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Mental models: a theoretical overview and preliminary study

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Abstract.

Within the socio-cognitive framework of sense-making, this paper explicates the term 'mental model' and its associated concepts, analyzes the controversies and connections pertaining to mental model research in information studies, and reports the findings of an exploratory study of the mental models of an academic information system. As one aspect of the process of making sense out of their experiences, individuals develop mental models of the systems and processes with which they interact. These models include (1) key components, (2) relationships between those components, and (3) techniques for interacting with the system or process. The small-scale study discussed here identifies three distinct patterns across the models of information seeking held by graduate students in a reference course.

Keywords: cognitive framework; information system design; information seeking; academic libraries; sense making

1. Introduction

> Our reasoning processes – learning, understanding, problem solving – are largely dependent on our mental modelling mechanisms. … A model is not a mere simplified version of a certain reality. A main characteristic of a model is that *it is a reality of its own*. … Being structurally unitary and autonomous, the model very often imposes its constraints on the original and not vice versa! [1]

One of the dominant paradigms of modern human–information interaction studies is that of sense-making. Sense-making posits the human experience as, in part, an active, socially rooted process of creating sense or meaning out of information problems, discontinuities, and disconnections, all of which are encountered daily in our personal and professional lives [2]. In this paradigm, information is inherent in human activity and its meaning is generated, negotiated, and transformed by

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human interaction and understanding [3, 4]. The individual's 'situated process' [5] of constructing meaning draws on personal experiences. Virtually every experience generates expectations, calling, then, upon the individual to make sense out of that experience.

Patterns across those particular expectations and activities that are connected with information seeking can inform the work of information system designers. In order to incorporate sense-making patterns into the design process, it is necessary for the designer to focus on the needs of the information seeker. One way of doing this is for the designer to have at hand information about the patterns followed by a particular population, such as graduate students in research courses. The social and practical contexts of sense-making embody the situated aspects of individuals' interactions with systems and with people, both internally and externally [6]. Individuals in a homogeneous population share some of the social influences that help them in their sense-making efforts and they also share similar goals. Those similarities show up in the development of mental models (MM) of information systems and processes. Those models identify key components in the system (e.g. Google, books, local experts) and discrete actions (e.g. search by keywords from research problem). System designers need to understand which components and actions individuals perceive as possibly, probably, or unlikely to be productive.

One of the reasons that mental models are so important is that for the individuals who hold them, those models have a value and reality all their own. Individuals believe in them, often without direct reference to their accuracy or to their level of completeness, and are reluctant to give them up. These mental models drive expectations, preferences, and reasoning in any interaction with the system or process represented by the model. Integral to the 'inherently creative' [7] act of processing information, these models are situationally bound and are developed by those who hold them based on their own life experiences. While programs designed according to the needs of separate individuals are not at present a realistic possibility, patterns can be found that apply to more than one person, and it is these patterns, once identified, that can be helpful to system designers.

As one step in gleaning productive patterns from among individuals' mental models of information systems and processes, this study provides an analysis of the theoretical foundations of MM research followed by the findings of a small exploratory study of the mental models used by graduate students in a reference course. An understanding of the theoretical foundations of MM is essential to understanding how research findings based on these foundations could apply to system design. Therefore, this paper also provides a review of the historical context, current applications of the definition, and critiques of the concept of mental models.

2. History

The modern history of MMs began in 1943 when Kenneth Craik described them as 'small scale models' [8] of reality. A generation later, cognitive psychologist Philip Johnson-Laird's approach to MMs [93–11] posited a logical reasoning approach in which people use their models to infer relationships, predict outcomes, understand the systems they encounter, determine a course of action, control that action, and experience events 'by proxy' [10]. This reason-centered approach contrasts with the physically-centered approach of D. Norman [12] who, at about the same time, presented MMs as limited internal diagrams that apply only to physical processes, such as moving pulleys [13].

Information studies scholars took early note of this work in cognitive psychology. The discussion was launched with De Mey's 1977 statement at the International Workshop on the Cognitive Viewpoint that 'any processing of information, whether perceptual or symbolic, is mediated by a system of categories or concepts which, for the information-processing device, are a model of his [the user's] world' [14]. Since that conference, various research threads in information studies have explored a socio-cognitive approach to MM study.

This approach recognizes the critical roles of social context, personal situation, and affective influences. It is closely related conceptually to the sense-making paradigm that leads most modern studies of information interaction behaviours, but by recognizing these very real components of

human interaction it goes beyond the Johnson-Laird focus on reasoning. This socio-cognitive approach in information studies posits mental models as

> internal cognitive structures that the individual constructs, explicitly or implicitly, to represent a particular target domain, be it an event, an activity, an object, or a subject area. In this sense, mental models are the conceptual frameworks that individuals form, based on experience and formal knowledge acquisition, which allow them not only to predict the results of explicit behaviors but also to interpret and understand their environment [15].

