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Doctoral Students' Mental Models of a Web Search Engine

Abstract: This paper reports on the first stage of a research on doctoral students' mental models of a Web search engine and factors that may affect their mental models. A modified version of a mental model completeness scale was developed and tested in a pilot study in Web search engine context.

Résumé : Cet article présente le premier stade d'une recherche sur les modèles mentaux des étudiants doctoraux avec un moteur de recherche Web et les facteurs qui peuvent les affecter. Une version modifiée d'une échelle de la perfection du modèle mental a été développée et examinée dans le contexte d'une étude préliminaire effectuée avec un moteur de recherche Web.

1. Introduction

By now, the Web has become the most popular and easy-to-access portion of the Internet and the most important information system in the world. But on the other hand, it has been recognized that users often feel it difficult or are unable to find relevant information on the Web (e.g. Chen et al. 2001; Khan and Khor 2004). Research has revealed that the majority of users utilize search engines to find information on the Web (Sullivan 2000; Liaw and Huang 2003). With the wide usage of search engines, some researchers are now studying the effectiveness of Web search engines (e.g. Spink and Xu 2000) as well as exploring users' searching behaviour on particular search engines (e.g. Spink et al. 2000; Spink and Xu 2000). It has been found that information searching by the public on the Web is significantly different from that on non-Web-based IR systems (Spink et al. 2000).

2. Purpose

This paper reports on the first stage of an exploratory research, the main goal of which is to go beyond previous studies by situating users' interaction with a Web search engine – Google within the framework of mental model research. The objective of this research is to investigate users' mental models of the Web search engine Google and explore factors that may affect their mental models. According to mental models theory, user performance is guided by the user's mental models (Norman 1983, 241-244), where these "are internal, predictive, explanatory models which individuals use to facilitate their interaction with the environment, with others, or with technology" (Dimitroff 1990, 11). A mental model "enables individuals to make inferences and predictions, to understand phenomena, to decide what action to take…, and above all to experience events by proxy…." (Johnson-Laird 1983, 397). So if a user's mental model of a device is known, it should be possible to predict his/her performance when interacting with the device.

Among the research efforts in information seeking and retrieval is the exploration of what affects search performance and how to improve search performance. One of the findings is that the information seeker's mental model of the search system strongly influences his/her performance (e.g. Borgman 1986; Dimitroff 1992; Zhang 1998). As Marchionini (1995) pointed out, people develop personal information infrastructures when seeking information. Mental models for information systems and domains of knowledge are an important part of a person's information infrastructure. These models can account for the user's expectations and therefore for his/her learning and behavioral changes (Zhang 1998, 2).

This research focuses on a specific group of users of Web search engines -- doctoral students. Of the existing literature on mental models none has concentrated on this specific group of users. Doctoral students are a

special group of information users because they are potential future scholars, who are in advance stages of their study. Cole (1998) suggests that it is advantageous to study Ph.D. students rather than professors or other scholars, because these students are generally more sympathetic and willing to be the subjects of research. They have interest in and ability to talk about the process of acquiring information for their theses. Ph.D. students are often considered as domain experts because of their research experience with their subject area. But it might be more appropriate to think of the Ph.D. students as those who, in order to earn the degree, must produce a thesis that is substantive and makes an original contribution to the area of study. They must prove to the satisfaction of the university granting the degree that they are domain experts in the chosen field of study (Cole 1998).

This research aims specifically at those doctoral students who have finished their course work and have started the research for the thesis. This is an appropriate group to investigate because to do the research for the thesis, students usually need to conduct a comprehensive literature review in order to substantiate their theoretical framework and their methodology. It is likely that Ph.D. students often search for information via Web search engines in addition to the use of traditional and more structured information retrieval systems. This is because in spite of the fact that Web search engines are dealing with very unstructured data, or at least data with very little consistency of structure (Hock 2001, 20), the information on the Web encompasses as many subjects as a library and search engines provide access to a large proportion of digital documents (Matherly 2000).

As mentioned above, this paper reports on the first stage of this research, that is, the development of a modified version of a mental model completeness scale (MMCS) and the conduct of a pilot study as a preliminary step that tests the feasibility and appropriateness of the modified MMCS for this research in the context of a Web search engine.

