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# An empirical study of web site navigation structures' impacts on web site usability

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**Abstract**

Web sites are intended to facilitate knowledge acquisition, often in the interest of supporting decision making. Based on a taxonomy of factors influencing Web site usability, hypotheses are developed about usability of alternative navigation structures. These hypotheses are tested via experiments that measure user performance in accomplishing knowledge acquisition tasks and user perceptions of usability. Two rounds of experimentation are performed for both simple and relatively complex task sets. Results show that a usage-oriented hierarchy or a combined hierarchy is a navigation structure associated with significantly higher usability than subject-oriented hierarchies, for both simple and relatively complex knowledge acquisition tasks.


*Keywords:* Experiment; Knowledge acquisition; Navigation structure; Web site design; Web site usability

## 1. Introduction

A primary function of Web sites is to serve as a means for both the providers and the users of those sites to acquire knowledge [12]. Organizations recognize the importance of the Web as a conduit for acquiring knowledge about customers, competitors, and partners. They provide Web sites that aim to facilitate Web users' acquisition of knowledge about their organizations' activities, archives, products, and services. Thus, it is important for the provider of a Web site to ensure that it is developed in a way that provides a high degree of usability to those who seek to acquire knowledge through it.

Web sites are not always as successful or as usable as they could be. Web site users can encounter various problems when trying to acquire knowledge from a Web site and trying to use a Web site's functionalities. This leads to dissatisfaction with Web sites and blockage in knowledge acquisition (KA). Although one can find many tips for Web site design [45,31,35], the research literature holds little in the way of well-substantiated prescriptions for designing Web sites, such as what navigation structures are appropriate for facilitating KA in various circumstances. Thus, there is a need for research that explores Web-based KA in the sense of how to allow it to be accomplished with great usability.

Designing a Web site that is highly usable for acquiring knowledge is not a trivial undertaking. Five classes of features have been identified as joint contributors to Web site usability: task features, user features, provider features, system features, and environment features [12],

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which are further explained later in Section 2.2. Of these, system features are the most controllable. For a given provider aiming to facilitate the KA activities of certain kinds of users engaged in certain kinds of tasks and operating within a given environment, what system features can be designed into a Web site to enhance its KA usability? The research described here facilitates to answer this question with respect to alternative navigation structures that can be designed into a Web site. It considers usability of this system feature from the objective standpoint of user performance, as well as the standpoint of users' subjective perceptions.

A large-scale survey conducted by Georgia Tech's Graphics Visibility Usability (GVU) Center has found that the top three uses of the Web are information gathering, searching, and browsing. All three are aspects of the knowledge acquisition function [20]. The survey [19] found that one of the main problems cited in using Web sites is that they are regarded as confusing and disorganized by their users. One contributor to such a problem may be a navigation structure that makes it awkward or difficult to traverse a Web site's pages when seeking knowledge.

In the next section, we examine related research that furnishes a background for appreciating the current investigation. Section 3 presents the research model and hypotheses about the impact of navigation structures on Web site usability. Section 4 describes the experimental platform and construction of the three Web sites that it uses. In Section 5, we describe execution of the experiment for data collection. Section 6 presents the results, and Section 7 discusses implications of the findings.

## 2. Background

### 2.1. Prior navigation structure research

There have been a few studies [29,24,25,7,27,37,31] of navigation structures for hypertext systems. However, as the summary in Table 1 indicates, no consensus has been reached about how to design such structures. The studies have been performed with fairly small hypertext systems for which the extent and the structure of the hypertext have been known to assessors. It is unclear whether results of these hypertext studies directly apply to the Web for several reasons, such as changing Web boundaries and lack of common organizing principles applied to Web sites, as indicated by Smith [49]. Moreover, unlike traditional hypertext systems, a Web site can involve multimedia and be distributed across the Internet.

### 2.2. Web site usability

Researchers and practitioners [e.g. 31,38,1] have employed the construct of usability to describe the usefulness of Web sites, hypertext and hypermedia

Table 1
Prior navigation structure research

| Navigation research publication | Research highlights |
|---|---|
| [38] | Indicates that a Web site can have a navigation structure that is linear, grid, hierarchic, mixed hierarchy, or pure hierarchy.<br>Advises that expressiveness and predictability should be considered in picking a navigation structure. |
| [32] | Asserts that structure should reflect the users' views of the site and its information and services.<br>Recommends that structure should also be determined by the tasks that users want to perform on Web site. |
| [27] | Empirically studied hierarchical, networked, and mixed structures hypertext systems, measuring mean time to answer questions and mean number of additional nodes accessed per question.<br>Using subjects who are knowledgeable about the subject matter covered in the system, it was found those navigating the mixed structure performed best. |
| [29] | Empirically studied hierarchical, networked, and mixed structures hypertext systems, examining their question-answering performance.<br>Using beginners in the subject matter, it was concluded that a mixed structure does not benefit beginners' performance. |
| [24] | Argues that navigation problems are not a function solely of navigation structure, task type, or individual characteristics.<br>Asserts that these three must be considered in unison. |
| [25] | Indicates that users' domain knowledge comes into play when navigating a hypertext document<br>Classifies users as knowledge seekers, feature explorers, and apathetic hypertext consumers |
| [7] | Studied students' search task performance in a hypertext system, using navigation maps and individuals' cognitive styles as independent variables.<br>Found that a navigation map had a significant main effect on search efficiency, but cognitive style did not.<br>Neither cognitive style nor navigation map had a significant main effect on search task completion. |

systems, and general information systems. Shackle [47] describes usability as "a technology's capability to be used easily and effectively by the specified range of users, given specified training and user support, to fulfill the specified range of tasks, within the specified range of environmental scenarios". There is an extensive set of usability evaluation methods that can be used, with a variety of performance measures [e.g. 2,3,16,53,30]. In this research, we gauge usability in terms of how well subjects perform a series of KA tasks with a particular navigation structure; this performance is measured by navigation speed and task correctness. We also gauge usability by directly asking subjects to reflect on and rate how usable the navigation structure with which they worked was for performing the series of KA tasks.

An important topic for providers, users, and researchers of Web sites is to better understand what factors can affect usability and in what ways. Although this study focuses on the factor of navigation structure under conditions of simple and relatively complex KA tasks, it is useful to place it in the larger context of a taxonomy of features that can impact Web site usability. This five-fold taxonomy is based on a synthesis of considerations found in the literature: task features, user features, provider features, system features, and environment features [12].