As with other aspects of sense-making, studying mental models requires the individual to be approached with due deference to the individual's environment and immediate situation, as well as to the continual changes in both. The difficulty of studying those phenomena, much less making direct, immediate application of such a study to information system design, has limited the exploration of mental models in information studies.

3. Current definition

Taking this socio-cognitive perspective into information system design, the following definition, proposed by Doyle and Ford, applies most appropriately to information studies. A 'mental model of a dynamic system is a relatively enduring and accessible, but limited, internal conceptual representation of an external system whose structure maintains the perceived structure of that system, [16]. Information systems are certainly dynamic, and the internalized representations of those systems, unique to each individual, are the locks for which information professionals strive to construct, not a key, but a set of lock-picks.

Mental models among users reflect varying levels of understanding of the systems or processes from which they are required to glean information. These models may be incomplete; they may consist primarily of analogies [17], which often work pretty well. People certainly function with varying levels of efficiency and effectiveness as they employ mental models that are inaccurate and/or incomplete. MMs need function only at a minimal level to be maintained, and they do not even need to be accurate for some researchers to feel they are getting all the information they need – a sort of 'ignorance is bliss' approach [15]. Indeed, research indicates that MMs can even be reinforced by a coincidence that makes a choice appear to be the result of correctly applying the model rather than simple coincidence [18]. Although it is possible to develop or correct a model by repeatedly using and revising it, people are quite likely to use a model without regard to its efficacy simply because it is emotionally comfortable and deeply familiar [19]. Obviously models that limit user expectations of success in regards to a particular tool or strategy may limit information access [15]. Research on the implications of these problems remains sparse.

One facet of mental model application that information system designers can use to influence user behaviour is that the models are dynamic. The act of applying a model can lead to changes in the model, even though people generally hold mental models without the self-awareness needed to easily verbalize their nature or to recognize the need for alterations. Their use and application to different situations deepens their imprint, particularly when they are used to make sense out of complex problems in focused arenas [20].

4. Related concepts of models

As Turner and Bélanger noted a decade ago, the terminology surrounding mental models is confusing because the same language is used in different ways by members of different disciplines [21]. These disciplines increasingly intersect as technological horizons expand. The following terms are most commonly associated with the mental model concept as it is addressed in information science literature.

System designers, as well as system users, have their own MM. In fact, they commonly utilize three different ones. The 'design model' delineates the actual components of the system in relationship to each other, much like the blueprint of a house. In this model, the user is a generic individual who receives the output of the system. The 'user model' is the designer's stereotype of the person [22] who is expected to use the system. Finally, the 'conceptual model' [23] is an explanation of the system created by the designer solely as a means of explaining the system to the user. A conceptual model may be just a metaphor or analogy [24], although the metaphor can be quite powerful [25]. Also known as 'user views' [26], a 'user conceptual model' [17] or a 'system model' [20], these constructs intend to provide an explanation of the system for the user. This model may not be complete or even fully accurate if the system designer thinks that a limited explanation is all the user could understand.

Both users and designers function with their own individual 'schema' for the larger environment within which the information system is placed. Schema hold general knowledge about objects (like buildings or keyboards), actions (like approaching a service counter or scrolling a web site), and events (like being offered assistance at a service counter or having a pop-up window appear on a web site) [27, 28]. The social norms which shape schema also shape mental models. Those commonalities form patterns which designers might use.

In the 1980s some designers tried to construct empirically validated 'information-processing models.' These models were 'an attempt to break down human tasks into discrete physical and cognitive actions and to assign probabilities of occurrence and performance times to these actions [thereby allowing] task behavior to be calculated and predicted' [29]. Initial information-studies work on mental models sometimes attempted to reduce them to this level of specificity in order to predict human behaviour in information-based situations. Although such a detailed reduction did not work out, the patterns that criss-cross mental models can be quite useful even though they will not support predictive theory in this detail.

5. Controversies and connections

From time to time, exaggerated or extreme claims about the value or nature of mental models have inhibited a deeper examination of their role in information seeking. When examined as one significant component of sense-making, rather than as the sole foundation of system design, mental models can contribute to an understanding of user behaviour, and they are no more problematic in their application than is any other internalized human phenomenon.

