented that information in MedlinePlus was common, basic, and factual. It covered a broad spectrum of medical topics and was updated regularly. Some information was even available in multiple languages. A couple of participants also began to form opinions about specific sections of content in the system. For example, one commented that:

> The general information on bodily systems and functions supplements and provides a foundation for the information on diseases.

Representations and evaluations of the information organization component. The information organization component was participants' representations of how information was organized in MedlinePlus. Table 6a lists concepts that participants contributed to represent this component.

Despite the lack of emphasis (35 concepts; 5.6% of all the concepts in the representations dimension), participants were able to recognize various information organization schemas in MedlinePlus, such as by subjects, alphabetical (array of letters, listing, encyclopedic), by body systems (anatomy, body parts), by gender, age, and other demographic information, and by generic and brand names of drugs. One participant noted that multiple facets were used to organize the information and several others noticed the cross listing of relevant categories.

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TABLE 6a. Participants' representations of information organization in MedlinePlus.

– Categories; Array of topics; Grouped; Organized by topic and concepts
– All body systems; anatomy; body parts; body systems
– Alphabetical; Array of letters; Encyclopedic; Listing
– Health related issues depending on gender/age/other demographics
– Multi-faceted
– Hierarchical
– Cross-listing
– Drugs are listed under both generic and brand names

When similar expressions were used to describe one concept, only one expression is listed in the table.

TABLE 6b. Participants' evaluations of information organization in MedlinePlus.

– Clearly listed
– Good multimedia structure
– Logical
– Simplified categories
– Well organized
– Provides a comprehensive flow map to information
– Not enough subgroups

When similar expressions were used to describe one concept, only one expression is listed in the table.

Simultaneously, participants expressed their evaluations of information organization (15 concepts) in MedlinePlus, as shown in Table 6b.

Participants formed largely positive feelings about the information organization. They agreed that information was clearly listed and logically organized, which provided a comprehensive map to the content of the system. Only one participant thought that there were not enough subgroups.

Representations and evaluations of the interface component. Participants represented the interface of MedlinePlus in relation to three aspects: interface elements, functions, and results, as shown in Table 7a.

After using MedlinePlus for 5 minutes, participants represented mostly general interface elements, such as about us, disclaimer, logo, banner, contact us, links, questions and answers, menus, and tabs. Some of them mentioned a few elements specific to MedlinePlus, such as purple, suggested articles, related illness, and hospital and doctor listings. When representing functions, participants emphasized the search function, particularly the general site-wide search (27 out the 39 concepts), but they also recognized that they could search for doctors or hospitals by state and search for different medications. Several participants mentioned browsing as an option for looking for information in MedlinePlus. Two functions that were not available in the system, symptom finder and pill identifier, were listed as well. It might reflect participants' need for the functions, as indicated by a comment in the semistructured interviews:

> . . ., but they could have symptom checker on the homepage, have instructions on if you want to find this information, go here and if you want to find this information, go there.

TABLE 7a. Participants' representations of the interface of MedlinePlus.

Interface elements (61)	– Color	– About MedLine
	– Links	– About us
	– Lines on Webpage	– Contact us; Contact information
	– Hospital and doctor listings	– Banner
	– Sections	– Tabs
	– Homepage	– Purple
	– Images	– Ads
	– Search bar, Search box	– Disclaimer
	– Subject headings	– Logo
	– Suggested articles	– Menus
	– Related illness	– Questions and Answers
	– Links to related topics	– Interface
	– Title	– Layout
Functions (39)	– Search	– Symptom finder
	– Local search	– Pill identifier
	– Browse	
Results (2)	– Search results yield snippets	– Suggested results

When similar expressions were used to describe one concept, only one expression is listed in the table.

When representing results, participants noticed the snippet that appears at the top of the result list and suggested results.

Participants' evaluations or emotions concerning this component were in relation to three aspects: look and feel, navigation, and search, as shown in Table 7b.

Look and feel refers to participants' evaluations of the visual appearance of the interface of MedlinePlus. As shown in the table, participants expressed mixed feelings. Some thought that the interface was simple, clean, easy on the eyes, interactive, and visually pleasing, while others commented that the interface was plain, outdated, cluttered, and lacked pictures. When evaluating navigations in the system, participants overall had a positive feeling, agreeing that the interface was streamlined, easy to navigate, and with decent flexibility. When evaluating the search function, however, they were more critical, pointing out that the system had limited searchability and there was no advanced search.

Pragmatic knowledge of using MedlinePlus. As has been introduced in the previous overview section, participants proposed three distinct strategies to tackle a hypothetical task using MedlinePlus: a general search strategy (strategy A), a browsing strategy (strategy C), and a combination of searching and browsing (strategy B). Table 8 shows the proposed use of the strategies. As shown in the table, 24 (63.2%) participants planned to use either general search strategy A or browsing strategy C to solve the hypothetical task. Fourteen (36.8%) planned to use multiple strategies in combination.

Concerning the use of each individual strategy, 28 (73.7%) participants planned to use the general search strategy A. Twenty-four (63.2%) planned to use browsing strategy C. Only one (2.6%) proposed to use strategy B, the strategy that was more aligned to the information architecture of MedlinePlus.