3. Definitions

Mental Model

Halasz and Moran (1983, 212) state that mental model is "a cognitive representation of the system's internal mechanics, i.e. its component parts and their behaviours – what Young calls a 'surrogate model'". Borgman (1984, 31) defined mental model as a "general concept used to describe a cognitive mechanism for representing and making inferences about a system or problem which the user builds as s/he learns and interacts with the system". Carroll and Olson (1987, 6) define the mental model from the human-computer interaction point of view as "knowledge of how the system works, what its components are, how they are related, what the internal processes are, and how they affect the components". Marchionini (1992, 55) describes the mental model as "internal representations for objects, events, and ideas" which are used to "help people deal with the world on a daily basis". Dimitroff (1990, 21) explains mental model as "a model representing the structure and internal relationships of a system which evolves as the user is learning and interacting with that system". Saxon (1997) followed Dimitroff's definition in his research of mental model formation, completeness and change of electronic information retrieval systems among seventh grade students. He states that "one of the central functions of the mental model is said to be the structured representation of knowledge in memory, as well as its ability to represent relationships of the parts to each other" (Saxon 1997, 23).

No matter how diversely defined, the broad meaning of "mental model" is generally agreed to be "any thought process in which there are defined inputs and outputs to a believable process which operates on the inputs to produce outputs" (Carroll and Olson 1987, 12). It refers to "representations in the mind of real or imaginary situations" (Johnson-Laird and Byrne 2000). This representation has a structure that captures or resembles the situation it stands for (Johnson-Laird 1995).

For the purpose of this research, mental model is defined as the model that a doctoral student has built in his/her mind representing the structure and internal relationships of the Web search engine Google, based on

his/her perception. This definition is formulated based on the ideas of Dimitroff (1990), Saxon (1997) as well as Johnson-Laird and Byrne (2000).

Mental Model Completeness

In the information retrieval literature several studies focused on a particular dimension of the mental model – completeness (e.g. Borgman 1984; Dimitroff 1990; Saxon 1997). Dimitroff defined mental model completeness as "the knowledge of an end-user searcher of all components of an interactive bibliographic retrieval system" (Dimitroff 1990, 21). Saxon followed Dimitroff's (1990) definition and pointed out that the degree of completeness may be represented on a scale (Saxon 1997, 18). He further explained that completeness is "that dimension of a mental model which accounts for the user's knowledge of structures deemed essential to understanding and/or using the system or concept" (Saxon 1997, 209).

In this research mental model completeness is defined as the perception by a doctoral student of all components and structures of a Web search engine -- Google. This definition follows Dimitroff and Saxon's way of defining the term, but it also gives consideration to the factor that the present research focuses on doctoral students' mental models of one particular Web search engine -- Google rather than other user groups' mental models of non-Web-based information retrieval systems.

4. Mental Model Completeness Scale (MMCS)

This research adapts and modifies Saxon's (1997) completeness scale of mental model of information retrieval systems to fit the research purpose. The dimension of mental model – "completeness" refers to the perception of a user of all components and features of a system. It can be represented as the sum of elements acquired and expressed in a certain way. The implication is that the more elements are accounted for, the better the understanding of the system should be (Saxon 1997, 208-209).

Saxon's mental model completeness scale, in turn, was adapted and modified from Borgman's (1984) and Dimitroff's (1990) scales. The following table illustrates the similarities and differences in the mental model completeness scales of Borgman's (1984), Dimitroff's (1990) and Saxon's (1997). All three scales account for the articulated understanding of the nature and contents of databases and system search features. In addition, Saxon assessed concepts of interactive roles between the searcher and the system. To make the comparison more clear the original sequential numbers assigned to the mental model elements of these three scales are retained, and all the elements of those scales are included. All elements are sequenced to the same component, with the comparable elements appearing in the same rows. If an element is alone in assessing a certain criterion, it is put in a row by itself.

Borgman (1984) (SS=college undergrad)	**Dimitroff** (1990) (SS=college undergrad)	**Saxon** (1997) (SS=7th graders)
		Database Structure
	1. DB=bibliographic	1. Contains my/all info
		2. All info not in DB
*1. Index=external to db	5. Multiple indexes &/or	3. DB is organized
8. Index=alphabetical for browsing	inverted indexes 4. Mult. fields within each record	
	3. Mult. types of DB's	4. Multiple types of DB

*2. Specific field searched *3. Search terms matched **4. Aware of "AND" ** 5. Aware of "OR" **6. Aware of "ANDNOT" 7. Use single words, not phrases.	7. Aware of keyword search 8. Aware of controlled vocabulary 6. Aware of "AND" and "OR" in MIRLYN system	**Search Features** 5. Aware of HelpAvail 6. Aware of "matching" 7. Aware of search types 8. Aware of search restrict/broaden features
Negative Points (-1 pt) 9. Do not think about it		
	2. Aware of feedback & revision of search	**Interactive Level** A. BlackBox/Find B. Stimulus/Response (I type, it finds; I choose…) C. Dialog (rephrasing, term reformulation)

*Gets 2 points
**Gets either 2 or 1 point, depending on complete or partial description.