One of the initial developments in understanding how people interact with systems derives from the comparison of *mental rules* – logic – with *mental models* – concepts that include the experience of the individual. The original work in cognitive psychology [30] and much of artificial intelligence (AI) research focused almost exclusively on the rules of logical reasoning. The affective and creative components of cognitive human interaction were cast as matters to be corrected or worked around. Although the study of MM originated in this work on mental rules, eventually it led to a more holistic approach, one that recognized the individual's whole perspective on a process or a system model. Rooted in George Boole's work, mental rules posit human reasoning as a series of 'if X, then Y' constructs. This, of course, puts the focus on form rather than content. Mental model theory, on the other hand, postulates reasoning that is based on content, and holds that people are capable of constructing understanding based both on events that they experience and on discourse. Rather than focusing on the syntax of mental rules, in mental model theory the basis of reasoning is semantic [31]. The use of mental models in developing consistency among a set of rational beliefs [32] is quite useful in those aspects of information seeking that depend more upon logic than intuition, but it should be noted that not all aspects of information seeking follow logic to the exclusion of emotion, preference and intuition.

Taking 'mental rules' theory to the next level, cognitivism posited that the human brain is, essentially, a computer, and that the mind is, essentially, a program that runs on that computer. Ironically,

cognitivism carries the 'rules' approach to an illogical extreme. Some early work in artificial intelligence proposed understanding mental models in order to develop computer systems that would replicate the models. This vastly oversimplified both the human mind and the human brain, and was a misuse of the mental model approach [33].

While cognitivism is more extreme than rule theory, mentalism pushes the imbalance between research and reality from the opposite perspective, that of the individual. Mentalism posits the individual's unique, internalized perspective as virtually the only factor worthy of analysis. As Frohmann [34] complains, mentalism over-emphasizes the individual's internal processes by studying them in such detail as to move beyond any expectation that they follow predictable, cognitive rules, putting them in such isolation that nothing but their own feelings influences them. Mentalism treats major external social and contextual elements as mere triggers on an individual's internalized world view, reducing the complexities of real life to a minor role with the individual's internal view as the critical, if not the only, factor [35]. Examinations of human cognition that attempt to simulate without genuinely duplicating human cognitive processes [36] lead to charges of 'mentalism.' In his commentary on the 'theoretical imperialism' of the mentalist perspective, Frohmann speaks of it as a stance which posits cognitive theory 'as a *total* theory for [library and information science], and as its *only* theory' [37].

As a way to balance these concerns, MM work is often explained in the context of Mikhail Bakhtin's activity theory, which posits that individuals construct their own internal knowledge through and as an inherent aspect of their physical, social, and subjective actions in daily life. 'Knowledge is thus both explicit in that it can be communicated through language and implicit, or tacit, in that it can be embedded within particular activities' [38]. The activity theory framework places information seeking in social and situational contexts, acknowledging the complexity of influences on mental model development without abandoning the notion that reason is a possible factor.

Although MMs are applied by the individual who has created them to specific situations, the nature of each MM varies. Because the MMs develop from what works in experience, models generally incorporate a good deal of what is true; however, because those who create these MMs seldom consciously examine them for flaws, they may not include note of what is false, leading the inexperienced into problems. The more models are required for a task, the greater the complexity of the work and, generally, the poorer the performance.

Those complex interconnections may be particularly critical in light of the impact of information technology on information seeking. Models of information seeking as a process are, in industrialized societies, inextricably intertwined with the technological tools of information dissemination and use, which can have a profound effect. Information communication technology can certainly privilege some groups over others with significant social and ethical consequences [39]. One well-known example is that differences in home computer ownership can actually increase the academic test score gaps across sex, income, and racial lines [40].

Finally, however, the primary difficulty in using mental model theory to support information system design lies in the mystery of the individual mind. The sense-making, grounded-theory approach of communication and information studies minimizes this difficulty through the use of interviews, observation, and think-aloud protocols [41]. These provide significant insight into both the sociological and the individual influences and constraints on MM development. Information studies scholars need to develop more structured MM analysis techniques so that those who design systems can more easily apply broad MM patterns to their system designs [42, 43].

A great deal of research on information-seeking behaviours has identified preferences, actions, tools, and other patterns of use within specific populations. MM theory has the potential to connect these pieces of the puzzle. A chance to better understand the 'why' in addition to the 'what' of user behaviour is certainly worth some effort. Sketchy MMs have long been used as a design guide or usability standard. Perhaps greater nuance is possible, which could improve design and raise the standards of performance.