### 2.2.1. Task features

A major rationale for the existence of Web sites is to allow for and facilitate KA tasks [13]. Such tasks involve the sub-activities of identifying a source for the knowledge to be acquired, capturing the identified knowledge, possibly organizing the captured knowledge for assimilation, and transferring the organized knowledge to processors or repositories that need it [20]. In the case of KA from a Web site, two prominent approaches are search (e.g., via keywords) and navigation (e.g., via links).

Table 2
KA task features that may influence usability

| Class | Feature | Examples |
|---|---|---|
| Domain | Subject | Operations management, physics |
| | Level | Introductory, advanced |
| | Scope | Wide, narrow |
| Magnitude | Complexity | Simple, complex |
| | Volume | 50 characters, 1 MB |
| | Duration | s, min, h |
| Constraints | Time | Limits |
| | Accuracy | Degree of confidence, completeness |
| Qualities | Novelty | One-shot, routine, repetitive |
| | Openness | Exploratory, goal seeking |
| | Mode | Numeric, textual, graphical |

Table 3
User features that may influence usability

| Class | Feature | Examples |
|---|---|---|
| Individual | Rationale | Decision support, hobby |
| | Personality/aptitude | Analytical, intuitive |
| | Knowledge/experience | Novice, expert |
| | Physical characteristics | Age, unimpaired, male |
| | Economic condition | Income segment |
| | Affiliation | Employee, consumer |
| | Language fluency | English, Chinese |
| | Familiarity | Repeat user, new user |
| Role | Economic condition | Budget size |
| Connection | Job category | Manager, engineer |
| | Task requirements | Planning, negotiating |
| | Training requirements | Degree certificate |
| | Other systems employed | Legacy, spreadsheet |
| | Network | ISP, intranet |
| | Hardware | Capacity, speed |
| | Software | OS, browser |

Aspects of a KA task that may affect the usability of a Web site include the task domain, task magnitude, task constraints, and task qualities. Table 2 shows specific features for each of these four kinds of task influences.

### 2.2.2. User features

Every user has his or her individual characteristics, role characteristics, and Web connection characteristics [36,31]. Table 3 shows specific features and examples for each.

### 2.2.3. Provider features

Provider features can be grouped into those at the enterprise level and those at a project level [36,31]. Each experimental Web site used in this study had the same provider, so such features did not vary.

### 2.2.4. System features

A Web site is a system of interrelated components working together to identify, capture, organize, and transfer knowledge between recipients and providers. System features can be understood in terms of such dimensions as interface [18], functionality, content [3], physical location, coordination, control, customization, and responsiveness [46,41,36]. Table 4 shows specific features and examples for each of these. Such features can impact Web site usability.

### 2.2.5. Environment features

Web site usage is exposed to various environmental constraints and social circumstances [31,52]. Environmental and social features such as laws, regulations, ethics, culture, immediate conditions (e.g., office setting

Table 4
System features that may influence usability

| Class | Features | Examples |
|---|---|---|
| Interface | Request | Form-oriented |
| | Presentations | Textual, tabular |
| Functionality | Surface | Following links |
| | Deep | Selection, generation |
| Content | Utility | Clarity, relevance, importance |
| | Validity | Confidence, consistency |
| | Scope | Broad, specialized |
| | Currency | Up-to-date, archival |
| | Navigation structure syntax | Hierarchy, network, linear |
| | Navigation structure semantics | Subject-oriented, usage-oriented |
| Coordination | Mechanisms | Market, file, task decomposition |
| | Drivers | User, system |
| Physical | Events processing location | Local, remote |
| | Host characteristics | Capacity, speed |
| Control | Requirement | Subscription |
| | Duration | Limit on duration of access |
| | Scope | Entire site, partial |
| | Openness | Security, privacy |
| Customization | Scope | Individual, group |
| | Approach | Manual, automatic |
| | Duration | Temporary, persistent |
| | Orientation | Interface, constant |

vs. mobile, noisy vs. quiet), education systems, politics, and economic conditions can influence usability.

## 3. Research model and hypotheses

Each of the features in the usability taxonomy is a candidate for operationalization as an independent variable in research examining influences on the dependent variable — Web site usability. As the research model in Fig. 1 shows, navigation structure and task complexity are independent variables in the present study. Other variables identified by the taxonomy are control variables (e.g., culture). The experiment designed to examine this research model is concerned with KA in the domain of production and operations management (POM).

Web site navigation can include multiple dimensions [33]. Navigation structure can be characterized in terms of two aspects: semantics and syntax. Semantics denotes the meaning of the language used in a navigation structure to organize or classify Web objects that refer to something perceptible by one or more of the senses in a Web site (e.g., text sentences, a static graphic, multimedia presentation). One common semantic approach is to organize based on subject matter covered by the Web objects (i.e., the site's leaf nodes). Another is to organize based on usage of Web objects (i.e., how the objects can be used). Syntax refers to a configuration of links provided to allow navigation to Web objects. This view of syntactic and semantic issues is built on Satzinger and Olfman's study [44] and the user interface model [15].

A navigation structure determines the possible sequences for accessing pages, imposes an organized layout on the site's Web objects, and furnishes consistency of navigation protocol. Navigation structure is an important design element, with the objective of allowing users to acquire more of the information they seek and making the information easier to find [26]. A crucial challenge in building a usable Web site is to create good links and navigation mechanisms [40]. Web site success is significantly associated with navigation characteristics (organization, arrangement, layout, and sequencing) [35].

Hierarchical and networked navigation structures tend to be the most widely-used navigation structures in Web site design [37,38,31]. Shneiderman [46] indicates that the main way to handle large and complex problems is to decompose them into several smaller problems in a hierarchical manner until each sub-problem is manageable. However, networks can allow greater traversal flexibility, providing multiple ways to reach the same Web object. Whether this greater flexibility (and

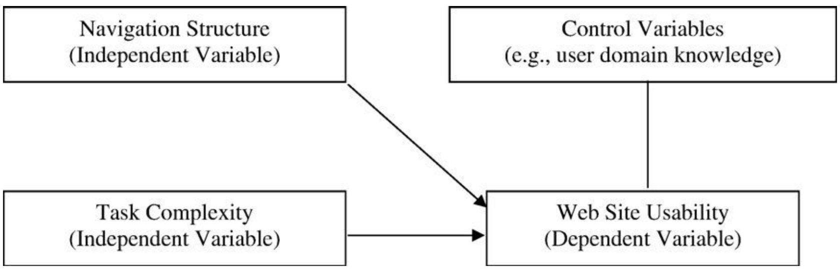


Fig. 1. Research model.

accompanying intricacy) makes for greater usability is an open issue, which may well be situation-dependent relative to variations in other variables in the taxonomy.