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TABLE 7b. Participants' evaluations and emotions concerning the interface of MedlinePlus.

Look & Feel (35)	– Clear layout – Clean lines on Website – Simple – Plain – Welcoming – Pretty, Colorful – Visually pleasing – Catchy title – No advertising! – Interactive – No clutter – Easy on eyes	– Old fashioned, A little outdated – Not extremely visually appealing – Lack of pictures, Need some design improvement such as addition of images, Few pictures – Needs new Website banner – Word-intensive, Text-heavy – Sometimes too much information on a single page, – Many words on each page – Some pages overwhelming with choices of topics
Navigation (14)	– Streamlined – Easy to navigate – Ability to jump topics with ease – Easy to follow from link to link – Easy interface	– Decent flexibility – Like the links to other pages – The variety of links on each page is helpful. – Helpful links
Search (3)	– Lacking search functions – Limited searchability	– No advanced search

When similar expressions were used to describe one concept, only one expression is listed in the table.

TABLE 8. Strategies that participants proposed to solve a hypothetical task.

Strategy	No. of participants
A[a]	14 (36.9%)
C[c]	10 (26.3%)
A + C	13 (34.2%)
A + B[b] + C	1 (2.6%)

[a]Strategy A: Search → read results.

[b]Strategy B: Search → top result → health topic page → review content and links.

[c]Strategy C: Browse: Homepage → Health issues → health topic page → review content and links.

Discussion and Conclusion

Participants in the study were a group of homogeneous undergraduate students. They were able to articulate an initial model of information-rich Web spaces. The initial model had three distinct dimensions. The first was a representational dimension, in which participants represented various elements of information-rich Web spaces, such as systems' audience, subject and format of the information, tabs, links, and homepage. The representations clustered into four components: system, content, information organization, and interface. Simultaneously, participants formed evaluations of or emotions about each of the components, pointing out that information-rich Web spaces overall were convenient and accessible. They contained a large amount of information and the information was rigidly organized. Their interfaces were easy to use, but could also be cluttered and distracting. These evaluations/emotions constituted the evaluation/emotion dimension. The third dimension was informed by the mental model theory and consisted of a set of practical strategies or approaches for using the spaces, such as search, browse, and glance for graphs and headings.

Measuring mental models is challenging. In this study we employed a new method, concept listing, to elicit participants' mental model of MedlinePlus. In the concept listing, participants were given an explicit instruction to list concepts concerning MedlinePlus in the sequence that the concepts appeared in their mind. The method is a variation of word association tests, a method that has been widely used in the field of psychology to understand people's knowledge structures and associative cognitive processes (Cramer, 1968; Goldsmith, Johnson, & Acton, 1991; Pejtersen, 1991). Wang, Bales, Reiger, and Zhang (2004) has used the concept listing method to explore the development of students' knowledge of a subject domain over a semester. However, few studies of mental models adopted the method as a means to elicit people's mental models of interactive information systems.

The result of the study suggests that the concept listing method was effective in representing mental models. Thirty-eight participants listed, in total, 829 concepts. The concepts described MedlinePlus from different aspects and allowed elements and dimensions of mental models to emerge naturally. The method was also very efficient. It does not need interference on the researcher's part in data collection and only required 5 minutes from the participants. Five minutes is reasonable because long pauses were observed toward the end of the session. The method, however, has a limited power in eliciting procedural knowledge. In the study, participants' procedural knowledge of using MedlinePlus was elicited by asking them to describe steps that they planned to take to solve a hypothetical task using the system.

The analysis of the concepts suggested that participants represented MedlinePlus in relation to four components: MedlinePlus as an integrated system, the content, the information organization, and the interface of the system. At the same time, they evaluated or expressed emotions about each of the four components. They also proposed different strategies to solve a task using the system. As a result,

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participants' mental model of MedlinePlus demonstrated a similar three-dimension and four-component structure to their model of information-rich Web spaces. This similarity suggests that the development of participants' mental model of MedlinePlus, an instance of information-rich Web space, might be scaffolded by the structure of their mental model of information-rich Web spaces in general.

Despite the structural similarity, participants' mental model of MedlinePlus was more elaborated than the initial model. When representing MedlinePlus as an integrated system, participants noticed the structure of the system, pointing out that the system was database-driven. It had its own information, but also linked to lots of outside information. They noticed agencies, such NIH and Centers for Disease Control (CDC), involved in the system. They observed general behavior of the system, such as pop-up windows. They thought about possible audiences for and potential usage of the system. They also recalled two similar sites, WebMD and PubMed, to help them make sense of the system. Simultaneously, they evaluated MedlinePlus as an integrated system in terms of its usefulness, usability, and some other attributes. They generally agreed that MedlinePlus was a data-rich and search-oriented system. It was useful and user-friendly.