6. Conceptual framework relationships

Mental model analysis bears a relationship to three primary conceptual frameworks of information studies: discourse analysis, domain analysis, and sense-making. Viewed from a socio-cognitive perspective, all three frameworks recognize, to some extent, the critical importance of cultural and social influences on the individual's cognitive processes in any given contextualized situation. Discourse analysis (see, for example, Foucault [44], Armstrong [45], and Potter [46]) approaches verbal and written communication as contextualized phenomena to be interpreted and analyzed, the purpose being to identify the underpinnings, implicit assumptions, and hidden agendas of the discourse. For example, Frohmann's examination of the information technology literature uses discourse analysis to identify social justice concerns in the application of communication technology [47]. Domain analysis (see, for example, Hjorland and Albrechtsen [48], Bates [49], and Palmer [50]) seeks the epistemological foundations of the differences and similarities across disciplinary domains in areas of information need, seeking, production, and use. For example, Andersen used domain analysis in his discovery of the relatively high levels of consensus among Danish social scientists regarding the more valued journals and scholars in their fields [51]. As already noted, sense-making (see, for example, Dervin and Foreman-Wernet [52]) is both a methodological technique and a conceptual approach to studying the phenomenon of individual construction and deconstruction of 'sense,' or meaning, through information interaction.

As Dervin urges information studies research to do [52], MM work employs an inter-disciplinary approach that weaves together elements of these three frameworks. The explanations, descriptions, and artifacts of MMs, once gathered, may be analyzed to identify the assumptions which underpin them – as in discourse analysis. In addition, these MMs of information seeking vary in relationship to the domain in which they are applied since the information environments force some modification of even the most stable model. It is sense-making, however, which most influences the application of MM analysis, for only this perspective provides a user-driven structure for the process of moving through a contextualized information encounter. The overall experience is so complex and recursive that the assumptions, domains, and problem-solving techniques combine to form a process, even when the experience remains incomplete or inconclusive for the user.

7. Application research: operationalizing MM principles

Rather than building a system matching the MM of a single individual, systems could be created to take maximum advantage of MM patterns which span a population or situation. Although the resulting systems would, undoubtedly, require iterative design corrections and developments, the original MM patterns should provide a valuable foundation. Research on the application of MM concepts has already accepted that principle in some design approaches. For example, incorporating MMs into usability testing [53] is suggested as essential to a user-driven design process, forming the basis of a software interface menu reorganization that was planned directly from models of users' goals, strategies, and problem-solving techniques. Patron expectations of web site components have been used as part of design criteria [54]. On a smaller scale, MMs are incorporated into screen design [55]. Several studies have examined the design implications of common and outlier problems [56] in a specific information retrieval context, such as library web-site use, OPAC searching, or search engine use [20]. Constructing information systems with MMs as a design base [57], but in full recognition of the limitations of MM work, prevents it from being viewed as design panacea [58, 59].

Several studies examine the impact of MMs on information interactions. Both situational goals and MMs determine searching patterns [60]. The level of MM completeness in relationship to bibliographic retrieval ability indicates a strong relationship between the two in terms of both success rate and error rate [61]. The relationship of MMs to information services certainly impacts both reference and user education work [62, 63]. MM application in a team situation is of increasing interest [65, 69], although it is very complex. Several studies examine the MMs of specific populations

in certain contexts, such as academicians' use of the internet [66], adolescents' use of the internet, [67], and MM development in children [68]. Much of this research indicates that MM may work well for simple situations but fail in more complex situations [69].

Mental models of information-seeking are definitely connected to learning. The development of both subject domain knowledge and MMs over a lifetime [70] must engage system designers. MMs of information technology [71] need to change continually, but training naïve users in OPAC use via a MM approach [72] has already been successful. MMs have been used as a context for comparative analyses; for example, high recall and high precision search outputs were equally useful to students who had participated in a MM visualization exercise [73].

The literature of information studies continues to reference the cognitive psychology, learning theory, and socio-cognitive approaches to mental models. High-impact publications in the field continue to publish research and theory which incorporate MM analyses. Within the framework of sense-making's 'attention to homogeneities and diversities, commonalities and differences, centres and peripheries, habits and caprice, the materially real and the hoped-for-dream' [52], this paper provides one additional exploratory study.

8. Research Study

8.1. Methodology

The research questions posed in this exploratory study were:

- What are the patterns of mental model components of the academic information seeking process held by graduate students in a reference course?
- What are the relationship patterns among those components?

Students in a graduate reference course served as the population for this study. Their personal and active acquaintance with academic information seeking provided a visceral connection with the information context they were to delineate. In addition, their work in this particular course repeatedly encouraged and even required them to recognize, identify, and verbalize their own expectations and knowledge of the information seeking process. From a self-reflective perspective, the use of MMs [74] by reference librarians influences their approach to working with information seekers. Therefore, their assignments, readings, in-class activities, and course discussions supported continuous development of their own internalized understanding of the information seeking system as well as the processes that individuals follow in moving through it.