Table 1. Mental Model Completeness Scales Adopted by Borgman, Dimitroff and Saxon, taken from Saxon 1997, 213

The table shows that both Borgman's (1984) and Dimitroff's (1990) mental model completeness scales are aimed at college students' understanding of system components and search features. Saxon, on the other hand, targeted the identification of mental models developed by seventh grade students. The differences between the scale used by Saxon (1997) and those adopted by Borgman (1984) and Dimitroff (1990) reflect the different research purposes and settings of the three researchers. Saxon's scale seems to be more robust and specific than the others'. It also shows the necessity for any adaptation of a scale to reflect the different natures of the information systems, environments, the particular interfaces, and subjects (Saxon 1997, 209). Borgman (1984) and Dimitroff (1990) studied college users' interactions with a single command-oriented system while Saxon (1997) explored seventh grade students' understanding of multiple menu-driven CD-ROM systems. Compared to Borgman's (1984) and Dimitroff's (1990) scales, Saxon's mental model completeness scale (1997) added the interaction assessment component, the system specific changes, and he expected a more general, rather than specific, understanding of elements.

What this study contributes is that the mental model completeness scale adapted from Saxon's scale fits in with the nature of the particular type of information system – Web search engine and the particular group of users – doctoral students. Web search engines are different from those non-Web-based information retrieval systems in that they can provide links from words in a document to other documents. Also compared with the subjects of Saxon's research, that is, seventh graders, the subjects of this research -- doctoral students can be assumed to be more mature, and with their high level of education and training, be more familiar with electronic information resources.

The mental model completeness scale (MMCS) adopted in this research encompasses the understanding of the nature of the Web search engine, searching features of the Web search engine, and interaction between the searcher and the Web search engine. The procedure of developing this mental model completeness scale (MMCS) is as following:

A prototype MMCS was first adapted from the scale of Saxon's (1997). Then a method to score the mental model components and differentiate completeness levels of subjects' mental models, based on the comparison of the scoring methods of Borgman's (1984), Dimitroff's (1990) and Saxon's (1997) scales and the consideration of the objectives of this research was developed.

A group of online information retrieval experts were invited to make suggestions and modifications on this prototype MMCS after its formulation. They included four experienced reference librarians and a system librarian from two major universities and a community college in Canada.

The decision to choose academic reference and system librarians for this purpose is based on the definitions and operational definitions of (online) information retrieval experts in the literature and the consideration of the nature of the subjects in this research -- doctoral students. According to Zhang (1998, 59), online information retrieval experts should be those who "have a depth of knowledge about information retrieval systems and online searching process". In the study performed by Meadow, Wang, and Yuan in 1992 on the differences in performance and attitudes of users with respect to information retrieval interfaces, online information retrieval experts were operationally defined as the group of users who had had formal training in conducting database searching and had normally performed searches on behalf of a client and who had been formally trained in conducting online searching and had had a fairly amount of previous search experience. The subjects they selected to represent online information retrieval experts were graduates from the Master of Library and Information Science program who had taken *Online Information Retrieval* course and other courses relating to the technology of information science and who had various amounts of experience with conducting online searches (Meadow, Wang, and Yuan 1992, 4-5).

The four online information retrieval experts invited for this research are also graduates from the Master of Library and Information Science program who had taken courses relating to the technology of information science including *Online Information Retrieval*. As reference librarians and system librarians, they themselves must have an in-depth knowledge of online information retrieval systems (including Web search engines) and must be expert (online) information searchers. Also as they work in University libraries with Ph.D. programs, they must be familiar with the needs of doctoral students (the librarian from the community college also has two years' experience of working in a major university library).