Mental schema theories offer theoretical rationale for predicting how or why certain navigation structures will yield better performance for a given set of tasks with a given level of complexity. There are two main types of mental models: structural and functional. A structural model assumes that a user has internalized (in memory) the structure of how the device or system works. A functional model presumes that users have internalized procedural knowledge about how to use the device or system. A simple distinction is to consider structural models in terms of "how-it-works" and functional models in terms of "how-to-use-it" [39].

When users deal with a subject-oriented hierarchic navigation structure to acquire knowledge from a Web site, they may be induced to adopt a structural model. A subject-oriented hierarchic navigation structure arranges a site's Web objects in terms of a subject matter classification for the discipline of interest, much like the table of contents in an ordinary textbook. Consequently, a subject-oriented navigation structure may tend to facilitate the formation of a structural mental model about Web objects.

When users employ a usage-oriented hierarchic navigation structure to acquire knowledge from a Web site, they may be induced to exploit a functional mental model. A usage-oriented hierarchic navigation structure organizes access to a site's Web objects according to their usages in a domain of interest, telling users how the Web objects are used in the domain. For example, one Web object may function as a concept definition, while another Web object functions as a recommended rule in operational practice (from a subject-oriented perspective, these two objects may or may not belong to the same subject class). Hence, a usage-oriented hierarchic navigation structure may tend to foster the development of a functional mental model about Web objects.

Constructing a structural model in one's mind often requires a great deal of effort, both in learning the model and in using it to work out what to do. As Miyake [28] points out, trying to infer a structural model is extremely difficult, if not impossible, for even the simplest of devices. In the context of this study, understanding a subject-oriented hierarchic navigation structure is, perhaps to some extent, like fathoming a structural model of the POM domain. If so, then doing KA tasks via this navigation structure can be expected to take more time and yield more errors.

On the other hand, users may access the existing knowledge of another domain to develop a functional model regarding how to use the components in a system. In this study, perhaps using a usage-oriented hierarchy navigation structure is akin to developing a functional model. Users might find similarities between the usages of the Web objects in the POM domain and usages of the Web objects in other domains, such as accounting. For example, Web objects in the accounting domain might be classified in the same ways as the Web objects in the POM domain would be, in terms of usage semantics (e.g., concepts, applications, practices). So, using such a navigation structure might be expected to benefit from a functional model that is analogous across domains.

Schema theory [42] can be used to explain the mental-model development process when a user learns and uses a navigation structure. In schema theory, learning is thought to involve either adding additional facts to existing schemata (accretion), making minor changes to existing schemata to account for a more sophisticated view of the world (tuning), making major structural changes to schemata based on new information (restructuring), or creating entirely new schemata when existing schemata do not align with observed phenomena [43]. Accretion and tuning are more common and less effort-consuming kinds of learning processes; restructuring and schema creation need considerable effort [42].

Learning and using a usage-oriented navigation structure appears to involve primarily accretion and tuning of existing schemata, because of the similarities between the usage-oriented semantics in this study and those in other domains with which users might already be experienced. Learning and using a subject-oriented navigation structure may require schema induction or restructuring, due to dissimilarities between subject-oriented semantics in this study and those in other domains with which users are more experienced.

Because schemata are activated based on sensory input, the visual appearance of navigation structure (presentation language based on specific semantics) might affect which schemata are activated when learning or using a navigation structure. Users depend on visual similarities when differentiating between known and unknown systems [51]. If a navigation structure appears similar to the ones previously used, activation and then accretion and tuning of existing schemata might be aided. On the other hand, if the new navigation structure looks different from the ones previously used, the number of inferences made about the navigation structure based on existing knowledge might be reduced and learning by accretion and tuning could be inhibited. Relative to a subject-oriented navigation structure, a usage-oriented navigation structure is more independent of domain and subject matter, and therefore easier to associate across Web sites having different knowledge domains. However, semantics of a subject-oriented navigation structure are more customized to a Web site's knowledge domain, suggesting that it likely looks less familiar unless a user is already familiar with the subject domain.

Another design alternative is to provide an interface with both subject-oriented and usage-oriented navigation hierarchies. This combined (i.e., mixed) hierarchy allows users to navigate in whichever way they prefer for each specific task faced. However, one way of facilitating learning is to make sure that users have no more options than necessary for acquiring knowledge. This notion forms the basis of a minimalist approach [5]. Compared to a usage-oriented hierarchy or a subject-hierarchy, a combined hierarchy presents more options in terms of both semantics and syntax. Therefore, it is relatively complex and requires more effort to learn.

Users of a Web site perform KA tasks that range in complexity from the simple to the relatively complex. For alternative navigation structures, a user's KA performance may vary differently as task complexity increases. According to Wood's task complexity model [54] and the notions of system complexity [48,23], task complexity is a function of the number of individual parts, the relationships among the parts, and changes in parts and their corresponding relationships. For purposes of this study, the "parts" are nodes in a navigation structure and their "relationships" are composed of the site's linkage pattern. Existing literature appears to have little theoretic discussion on the relationship between navigation structure and task complexity, and consequent effects that complexity level may have on site usability for each kind of navigation structure. Nevertheless, it is clear that navigation needed to complete a KA task can be simple or relatively complex. For instance, a simple KA task may entail visiting a single Web object that holds all of the knowledge needed for task completion. A relatively complex task could require access to multiple Web objects via their relationships and synthesis of knowledge acquired from each in order to accomplish the task. For a given navigation structure, we should expect that users tend to spend more time and generate more errors in doing complex tasks versus simple tasks, assuming other factors in the taxonomy are held constant.

Which syntax and/or semantics are "best" for Web site development? Which yields greater Web site usability? Three navigation structures are investigated in our study: usage-oriented hierarchy, subject-oriented hierarchy, and combined hierarchy. The latter presents a user with both of the former, yielding a tabular (i.e., network) structure whose two dimensions involve subject and usage semantics.

Table 5
Experimental cells across navigation structures and task complexity levels

| Task type | Usage-oriented hierarchy | Subject-oriented hierarchy | Combined hierarchy |
|---|---|---|---|
| Simple task | 1 | 2 | 3 |
| Complex task | 4 | 5 | 6 |

In the context of the research model, the following two basic directional hypotheses are advanced. G1: Web site navigation structure affects Web site usability; G2: Task complexity affects Web site usability. More detailed instances of these hypotheses can be investigated. Because usability has multiple aspects, more detailed hypotheses are: Web site navigation structure affects Web site performance usability; task complexity affects Web site performance usability; Web site navigation structure affects Web site usability perceptions; task complexity affects Web site usability perceptions. Measures of usability performance and perception appear in Section 5.2.