The content component was the most emphasized component in participants' mental model of MedlinePlus. This is not surprising, considering the fact that content often matters the most to end users. In the study, participants represented general subject areas, such as medicine, symptoms, and treatments, and specific topics such as diabetes, high blood pressure, and vitamin A. They also pointed out basic information types in the system, such as dictionary, encyclopedia, news, and directories; general formats, such as image and PDF; and different ways in which the information was presented, such as overviews and summaries. Similarly, participants quickly developed opinions about the content. They were impressed by the quantity of information in the system and made judgments about its comprehensiveness, currency, depth, as well as quality and utility. They also started evaluating some specific sections of content.

Information organization is important for a hyperlink-based Web system and is of particular interest to researchers in Information and Library Science (ILS) (Morville & Rosenfeld, 2006). In the study, participants paid the least attention to this component. Nevertheless, they were able to represent basic information organization schemas, such as alphabetical, hierarchical, by body systems, and by demographic characteristics. At the same time, they formed a positive feeling about this component, pointing out that information in MedlinePlus was clearly listed and logically organized.

In representing the interface of MedlinePlus, participants mainly focused on the interface elements and functions. The most-listed elements appeared at the surface of the system, such as contact us, disclaimer, tabs, and logo. The most-emphasized functions were search and browse. Correspondingly, their evaluations of the interface focused on the look and feel, navigation, and search. For the look and feel of the interface, some thought it simple, clean, and welcoming, while others thought it plain, outdated, and cluttered. For the navigation, participants recognized that the interface was streamlined and easy to navigate. For the search function, participants were more critical, pointing out a lack of advanced search.

In terms of the procedural knowledge of using the system, the majority of the participants planned to use search, browse, or the combination of the two to solve a hypothetical task. Only one participant proposed a strategy more aligned to the capacity of the system.

Participants' multidimensional and multifaceted mental model of MedlinePlus suggests that when people start to use a new system, they do not focus on only one or two aspects of the system; rather, they represent and evaluate the system from many different aspects, trying to decide what they can do with the system, whether the system fits them, what types information are available and in which formats, how information is organized, and what functions are provided. Based on the representations and evaluations, they formulate perceptions about how to solve tasks using the system.

Although being multidimensional and multifaceted, participants' mental model of MedlinePlus after a brief exposure to the system was rather superficial. They tended to focus on elements at the surface of the interface and easily observable information, such as the subject, type, and format of the content, and system behavior such as pop-up windows. Their evaluations focused more on the easily observable aspects, such as usability, navigation, and the look and feel of the system. Few participants mentioned the underlying working mechanisms, such as how their search engine processes search queries and how MedlinePlus links all the content together in an integrated manner. In terms of the procedural knowledge, only one participant identified a search strategy more specific to the system.

The construction of mental models is a result of a constructive interaction between knowledge in the head and knowledge in the world (e.g., Jonassen & Henning, 1999). The impact of the knowledge in the head on mental model is reflected by three observations in the study. First, the structure and composition of participants' mental model of MedlinePlus inherited that of their initial model of information-rich Web spaces. Second, some participants employed more familiar systems, PubMed and WebMD, in their knowledge base to assist them in understanding MedlinePlus. Metaphors were long considered as a tool that could facilitate learning (Carroll & Olson, 1987; Staggers & Norcio, 1993). Third, participants incorporated two functions, "symptom finder" and "pill identifier," in their current knowledge base but not available in MedlinePlus into their mental model of the system. The impact of the system (knowledge in the world) is reflected by the observation that although the structure of the mental model of MedlinePlus was similar to their initial model of information-rich Web spaces, the substance was more MedlinePlus-specific, encompassing MedlinePlus-specific elements and functions and evaluations of various aspects of the system.

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The research results have implications for system design. First, it is apparent that users perceived information-rich Web spaces in relation to four components: system, content, information organization, and interface. To help users build correct mental models of an information-rich Web space, designers need to consider how to convey the system's conceptual model in a way compatible with the ways in which users perceive the system. Furthermore, designers could consider how to present other less visible but important aspects of the system to users. Second, in their brief encounter with MedlinePlus, participants tried to learn the system by paying attention to the structure, audience and potential usage of the system, various types and formats of information, and elements and functions at the surface of its interface. Participants' attention at this time suggests that system designers should convey such information in a conspicuous manner to help users develop a model of the system. Meanwhile, participants made quick judgments about the usefulness of the system, the quantity, quality, and utility of the content, and the look and feel and navigation of the interface. How to design interface cues to foster users to develop good impressions of these aspects of the system will also be worthwhile to consider.

As with other studies, this study has limitations. Learning a system is a developmental process, as is the construction of mental models of a system. This study only addresses people's perceptions and representations of MedlinePlus after they used the system for 5 minutes. It will be worthwhile to investigate whether users will switch their attention to some other aspects of the system and whether there will be new aspects from which they perceive and evaluate the system, when their experience with the system increases. In the study, participants were asked to freely explore the system as they normally do. Although in some cases people explore a new system to learn about the system, many come to a system with a specific task. So in future studies it will be worthwhile to study people's mental models of a system after they perform a specific task. This study looks at people's mental models of MedlinePlus from a collective perspective. Future studies should look into individual users' mental models and explore whether there are different patterns of models.

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