A secondary facet of the study was the efficacy of the research approach itself. The difficulties inherent in eliciting mental models of any reasonably complex process are substantial. Using open-ended visual and narrative techniques, this approach sought to maximize individual self-expression of this highly internalized phenomenon. Based on a sense-making approach to understanding information-seeking, this method encouraged students to verbalize and visualize the six primary dimensions of the sense-making process: gaps (the needs), bridges (the procedures used to construct/deconstruct sense in order to move across the gaps), verbings (the acts of which the bridges consist), and outcomes (the help/hindrance) of a particular situation (in this case, the assigned paper) in a particular context (in this case, a graduate student at this university) [75].

In full recognition of the limitations inherent in a small qualitative study, these findings are presented on the basis of the following assumptions. First, while these students are heavily studied and atypical, their future professional activities require them to apply, teach, and make heavy use of the mental models of information seekers. The models held by reference librarians influence their interactions with users, the feedback they provide to database vendors, and their own search patterns as they seek information on behalf of users. Therefore, there is inherent value in

understanding their models even if those models are not typical of the academic population as a whole. Second, since this is a qualitative study, the findings are not intended to be generalized but rather to be used to explore a relatively unknown phenomenon. Too little is known of the actual mechanisms by which MMs are used in sense-making to support the hypothesis testing of an empiricist's approach to the phenomenon. Qualitative research's well-established techniques for insuring trustworthy data gathering and analysis have been fully employed in this study, as explained below.

8.2. Data gathering

The population for this exploratory study consisted of the 34 students in an elective, graduate, reference course. Their demographic characteristics were as follows: primarily female (6 males); aged 22–61 but primarily in their 20s (23 to under 30); most undergraduate majors were in the social sciences or humanities; four with additional Masters degrees; 19 with some library experience; 10 had completed the required course on user needs and four were concurrently enrolled in it; 12 had completed one of the courses in information organization and 11 were concurrently enrolled in one. Those demographics do not, of course, provide a template for extrapolating this study's findings to any other context or population; they are provided solely as background information.

As further context for understanding the data, students were asked for their self-perceptions of their own skill levels in certain information technology areas. These were *not* solicited as an accurate means of determining actual skill levels but rather as a means of gauging each student's sense of self-efficacy as it pertained to several common information technology tools. Word processing, email, and Google searching were the areas in which they felt most competent. Personal bibliographic control software (e.g. EndNote) use and web site management were the areas in which they felt least competent. In addition, students were asked to identify personal information technology tools which they considered to be a routine part of their lives; wireless laptops and wired desktops (16 each), cell phones (15), and digital cameras (11) were most commonly listed.

As part of an in-class, required exercise at the beginning of the semester, students documented their mental models of the information-seeking process a graduate student would be likely to experience in preparing a course research paper. Since documenting a deeply internalized and personal phenomenon such as a mental model is so difficult, the first step in the documentation process consisted of an analogous modelling experience using a culturally common experience, namely grocery shopping. Working in small groups then sharing results in full-class discussions, everyone participated in diagramming and verbalizing the process by which an individual enters and navigates a typical suburban grocery store. Students noted the steps involved (e.g. select items, pay), the sequence of those steps (e.g. select frozen items last), the options available (e.g. ask for free samples at the cheese counter but not the pharmacy), the support available (e.g. ask for help from those with nametags or aprons), and the social norms (e.g. blocking aisles is considered rude). From the perspective of an immigrant who is unfamiliar with American suburban grocery stores, students sought to identify and explain the process involved in shopping so carefully that the hypothetical immigrant would not be disconcerted or frustrated at any point.

Students were then asked to use that same narrative and visual documentation technique to express their own understanding of the academic information-seeking process that a graduate student would be likely to experience in preparing a course paper. Students took 45–55 minutes to create elaborate diagrams and write lengthy descriptions of the models they held of the process. These documents were attached to their background information sheets and handed in anonymously. As was made explicitly clear to them, no means existed by which any individual's work could be identified.

At the mid-point and at the completion of the course, they took 30–45 minutes in class to augment and/or alter their original explanations to include any changes or enhancements that they had developed over the intervening weeks. Each of these revision sessions was followed by discussions of the changes in their models and the models were referred to frequently in class as students strove to become aware of their own expectations of information-seeking in relationship to the potentially

different expectations that might be held by the users they would encounter in the course of their professional experiences.

8.3. Data analysis

Data analysis on the narratives and diagrams concentrated on identifying components of the information system and strategies for moving through that system. Using the constant comparison method of narrative data analysis, a directional set of hierarchical coding terms developed directly from the texts and was applied consistently. The full text of the narratives was transcribed and entered into individual files along with the background information on each student. Emergent coding of the narrative files as supplemented by the diagrams yielded 259 codes, including the background information codes, which are analysed in the following section. HyperResearch 2.6 software was used to track and organize application of the codes to insure that they were applied consistently and accurately. Using the standard means of establishing trustworthy data analysis, the study included several notes on specific points of analysis and an audit trail of the entire procedure [76]. Surpassing the minimal 90% code-recode rate, this data analysis achieved a code–recode rate of 92% on the recoding of four randomly chosen files [77, 78].