We use a three-by-two factorial design, crossing the type of task (simple or complex) with the type of navigation structure (usage-oriented hierarchy, subject-oriented hierarchy, combined hierarchy). Subjects were randomly assigned to one of the six experimental cells shown in Table 5 (e.g., simple task-subject-oriented hierarchy, simple task-usage-oriented hierarchy, and so forth). To collect data for these cells and study hypotheses G1 and G2, an experimental platform was constructed, plus three Web sites and two task sets.

## 4. Constructing the experimental platform, web sites, and task sets

The experimental platform is devised to administer experimental sessions in which a user interacts with a Web site in order to acquire knowledge needed to perform online tasks. The platform presents a task, records a user's behavior in using a Web site to help accomplish the task, records the task outcome that the user produces, and then repeats this cycle with successive tasks. In the present study, the experimental platform is equipped with three distinct Web sites presenting knowledge about the domain of POM. Although each site has the same Web objects, they differ in terms of navigation structure: one being a subject-oriented hierarchy, another being a usage-oriented hierarchy, and a third providing a navigation structure that combines the former two. In this study, the experimental platform is equipped with two distinct sets of tasks which we call simple and complex. Designs of the three Web sites and two task sets are discussed below.

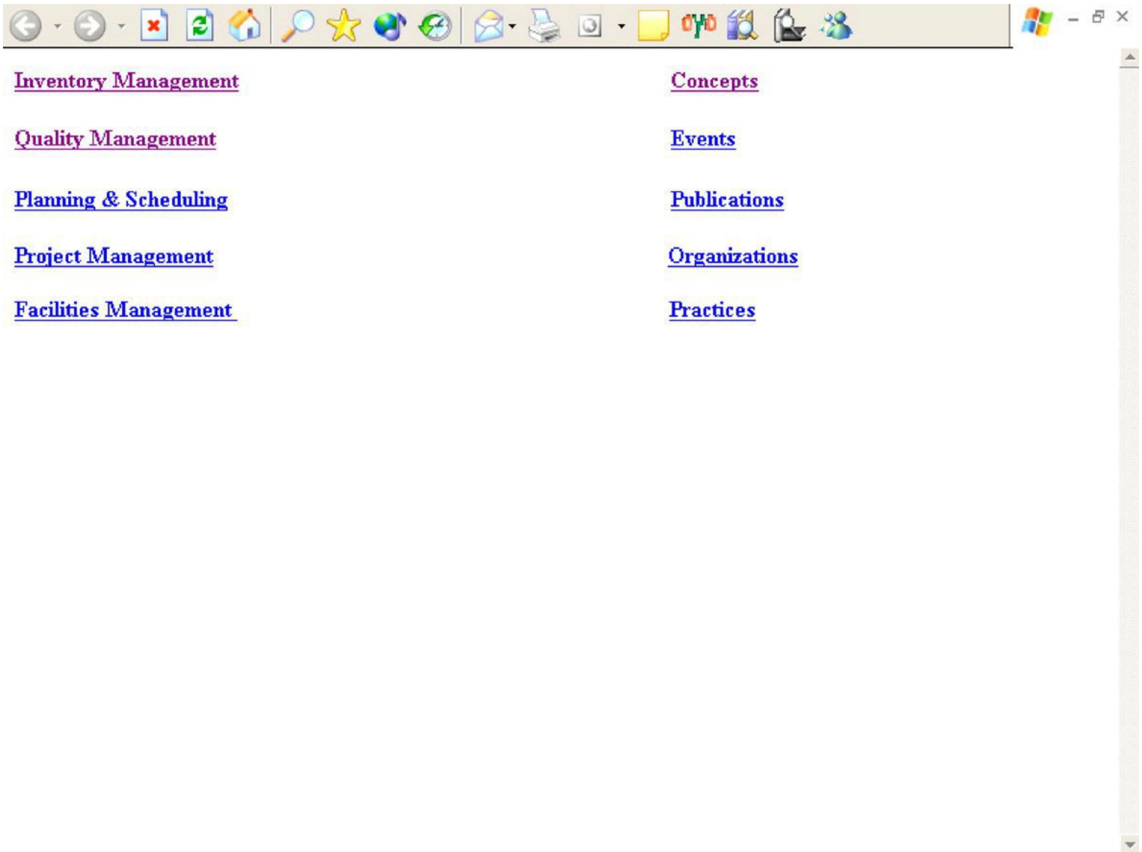


Fig. 2. Opening page for combined hierarchy.

The platform allows each experimental subject to have access to exactly one of the three sites, where site assignments are randomly determined based on his/her ID number. Similarly, each subject is randomly assigned to one of the two task sets. The platform presents a subject with tasks from the assigned task set. Each task takes the form of a question pertaining to the POM domain. For each task, the subject uses the assigned Web site's navigation structure in an effort to acquire knowledge needed to answer the presented question. Behind the scenes, the platform tracks the navigation time and records the subject's answers for subsequent analysis.

### *4.1. Web sites*

Each pure hierarchy has five tiers of classification leading to its Web objects. This number of tiers is selected to have a Web site design that is neither too trivial nor too overwhelming. The combined hierarchy shown in Fig. 2 also displays the two pure hierarchies of five tiers each, with the subject-oriented hierarchy on the left. The top tier of each pure hierarchy has five link nodes. Succeeding tiers for each pure hierarchy also have an equal number of nodes.

A user of the subject-oriented (or combined) hierarchy seeking descriptive knowledge about P charts may click the Quality Management link leading to a branch of tier two (Fig. 3). If he or she clicks the Statistical Quality Control link, he will arrive at a branch of tier three (Fig. 4). Clicking the Process Control link brings him or her to a branch of tier four (Fig. 5). Then, clicking the P chart link, he or she arrives at a branch of tier 5 (the Web object tier) that has a detailed description about a P chart (Fig. 6).

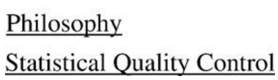


Fig. 3. Navigation page linking to quality management.

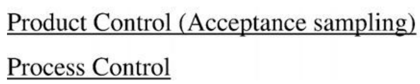


Fig. 4. Navigation page linking to statistical quality control.

R Chart

P Chart

Six Sigma Conference

WA11 Session of INFORMS Conference

Taguchi Methods

Taguchi Methods Application

Six-Sigma Limits

Fig. 5. Navigation page linking to process control.

Alternatively, a subject with the usage-oriented (or combined) hierarchy can acquire the same knowledge about P charts by taking a path starting at the Concepts link node (see the right hand side of the combined hierarchy in Fig. 2). From this point, the user needs to traverse the same number of hierarchic levels (each with the same number of link nodes) as the user of the subject-oriented hierarchy to reach the P chart description.