Formal interviews were conducted with the experts to solicit their opinions about the prototype MMCS. Based on their comments and suggestions, a revised MMCS was formulated and then sent to them for further comments. With their feedback, the final MMCS with the scoring method of the mental model components and the differentiating way of mental model completeness levels was decided on as following:

Model Element	Definition and Delimitation
Nature	**Choose all that apply.**
1. Specific/General Info	1. Perception of Google's ability to retrieve specific or general information.
2. Limited Info	2. Perception of Google's inability to retrieve all information.
3. Indexed Pages/Sites	3. Perception of the indexing of Web pages/sites for retrieval.
4. Info Authority	4. Perception of different levels of authority of the information retrieved via Google.

Search Features	**Choose all that apply.**
5. Search Assistance	5. Perception of search assistance availability.
6. Matching	6. Perception of some matching process.
7. Search Types	7. Perception of different types of searches.
8. Restricting/Broadening	8. Perception of mechanisms for restricting or broadening searches.
9. Ranking/Sorting	9. Perception of the ranking or sorting process of search results.
Interactivity Level	**Choose only one category.**
A. Magic Finding	**A. System is primary.** Effortless retrieval. Expresses the mere sense that information "is obtained."
B. Stimulus/Response	**B. Search is system-directed, user-responsive.** Limited system/user partnership. Explicit stimulus-response sequence in evidence.
C. Negotiated Dialog	**C. Search is user-directed, system-assisted.** Sense of user reformulating search terms; system's difficulty in matching.

Table 2. Mental Model Completeness Scale for the Present Research

To have a complete mental model of Google (a perfect score on the MMCS) doctoral students must have the perception that by searching Google they would be able to retrieve some specific or general information, but not all the required documents. They should perceive that some information might not be able to be retrieved via Google. They should have the perception of how Google indexes Web pages/sites for retrieval and the perception of different authority levels of the information retrieved. They should perceive such search features as the availability of search assistance, matching process, different types of search, mechanisms for restricting or broadening searches and the ranking or sorting process of search results. They should perceive the existence of some interaction between them and Google when they search for information via this Web search engine. The ideal level of interaction between the searcher and the Web search engine should be Negotiated Dialog, that is, search is user-directed and system-assisted.

With this scale, a subject's mental model completeness level will be determined by how many components of the first two parts of the scale are described and which level of interaction between the subject and Google is revealed during the searches. If a subject can describe any component of the first two parts of the scale, s/he will score 1. If s/he can describe all nine components, s/he will score 9. For the interaction level, if a subject reveals it as Magic Finding, s/he will score 0. If s/he describes it or reveals it through the actual information searches as Stimulus/Response, s/he will score 1. If s/he describes or reveals it as Negotiated Dialog, s/he will score 2. The scores of the three parts will be aggregated. If a subject altogether scores 10-11, s/he will be considered to have a complete mental model of Google. If s/he altogether scores 8-9, s/he will be considered to have a good mental model. If s/he scores 6-7, s/he will be considered to have an incomplete mental model. If s/he scores 5 or below 5, s/he will be regarded as having a poor mental model.

5. Pilot Study

A pilot study was conducted to verify the MMCS. Five subjects (three females and two males) were recruited from different disciplines from two universities in Ontario. Semi-structured interviews were performed with them and they were observed when they were doing actual Web information searches.

Results

By analyzing the interview and observation data, the researcher differentiated the five subjects according to their mental model completeness levels: Two subjects have a good mental model; two have a poor mental model and one has an incomplete mental model. The following tables illustrate the background and factual Web search information as well as the mental model completeness levels of the five subjects:

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Gender	Female	Female	Male	Male	Female
Discipline	Mathematics	Mathematics	East Asian Studies	Biostatistics	Industrial Engineering
First Time to Use a Computer	1995	1990	1994	1985 or 1986	1986
Frequency of Using Computers	Daily	Daily	Daily	Daily	Daily
Purpose of Using Computers	Multiple	Multiple	Multiple	Multiple	Multiple
Formal Training Received	Yes	No	No	Yes	Yes

Table 3. Subjects' Background Information

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
Purpose of Searching the Web	Multiple	Multiple	Multiple	Multiple	Multiple
Frequency of Searching the Web	Daily	Daily	Daily	Daily	Daily
First Time to Search the Web	1999	1994	1995	1996 or 1997	1997
Learning Method	Learning from Friends	Learning from Friends	Self-Teaching	Learning from Friends	Learning from Friends
First Time to Use Google	2000	1997 or 1998	1995	2000	1997