This single pool of data analysed from a naturalistic perspective is, of course, unsuitable for generalizations or extrapolations; nevertheless, the analysis identified significant elements of the mental models of some of these students. Understanding those elements may contribute to discussions of mental models of information seeking.

8.4. Findings

The research questions posed in this exploratory study were:

- What are the patterns of mental model components of the academic information seeking process held by graduate students in a reference course?
- What are the patterns of relationships among those components?

8.4.1. Components of the mental models: the user, the internet, the library, and people. Patterns of the primary components of the process were consistent across all models and included the user, the internet, the library, and people. Variations on the details of those patterns related to judgments about the user's abilities, the internet's complexity, the library's structure, and the people's social roles.

The user was generally envisioned as active, decisive, and in control of the entire process yet shackled at times by internalized biases, assumptions, and knowledge limitations. Responsible for 'rising above' [79] those limitations, the user was sometimes envisioned as the literal centre of the information world, with access to digital information on a constant basis. A few students focused on what one person called the information-seeker's 'opportunity to learn, to become an expert in some new realm [80].'

The internet was viewed as a separate entity. Almost a physical place, like a library building, the internet existed apart from other information resources. Occasionally described as a 'quick and easy' first-step in the process of finding academic information, the internet was rarely seen as a channel for getting to a wide range of information resources. Most often it was seen as an end in itself and that end consisted almost entirely of web sites. Set in opposition to the library, the internet was sometimes identified as related to the library and even used by the library. Several students indicated an expectation that the quality and nature of 'authoritative' web-based information required careful review, echoing Dervin's recent postulates that the 'information environment is increasingly marked by decreasing trust in expert and institutional sources' and that 'lay people are increasingly wise about how information is tied to vested interests' [81].

The library was a disconnected entity. Viewed as a physical space for storage of last-resort print materials, the library's primary role was, as might be expected for this population, to provide a home for the reference librarian who served as a guide, facilitator, or even partner in the search process. The user chose when to interact with the librarian and determined the nature of that interaction, be it instructional or supportive, affective or cognitive. Again, as might be expected with this population, that interaction was generally seen as either essential to an efficient search, supportive for a complex search, or useful only to those users who lack the independence to master the information system for themselves. By the second round of explaining their models, however, most students incorporated firm ties between the library and the internet.

Finally, people were envisioned as sources to be consulted at problem points or for advice on complex matters. Family, friends, and classmates were seen as useful at any point in the process while faculty and subject experts were consulted at the beginning of the process in hope of better understanding the academic parameters of the research or identifying major authors/works in the field. Librarians were of potential use throughout the process.

8.4.2. Relationships between the mental model components. The relationships between these components and their subcomponents are complex and rich. Sixty-nine separate strategies were described by these 34 students as means of utilizing these components in the information seeking process. The library's online catalogue, for example, was viewed as a pathway to journal databases which were to be searched by keywords drawn directly from the topic statement of the research assignment.

The process of seeking academic information was, for most students, envisioned as a matter of deliberate focusing. As one student noted, the process 'essentially asks a person to move from a relatively out-of-control position to one that's more stable, more concrete.' Although many techniques were noted as being of limited value in this search for focus, the advice was that as 'long as something works, keep using it.' Those who expected the user to take some level of personal responsibility for learning more about why some strategies were more effective than others would generally posit the librarian as the support for that instructional segment of the process. Focus, even when successful, demanded flexibility from the user about keywords, resources, relevance criteria, physical format, and even the topic itself. Each of the components required a fluid approach, particularly use of the internet.

Most students viewed the process as inherently reiterative. Keywords would be used repeatedly in databases and search engines; topics would be re-examined after reading encyclopaedias and journal articles. As might be expected from students familiar with user needs literature, the role of the individual in developing meaning from the actual process of filling information gaps was described as a common trigger for reiterative searches on any topic, even one which had been laboriously narrowed. The inevitable need for variations in framing the research question as posed on the internet (in search engines and on web sites), in libraries (in databases and catalogs), and to other people (librarians, experts, friends, and faculty) was often viewed as the primary disconnect between the components.