To control for other system features (recall Table 4), the Web sites are designed in such a way as to avoid system feature differences other than syntactic or semantic differences in the navigation structures. For example, all three Web sites share the same background color, font size, spacing, format, Web object label size (1–5 words), and Web object size (3–6 lines of text).

In this study, we avoid investigating Web sites that are trivial in the scope of their knowledge content. This would not be representative of real-world Web sites. On the other hand, there is little to be gained from incorporating a vast number of Web objects in the Web sites. Past experimental experience and pretest results indicate a subject can tolerate up to about 75 min of navigation and task performance without getting overly tired or impatient. Thus, we need to avoid so many objects that we end up with long tasks and very few tasks performed per subject.

From a widely-used POM textbook [6], we selected about 120 candidate Web objects that were evenly distributed across five subject areas and five usage areas. The five subject areas are quality management, production planning and scheduling, facility management, inventory management, and project management. The same 120 Web objects were classified into five usage areas: concepts, events, publications, organizations, and practices. As the foregoing navigation example illustrates, each major subject and usage area has its sub-areas. Similarly, each sub-area has its own sub-areas (e.g., Quality Management has Philosophy and Statistical Quality Control as two sub-areas, while Statistical Quality Control has Product Control and Process Control as two sub-areas). Even distribution of objects across both subject and usage semantics allowed usability of both hierarchies to be evaluated on an even footing. In the case of the combined navigation structure, there are two ways to navigate to any Web object of interest.

### 4.2. Task sets

We designed two sets of tasks: simple and complex (see Appendix A for examples). For simple tasks, a subject needs to navigate to the single relevant Web object in order to acquire the knowledge needed to provide the correct answer. As for complex tasks, Wood's task complexity model [54] is adopted. That is, the number of individual objects and the relationships between them are taken into consideration. For a relatively complex task, a subject must access at least two Web objects relevant to the task, and then identify and understand the conceptual relationship between these objects in order to acquire the knowledge needed for a correct answer.

For relatively complex tasks, the number of Web objects needed and the nature of their conceptual interrelationships vary from task to task during the experimentation time period. For instance, one complex KA task may require accessing knowledge contained in three Web objects, relating (e.g., synthesizing, interpreting) the knowledge from those sources to determine the correct answer. Another complex KA task might involve identifying pieces of knowledge in four Web objects, making comparisons among them in terms of one or two criteria, and selecting one piece of knowledge as the correct answer. In designing tasks, care was taken to avoid questions that implied favoritism toward a particular navigation structure.

Additionally, each task set is designed so that its tasks are uniformly distributed across both the subject classes and the usage classes. Within any particular class, the tasks are also evenly distributed across its sub-classes. Thus, the number of tasks created is practically the same across class and sub-class.

**P Chart** In a P chart, p bar is the fraction defective. p bar can be calculated by taking total number of defects from all samples divided by the product of number of samples and sample size.

Fig. 6. Web object for P chart.

Table 6
Perception and performance values across cells in round one

| Measure | Cell 1 | Cell 2 | Cell 3 | Cell 4 | Cell 5 | Cell 6 | Average |
|---|---|---|---|---|---|---|---|
| Ease of use in general (Q1) | 4.5 | 4.22 | 4.61 | 4.27 | 4.1 | 4.05 | 4.29 |
| Satisfaction in general (Q2) | 4.91 | 4.43 | 4.26 | 3.82 | 4.14 | 4.09 | 4.28 |
| Ease progression (Q3) | 5.95 | 5.26 | 5.35 | 5.59 | 4.86 | 4.91 | 5.32 |
| Satisfaction progression (Q4) | 5.45 | 5.04 | 4.78 | 5 | 4.86 | 4.82 | 4.99 |
| Correct answer ratio | 0.84 | 0.73 | 0.86 | 0.6 | 0.58 | 0.66 | 0.71 |
| Navigation time | 83.53 | 121.29 | 93.26 | 115.77 | 183.01 | 138.94 | 122.63 |
| Sample size | 22 | 23 | 23 | 22 | 22 | 22 | 22.33 |

Thirty complex tasks and forty simple tasks were developed with the support of many people, including POM instructors, senior POM professors, and business undergraduate students. Specifically, we held multiple meetings and interviews with these people, got feedback about the clarity of the tasks, and made modification accordingly. Eventually, we dropped some complex tasks and simple tasks because of a lack of conciseness, unclear phrasing, and possible semantic bias. We then randomly selected 12 from the remaining 20 complex tasks and 18 from the remaining 31 simple tasks. These became the experiment's simple and complex task sets.

Before conducting the experiment, a pilot test was undertaken to examine the customized platform, its Web sites, and tasks. The pilot test also checked demographic and perception questionnaires to be administered to all subjects. In addition, the pilot test gave insights into variations in the performance data and perception data.

Some participants in the pilot test made valuable suggestions about phrasing, formatting, and classification of the Web objects. This led to about twenty Web objects being dropped. The remaining 100 Web objects were used in each of the three experimental Web sites. Another purpose of the pilot test was to find out how much time each subject needed to finish a series of tasks. Based on pilot test results, we determined that 12 complex tasks and 18 simple tasks could be accommodated within the 75-minute target for the experiment. Nine persons pilot-tested the platform: computer professionals, faculty members, graduate and undergrad business students.

## 5. Execution of the experiment

### 5.1. Subjects

There were 134 subjects in the experiment's first round. One semester later, the experiment was repeated with 99 subjects. Statistical analyses showed no significant demographic differences among the six groups of cell subjects in either round. Nor were there significant demographic differences for any of the six cells between round one and round two subjects. The sample size in each experiment cell of each round experiment is specified in Tables 6 and 7, respectively.

All subjects were upper-division undergraduate business students who had completed 12 weeks of the instruction in a core POM course. All had been taught using common coverage from the same POM textbook. This coverage familiarized all subjects with topics in the five categories in the subject-oriented hierarchy's top tier, as well as other POM topics.

Subjects were volunteers interested in this study because of its relevance to their course work and the potential of rewards tied to their performance. The best performers in each cell received substantial cash prizes and all participants were eligible for extra credit in the POM course proportional to their performance in the experiment.