Table 4. Subjects' Factual Information on Web searching

Model Element		**Score**				
		Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**
Web Search Engines	Specific/General Info	1	1	1	1	1
	Limited Info	1	1	1	1	1
	Indexed Pages/Sites	0	0	0	0	0
	Info Authority	1	0	0	0	1

Search Features	Search Assistance	0	0	0	0	0
	Matching	1	1	1	1	1
	Search Types	1	0	0	1	1
	Restricting/Broadening	1	0	0	0	1
	Ranking/Sorting	1	1	0	1	1
Interactivity Level	Magic Finding		0	0		
	Stimulus/Response	1			1	
	Negotiated Dialog					2
Total Score		8	4	3	6	9

Table 5. Subjects' Mental Model Completeness Level

Discussion

The three tables reveal how the five subjects are differentiated according to their mental model completeness levels and their respective background and Web search experience. The first subject is a female doctoral student whose major is Mathematics. She first began using computers in 1995, having received formal training in computers. Her first experience doing searches via Web search engines was in 1999. This subject has a good mental model, with the perception of such mental model components as Specific/General Info, Limited Info, Info Authority, Matching, Search Types, Restricting/Broadening, and Ranking/Sorting. The interactivity level between her and the Web search engine is Stimulus/Response.

The second subject is a female doctoral student majoring in Mathematics as well. She first began using computers in 1990 but has never had any formal training in using them. Her first experience in doing Web information searches was in 1994. This subject has a poor mental model, having the perception of Specific/General Info, Limited Info, Matching, and Ranking/Sorting. The interactivity level between her and the Web search engine is Magic Finding.

The third subject is a male doctoral student whose domain is East Asian Studies. He first began using computers in 1994, but has never received any formal training in using them. His first experience doing Web information searches was in 1995. This third subject has a poor mental model, having acquired such mental

model components as Specific/General Info, Limited Info, and Matching. The interactivity level between him and the Web search engine is also Magic Finding.

The fourth subject is a male Ph.D. student, whose major is Biostatistics. As far as formal training in using computers is concerned, he has taken classes in Fortran, Basic, SAS, and has also learned C language. He first used the computer in 1985/1986. His first Web searching experience was in 1996/1997. This subject has an incomplete mental model, with the perception of Specific/General Info, Limited Info, Matching, Search Types, and Ranking/Sorting. His interactivity level with the Web search engine is Stimulus/Response.

The last subject is a female Ph.D. student majoring in Industrial Engineering. Her first contact with the computer was in 1986. She has received formal training in computer science and has taken such courses as Introduction to Computer Science and Introduction to PC. She has also taken courses in Computer Programming and Web Design and has learned to use certain software and databases. Her first experience in Web information searching was in 1997. This subject has a good mental model, with the perception of Specific/General Info, Limited Info, Info Authority, Matching, Search Types, Restricting/Broadening, and Ranking/Sorting. The interactivity level between her and the Web search engine is Negotiated Dialog.

The main aim of this pilot study is to verify the appropriateness of the modified mental model completeness scale (MMCS) for the research purpose of eliciting doctoral students' mental models of Google. The result has achieved this aim and has proved that with the modified version of MMCS, doctoral students' mental models of Google can be differentiated according to the dimension of completeness.

In addition to the achievement of the main aim, the pilot study also reveals the following points:

Doctoral students should be an interesting group to look at. Also doctoral students are found to have an interest in this topic, as they rely on Web search engines for their information now, more than they did in the past.

Semi-structured interview and direct observation are appropriate techniques for the elicitation of users' mental models. By analyzing both interview and observation data, it has been found that the two types of data supplement each other in figuring out the completeness levels of doctoral students' mental models of Google.

Semi-structured interviewing suits the purpose of this research better than any other interviewing technique. To elicit the subjects' mental models of a Web search engine a fixed set of questions must be asked since the answers to these questions are essential to the understanding of the subjects' mental models. Yet, during the process of interviewing it is necessary to make probes at times, given that the subjects may not always understand the exact meaning of the questions. Only by probing can the subject's mental model completeness level be found out.

6. Conclusion

In conclusion, the pilot study has shown the feasibility and applicability of the modified mental model completeness scale (MMCS) for the elicitation of the doctoral students' mental models of Google. This scale fits in with the nature of the particular type of information system – Web search engine and the particular group of users – doctoral students.

With the confirmation of the appropriateness of the modified MMCS for the research purpose, the pilot study will be expanded into a full research study, which is expected to elicit doctoral students' mental models of the Web search engine Google and to find out the factors that may affect their mental models.

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