Some sub-sections of these components were mentioned with almost deliberate ambiguity. Bibliographic databases of scholarly journal articles, for example, were commonly recognized as a key component of the academic information system but they were often envisioned as part of the internet and related to the library only in terms of problems (e.g. they require an ID, library collections fail to hold full-text on all the citations). Google, which almost all students felt competent to search, was consistently mentioned as part of the process but primarily as a means of intellectual orientation to the basic nature of the research topic rather than as a viable source of meaningful information. Physical formats were seen as a reasonable relevance criterion (e.g. print was 'inconvenient' and digital could be 'misleading') but also as essentially irrelevant in the sense that such formats blur and overlap. As one student put it, the 'highways' represented by these formats are 'crisscrossing each other in a chaotic fashion.' Keyword searching, mentioned by almost everyone as a primary strategy, was seen as a scattershot method of getting a toehold on the internet, as well as a means of deliberately mining rich veins of material in limited databases.

Table 1
Mental model patterns: component analysis

	Decision tree	Network	Storm
User	User is the primary determinant of each choice and action; in charge	User struggles to simply function; makes expedient choices	User stands firmly rooted in an internalized view of the information. need; makes clean choices and learns about the self
Internet	Internet is a vast but poorly structured source of both sound and suspect information	Internet is a chaotic and ever changing realm of exciting, useful, and occasionally poor information	Internet is a maelstrom of rapidly morphing information that is often useless but occasionally priceless
Library	Library is a finite but highly structured source of excellent information which requires some critical thinking to use	Library is an oasis of relative consistency and quality that requires some patience and persistence	Library is a carefully collected array of widely divergent perspectives to be used readily but without undue deference
People	People are rarely needed but can be of great use for quite finite pieces of advice and information	People can serve as real partners through phases of the search process; can be guides and gatekeepers	People are potentially fascinating and substantive sources of really useful and novel information; sharing and learning are valued

8.4.3. Three overarching patterns. Finally, one of the most fascinating findings was the fact that every single model fell into one of three clear patterns: a decision tree, a network, or a storm. These three overarching patterns were clearly seen in both the diagrams and the narratives. While other patterns may certainly emerge from studying additional groups of graduate reference students, much less other populations, the consistency of these patterns in this class is certainly worth consideration.

Those who drew/described *decision trees* developed an approach based on linear reasoning. In these models, the process had a beginning, a middle, and an end, with progress determined by sets of choices. The choices pertained to such matters as relevance criteria, tool selection, search string creation, and sufficiency determinations. The entire process was task driven with little connection to other aspects of the user's experience.

In the *network* model the process was seen as more haphazard, less controlled, and more problematic. A complex network of information repositories was described/drawn and the user moved among them. Looking rather like a schematic for a badly designed lighting plan, these models highlighted the chaos of information seeking by noting the variations, lack of standards, and lack of meaningful connections among the many producers and distributors of information. The user, however deliberate, experienced, knowledgeable, or focused, moves within the network rather like a pinball being bounced from point to point, since some of the results of searching are viewed as almost random.

Finally, a few people created a kind of gentle *storm.* In these models, the user stands firmly at the center of the experience, rooted in internalized choices and values about the information need. The process of finding information is quite powerful but not at all linear. Information structures and resources exist in their own 'storm' of constant motion and change. The user is seen as one who steps into the storm and, as useful items whirl by, deliberately plucks out the useful elements or makes use of the most appropriate resource. The storm is gentle in the sense that this process of pulling out the best is invigorating and productive. It certainly recalls Bate's classic berry-picking model [82], although these users are recognizing the potentially useful in an incoherent flood of options rather than deliberately choosing the best from a stable array of finite options. The storm

Table 2
Mental model patterns: component relationship analysis

	Decision tree	Network	Storm
User	User controls the interactions with the other components	User tries to control or correct for impact of all components	User stands apart from all the components; takes from them what is useful/interesting
Internet	Internet is a separate array of information to be searched; includes access to some library materials and tools	Internet is a large part of academic information landscape with unexpected links to libraries and people	Internet is a whirling torrent of information that must include libraries and people as well as links to their artifacts/shells
Library	Library makes minimal use of internet as a channel and is tied to a few librarians but not to other people	Library makes significant use of the internet and some use of people is a viable by-product of good library use; get ideas, experts, and terms to be used in reiterative searching	Library blurs with the internet but also stands apart as an astounding collection of print materials with many ties to subject experts, librarians, and faculty
People	People are seen primarily as librarians (connected to libraries) and faculty (connected to the internet) but few other contacts are productive; people provide terms and tips, not general information	People are seen primarily as the librarians, faculty, subject experts, and authors connected via the internet; the sources for more than terms; family and friends provide advice in general terms	People are seen as having a vast array of differing levels of expertise beyond subject areas; insights and ideas are available via the people who can be reached via the library and the internet

approach fits Dervin's postulate that what might appear to be 'chaotic behavior is in fact patterned information seeking and use' [83].