Each subject supplied demographic data and was randomly assigned to one of the six experimental cells shown in Table 5. For the assigned task set, each KA task required the subject to answer an online question. Each

Table 7
Perception and performance values across cells in round two

| Measure | Cell 1 | Cell 2 | Cell 3 | Cell 4 | Cell 5 | Cell 6 | Average |
|---|---|---|---|---|---|---|---|
| Ease of use in general (Q1) | 4.65 | 3.76 | 4.53 | 4.44 | 3.25 | 4.44 | 4.18 |
| Satisfaction in general (Q2) | 4.88 | 3.53 | 4 | 4.69 | 4 | 4.38 | 4.25 |
| Ease progression (Q3) | 5.35 | 4.88 | 4.94 | 5.25 | 4.88 | 5.06 | 5.06 |
| Satisfaction progression (Q4) | 4.94 | 4.29 | 4.18 | 4.63 | 4.69 | 4.81 | 4.59 |
| Correct answer ratio | 0.85 | 0.72 | 0.79 | 0.63 | 0.57 | 0.64 | 0.70 |
| Navigation time | 86.33 | 105.73 | 102.39 | 118.56 | 149.19 | 118.89 | 113.52 |
| Sample Size | 17 | 17 | 17 | 16 | 16 | 16 | 16.50 |

such task drove the subject to navigate the assigned Web site's contents in search of knowledge needed to complete the task, gathering as well as organizing the acquired knowledge to form a final answer. Before beginning a task set, the user was given a couple of practice tasks to become acquainted with the operation of the platform, the nature of the assigned tasks, and the assigned navigation structure. Upon finishing the assigned series of tasks, the subject was asked via a brief questionnaire to furnish his/her perceptions of the assigned navigation structure's usability for the KA tasks.

Based on demographic data from the subjects, they fit a profile of being regular World Wide Web (WWW) users, visiting WWW sites to acquire knowledge for their course work and for satisfying their personal interests and hobbies. Importantly, the subjects' knowledge of the POM domain stems primarily from the 12 weeks of POM study, rather than work experiences or other course work. This ensures relative homogeneity of domain knowledge and avoids cases of subjects who are so knowledgeable in POM that they can skip the KA and directly answer the experimental task questions without Web site navigation.

Two rounds of experimentation were conducted, the second being a repetition of the first to examine result consistency. Within each round, the same two task sets were employed: a set comprised of 18 simple tasks and a set of 12 relatively complex tasks. In each round, the experimental platform not only randomly assigns subjects to one of the six experimental cells, but the order in which the assigned tasks are presented to any particular subject is also randomly determined at run time. In this way, the study investigates whether relative usability for navigation structures varies with changes in task complexity, and whether the results are reproducible.

### 5.2. Dependent variable measurement

In the experiment, we collected data on six dependent variables [11] as measures of Web site usability. Two variables measured subjects' objective performance in carrying out tasks by using an assigned Web site. Four variables measured subjects' perceptions about Web site usability.

Each subject uses a single Web site in performing a series of either simple or complex tasks. Each task requires the subject to acquire knowledge from the Web site in order to answer an online question. Quality of a subject's performance is measured by a correct answer ratio (CAR), calculated by using the number of correct answers as numerator and the total number of tasks as the denominator.

The average navigation time (NT) a subject spends per task is also measured. This is calculated by using the total amount of navigation time that a subject spends on all the tasks he/she performs as numerator, and using the number of tasks performed as denominator. Mean navigation time reveals how fast a subject can acquire knowledge from a Web site. After reading the online question, clicking a "Ready to Navigate" button starts navigation. Clicking a "Ready to Answer" button allows a user to stop navigating and type an answer in a message box. A user can always clear the answer. However, a user cannot go back to a previous task after clicking the "Ready for Next Question" button (Fig. 7).

Measuring subjects' perceptions about using the Web sites to acquire knowledge is another part of dependent variable measurement. Questions in the questionnaire measure overall perception as well as perception about progression of usability across tasks. As for overall perception, one question measures how easy a subject perceives knowledge acquisition to be across a series of tasks. Another question measures how satisfied he or she is with the way in which the knowledge is organized in the Web site. As for perception progression, we ask about changes in ease with which subjects perceive that they are able to acquire knowledge they seek as they progress through the tasks. We also measure subjects' perceptions of how their satisfaction with navigation structure changes as they progress through the tasks.

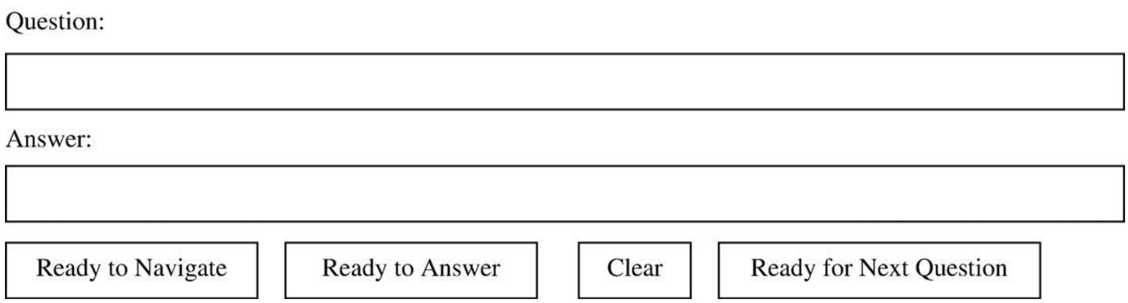


Fig. 7. Interface for performing tasks.

The measurement of all the four perception questions is scaled from one to seven. Each subject completes the questionnaire about perceptions after finishing all online tasks.

Pilot testing showed that collecting subject's perceptions per task substantially increases the time for the experiment and results in subject fatigue that may confound KA performance and perceptions. Thus, this study focuses on performance rather than perception. Perception may be considered as a function of performance, because it intuitively seems reasonable to expect an underlying causality to proceed from performance experienced to preference expressed, although it may also be true that people perform better when they really like a system [32]. Appendix B shows four questions used to measure usability perception.

### 5.3. Experimental procedures

To execute a round in the experiment, an announcement of the round was circulated among all students in the course. To elicit subjects' best efforts, volunteers were offered two types of incentives: course extra credit and cash prizes for top performers in each cell.

When subjects arrive at the lab, a researcher distributes a handout to each subject. The first page of the handout is a demographic questionnaire. The second page contains instructions for doing the experiment. The third page is a post-experiment questionnaire designed for capturing subjects' perceptions about site usability. The researcher gives a brief introduction to each page of the handout, and performs a demonstration to acquaint subjects with using the platform (such as how to input an ID number, get a task, acquire knowledge for a task's answer, type an answer, edit or clear an answer, and so forth).

In particular, the researcher tells the subjects that the rules on the instruction page must be followed. Failure to follow the rules will result in discarding a subject's data input and elimination from cash prize consideration. Throughout each session, the researcher stays in the lab, ensuring that subjects do nothing that may cause biased and false results (such as collaborating, interrupting other subjects, and resorting to other approaches for finding the correct answers).

A subject fills out the demographic questionnaire first, then reads the instruction page, performs two practice tasks, performs the assigned set of online tasks, and finally completes the perception questionnaire. The practice tasks are not counted for performance evaluation. The finished demographic and post-experiment questionnaires are turned into the researcher.

## 6. Data analysis results

### 6.1. Results from round one

Even though subjects are randomly assigned to each of the experimental cells, we are interested in assessing whether demographic data across experiment cells are uniform and similar. Critics may argue that random assignment cannot guarantee that subjects' demographic backgrounds across cells are identical. Results of a Chi-square analysis reveal no statistically significant differences in subjects' demographic backgrounds across six experiment cells at an alpha level of 0.01.

Before comparing any individual cells regarding usability differences, we run MANOVA (Multivariate Analysis of Variance) on performance data from all the cells. Particularly, we are interested in assessing the navigation structure main effect, the task main effect, and the interaction between them. Similarly, we perform a second MANOVA on the perception data in round one to assess navigation structure, task, and interaction effects. Table 6 shows the cell-wise averages for all usability performance and perception measures.

Using the correct answer ratio (CAR) and navigation time (NT) as dependent variables, the MANOVA across all the experimental cells shows significant navigation structure main effects and task main effects. However, the interaction between navigation structure and task complexity is not significant at a 0.05 level (Table 8). In terms of site main effects, the CAR for the usage-oriented hierarchy is 6% higher than the CAR for the subject-oriented hierarchy. The CAR for the combined hierarchy is 10% higher than the CAR of subject-oriented hierarchy. The navigation time for the subject-oriented hierarchy is 52 s higher than the NT for the usage-oriented hierarchy, and 36 s higher than NT for the combined hierarchy. As for task main effects, the CAR for the simple tasks is 19.5% higher than the CAR for the complex tasks. The NT for complex tasks is 46 s higher than the NT for simple tasks.

The statistically significant results for CAR are as follows: both usage-oriented hierarchy and combined

Table 8
MANOVA statistics for experiment round one

| Measure | Navigation structure main effect | Task main effects | Navigation and task interaction |
|---|---|---|---|
| Performance | $F=10.67$, $p<0.001$ | $F=60.59$, $p<0.001$ | $F=1.08$, $p=$ns |
| Perception | $F=1.75$, $p=$ns | $F=1.49$, $p=$ns | $F=0.82$, $p=$ns |

hierarchy are more usable than subject-oriented hierarchy. For navigation time, statistically significant results are that both usage-oriented hierarchy and combined hierarchy are more usable than subject-oriented hierarchy. Thus, for both usability measures, usage-oriented hierarchy and combined hierarchy navigation structures are superior to the subject-oriented hierarchy.

Using the four perception questions as dependent variables, the MANOVA results show that navigation structure main effects, task main effects, and the interaction between navigation structure and task are not significant (Table 8). Each subject was exposed to only one cell (i.e., one navigation structure and one task type), and thus had no basis for comparing alternatives. Interestingly, even though subjects' perceptions of usability were relatively homogenous, their usability performances yielded significant differences. This indicates that relying either on performance only or on perception only is not sufficient to gauge Web site usability.

### *6.2. Results from round two*

In the subsequent semester, the experiment was repeated for the purpose of confirming the results obtained from round one. This second round was conducted with the participation of 99 subjects. Chi-square analysis indicates that there are no statistically significant demographic differences between the subjects in round one and round two. Neither is there any statistically significant demographic difference across the six experimental cells within round two.

Using the correct answer ratio (CAR) and navigation time (NT) as dependent variables, MANOVA again shows statistically significant navigation structure main effects and task main effects. As in the case of round one, the interaction between navigation structure and task type is not statistically significant at a 0.05 level (Table 9).

In terms of site main effects, the CAR for the usage-oriented hierarchy is 9% higher than CAR for the subject-oriented hierarchy. The CAR for the combined hierarchy is 7% higher than CAR for subject-oriented hierarchy. The NT for the subject-oriented hierarchy is 25.0 s higher than the NT for the usage-oriented hierarchy, and 16.4 s higher than the NT for the combined hierarchy. As for task main effects, the CAR for the simple tasks is 17.2% higher than the CAR for the complex tasks. The NT for complex tasks is 30.7 s higher than the NT for simple tasks. Similar to the results from round one, the usage-oriented hierarchy and combined hierarchy navigation structures, for the second time, are statistically significantly more usable than subject-oriented hierarchy, in terms of both CAR and NT performance measures.

Using the four perception questions as dependent variables, the MANOVA results for round two show that navigation structure main effects are significant, which is different from the results in round one. Yet, again, task main effects and the interaction between navigation structure and task are not significant (Table 9). In particular, compared to those using the subject-oriented hierarchy, subjects using usage-oriented and combined hierarchies rate their navigation structures statistically significantly higher, in terms of Q1 (ease of use in general) and Q2 (satisfaction in general). Thus, perceptions and performance in round two are more consistent with each other than in round one. The correlation coefficient between the perceived complexity, serving as a manipulation check, and the task complexity operationalized in the experiment is 0.78, denoting the extent of the successful manipulation of complexity. Table 7 shows the cell-wise averages for all usability performance and perception measures.

### *6.3. Reliability*

Reliability, the extent to which an individual answers the same question the same way each time it is asked, was assessed using Cronbach's α [10]. In experimental rounds one and two, the survey questionnaire measuring perception exhibits reliabilities from 0.73 to 0.75, which are acceptable by Nunnally's [34] later standards.

### *6.4. Construct validity*

Instead of asking subjects to fill out a bulky questionnaire after performing a collection of tasks, this study's questionnaire focused on ease of use and satisfaction measures which are also included in the well known perceptual measures for usability [46,41,35]. The scale used in this study's perception measures is also consistent with those used in the aforementioned studies. Due to the 75-minute maximum time target for experimental sessions, this study concentrates on actual performance measures, and secondarily briefly asks

Table 9
MANOVA statistics in experiment round two

| Measure | Navigation structure main effect | Task main effects | Navigation and task interaction |
|---|---|---|---|
| Performance | $F=3.05$, $p=0.0184$ | $F=23.64$, $p<0.001$ | $F=0.74$, $p=$ns |
| Perception | $F=3.50$, $p=0.0009$ | $F=1.41$, $p=$ns | $F=0.67$, $p=$ns |

subjects to answer a few perception-related questions (seeking to avoid substantial fatigue effects). Because subjects are assigned to each cell of the experiment, therefore interacting with one Web site only, inter-rater reliability analyzed via Cohen's [8] coefficient Kappa does not apply. Having incorporated the same scale and some very similar construct measures from the aforementioned perception usability survey instruments with verified construct validity, construct validity is to be expected for the present study as well.