In Table 1, these three patterns are analysed in terms of the four primary mental model components: users, the internet, the library, and people. In each of the patterns, the four components are viewed differently.

These variations reflect differing expectations of the qualities and uses of the internet, libraries, people, and the users who interact with them in information seeking. As Table 2 indicates, not only did the components vary across the three models, but so too did the relationships between the components.

These expectations of the connections between the primary components influence choices on two levels. First, they differentiate between potentially useful and useless search strategies and tools. Google, for instance, is commonly identified as potentially useful even when the information it retrieves is viewed as suspect. Second, they underpin the 'intuitive' paths that individuals follow when they move from one resource to another. Since some components are expected to be linked, people search for the links they expect to find, perhaps overlooking others which could be equally, or possibly more, useful.

9. Implications

So what might be done to improve information seeking for these students based on these patterns among their models? At least three concrete possibilities are worth considering. First, the four part pattern for process components could be acknowledged and incorporated into a library's web site. Providing choices among the four types of information resources as a regular component at various levels of the web site could lead them to faculty, experts, subject-specific web portals, databases,

chat reference, and so on. By using what they recognize in a structure that they find comfortable, such a design could enhance their sense of self-efficacy.

Second, an option to follow the decision-tree, the network, or the storm approach might encourage individuals to recognize and use their own affective preferences for interaction. Rather than offering a single tool-based approach to navigation, this option could peel out people in various paths. For example, those who want to track their progress down a decision tree could have a visual representation of their progress kept current for them with records of their searches, lists of productive keywords, and suggestions for additional resources generated by the system and/or suggested by a reference librarian. The network users could have a more navigational approach offered to them, a kind of roadmap service in which the system, with or without librarians, suggests likely pieces of the network. Finally, the storm users could be given a shopping basket in which to keep their finds, a basket with compartments for the resources, keywords, and ideas garnered from the experience.

The third opportunity is more subtle but might be helpful across the board. All of these models contained some element of inaccuracy or inconsistency. Throughout the library web site, critical thinking support structures could be embedded in the language, options, and juxtaposition of those options to reinforce accuracy in mental models. Rather than deliberately blurring the information world into a single one-box Google-style search image, a careful effort could be made to strengthen mental models of this complex process. For example, a recent study identified a sequence of steps that information-seekers move through in their interaction with service providers [86]; support for the steps in that interaction could include prompts and suggestions.

This study identified some components of the information seeking process as well as strategies for utilizing those components within one very limited and tiny population. Even these exceptionally self-aware, well-educated, and personally motivated students had some difficulty in verbalizing and/or visualizing their own mental models of one particular information seeking situation. The method of eliciting the models did produce a substantial amount of detail, but still requires refinement.

Information system and service design efforts often function on the small-scale, tactical level. However, moving from the tactical to the strategic is essential for any significant increase in searching efficacy. In general, 'interface aids lose their significance because the limiting factor in the task becomes strategic. What can be done to solve this essential and critical problem? Again, the key is the user's "mental model" of the information retrieval process' [84]. A socio-cognitive approach to mental models can help delineate the user's perspective on sense-making strategies.

Customization support requires systems that prompt users to recognize their own approaches to information interaction. 'Applied wisdom suggests that designers should aim to give people control over powerful tools in a symbiotic manner to optimize human abilities to think, create, and reflect, and computer capabilities to store, display, and retrieve' [85]. If Baguley and Payne are correct in their conclusion that episodic memory helps people recall the process of constructing a MM while long-term memory retains the spatial and temporal aspects of the situation [86], then deliberate structural supports for increasing the efficacy/complexity/accuracy of models [87] over the lifetime of the user could be built into information systems that recognize actual, real-world users.

A great deal of research is needed on the differences in how MMs are formed. One study indicates that people with strong memories and awareness of social environments focus on the contextual implications of particular situations as they form mental models. Social environment cues pertaining to interpersonal relationships combine with strong memory skills in mental model formations. Subjects with poor memories were not generally able to form mental models, relying instead on a dogged effort to memorize details [88]. Does this hold true for MMs of information seeking? What other factors or characteristics might be involved?

This initial, exploratory study suggests that further development of a contextualized approach to both narrative and visual elicitation of mental models would prove to be helpful for system designers. The 'reality' of their mental models certainly directs user behaviour. Understanding that reality, even to a limited extent, may enhance our understanding of the broad patterns of human behaviour which are a critical component of information system design. As designers have long acknowledged, the 'user's mental model of the system is so integral to the system's use that it should be a

starting point for design' [89]. This study provides one more perspective for understanding that complex starting point.

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