### 6.5. External validity or generalizability

To be useful for the research community, findings should be applicable across other subjects and conditions [9]. No significant variance from round one to round two is identified (i.e., block main effect is non-significant). The two semesters in which the two experiments were conducted can be regarded as a reasonable sample of size two from all possible semesters. Hence, the findings may be applicable to other semesters at the same school. Moreover, the use of the varying samples of undergraduates with different make-ups of majors suggests that the findings may be generalized to various majors at the same business school [17]. The repeated navigation structure and task main effects on performance usability across both experiments conducted in two randomly selected semesters provide at least some evidence of generalizability [50].

## 7. Discussion

### 7.1. Explanation for the findings

Mental model and schema theories offer insights that can help understand the results of this exploratory experiment. In experimental results from both rounds it turns out that the subject-oriented hierarchy was less usable than the combined hierarchy in terms of user performance. An interpretation is that the positive effects from including a usage-oriented hierarchy in a network are so strong that it not only counteracts negative effects from having more options (both in terms of semantics and syntax), but also yields some additional positive performance effects.

MANOVA results for perception data in the first round showed no significant navigation structure main effects. However, MANOVA results for the second round showed significant main effects for navigation structure (pointing out the vulnerability of relying on findings from a single repetition of an experiment). Compared to perceptions of the subject-oriented hierarchy's users, the usage-oriented hierarchy and combined hierarchy received higher ratings in terms of satisfaction and ease of use. Interestingly, these higher perception ratings correspond to the better performances with usage-oriented hierarchy and combined hierarchy navigation structures. The explanation for these higher ratings is the same as those offered for the performance difference across three navigation structures in the previous paragraph.

In theory, navigation structure's semantics, syntax, and task complexity affect Web site usability. Compared to subject-oriented hierarchy, usage-oriented hierarchy and combined hierarchy associate with better performance usability. Not surprisingly, simple tasks associate with better performance usability than complex tasks for each type of navigation structure.

### 7.2. Limitations

As with any research, the study discussed in this paper is not without its share of limitations. The taxonomy introduced in Section 2 may not identify all major constructs. It may include features that do not affect usability in some circumstances. The presentation of the taxonomy does not include an exhaustive treatment of every identified feature. The empirical portion of this paper has operationalized and examined only a few of the features as independent variables, leaving a large number of constructs uninvestigated. More in-depth consideration of the constructs may raise other interesting issues that can be explored in a controlled environment, perhaps using the same experimental platform (e.g., but with different Web site variants).

This study may be limited in terms of the generalizability of its findings. This could be due to the specific settings of the many control variables. For instance, the POM task domain may yield different results than would be found for other domains. Further empirical studies are needed to determine whether our findings can be extrapolated to other domains. There could also be limits on generalizability due to specific user features (e.g., domain familiarity), provider features (e.g., profit versus non-profit rationale), systems features (e.g., monitor size, Web browser, navigation structure scope, Web object size), and environmental features (e.g., economic climate).

In discussing experimental results, the terms "significant" and "non-significant" have been used. They refer to statistical significance. This statistical significance can be different from practical significance as perceived by individuals. The understanding of practical significance might also vary from one individual to another.

Consider the CAR values in Table 6. Comparing the CAR for cell 1 versus cell 3, there is no statistically significant difference. However, the CAR for either of these cells has a statistically significant difference from the CAR in cell 2. Is there also a practical significant difference between the CARs in cell 3 and cell 2? Some observers may answer "No," suggesting that 0.73 is not that different from 0.86. However, other observers would answer "Yes," maintaining that having the correct knowledge 86% of the time is substantially better than having the correct knowledge 73% of the time (particularly in the context of important decision making).

### *7.3. Directions for future research*

Although this research does not provide a definitive answer about the "goodness" of any particular Web site design, it does give an initial basis for assessing relative usability of alternative navigation structures. It is the first experimental study to do so and offers a template for designing future empirical investigations of features that may impact Web site usability. One example of such an investigation is exploring the usability of alternative Web site designs for cognitively disabled persons [21,22]. Another examines usability of alternative navigation structures for differing levels of user domain knowledge [14].

This research provides additional insight into the challenges associated with effective Web site design. Further, this study approaches Web site usability from a knowledge acquisition (KA) perspective, which is potentially generalizable to a number of task domains. This study has the potential to spawn a programmatic series of studies that might benefit interdisciplinary study in the information sciences and among Web site design practitioners. Along the conceptual dimension, further work could be done in refining and perhaps extending the taxonomy. We view taxonomy development as a challenging task that has a dynamic nature, with improved taxonomies being stimulated by and built on their predecessors.

The same set of hypotheses tested in this study could be examined in a different domain to see if the same findings hold. The experiment could be replicated with a different set of Web site users (e.g., senior citizens, students in another country). New research models with different independent variables can be developed from the taxonomy features to assess other variables' impacts on Web site usability. Examples include Web site object size and the extent of annotation for Web site links. In all of these cases the same experimental platform can be employed; what may change are the Web sites and tasks sets for subjects.

The opportunities for KA research in the e-commerce arena are just opening up. We believe that this research effort lays a foundation for such work and points out directions to be pursued. The study presented here can serve as an impetus to researchers interested in conducting Web site usability research. It can also give some guidance to practitioners interested in Web design and in evaluation of the Web sites' KA usability.

## Appendix A. Sample tasks

Simple task one: Who wrote the article "*Furniture maker uses MRP II to cut lead time*"?

Simple task two: In P chart, what is the meaning of P bar?

Complex task one: Name a specific software product for the new generation MRP.

Complex task two: Which (if any) of the approaches did IBM adopt: Taguchi methods or Six Sigma Limits?

## Appendix B

Follow-up questionnaire

1. In this experiment, how easy was it to acquire the knowledge needed to answer the questions?

| | | | | | | |
|---|---|---|---|---|---|---|
| Very difficult | | | | | | Very easy |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

2. In this experiment, how satisfied were you with the way in which the knowledge was organized in the Web site?

| | | | | | | |
|---|---|---|---|---|---|---|
| Very dissatisfied | | | | | | Very satisfied |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

3. As you progressed through the questions, the ease with which you were able to acquire knowledge you sought

| | | | | | | |
|---|---|---|---|---|---|---|
| Decreased greatly | | | | | | Increased greatly |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

4. As you progressed through the questions, your satisfaction with how knowledge was organized in the Web site

| | | | | | | |
|---|---|---|---|---|---|---|
| Decreased greatly | | | | | | Increased greatly |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

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