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Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 32(32)

ISSN

1069-7977

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Publication Date

2010

Peer reviewed

Topical Relevance and Information Quality in Cognitive Models of Web Search Behavior: Introducing Epistemic Scent into Information Foraging Theory

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Abstract

Current cognitive models of Web navigation (e.g., Information Foraging Theory, IFT, Pirolli, 2007) are based on the assumption that users' behavior is guided by evaluating the topical relevance of information encountered on the Web. This "information scent" has been successfully used to model Web search behavior. In this paper, however, we claim that topicality-oriented theories like IFT need to additionally consider the evaluation of information quality in order to address a broader class of realistic search tasks. For instance, when search tasks are complex and the quality of available Web information is highly variable, Web navigation will also depend on evaluating information quality, in addition to evaluating topical relevance. In this paper we first provide a theoretical framework of quality evaluation during Web search. Second, we review two experimental studies to substantiate this theoretical framework. Finally, we propose an extension of IFT using the concept of *epistemic scent* to incorporate evaluations of quality into the theory.

Keywords: information scent; evaluation processes; complex search tasks; interface design; epistemological beliefs

Web search and information quality

With the exponential growth of information available on the World Wide Web (WWW), the Web has evolved into one of the most important information sources. Besides searching for simple and uncontroversial facts or researching product purchases, the Web increasingly serves as a rich information source for conducting research on more complex academic or science-related topics (cf. Horrigan, 2006). For instance, in the context of personal concerns of individuals, such as medicine and health care, using the Web as a supplement to the interaction with experts has achieved great popularity (Moharan-Martin, 2004).

However, as anyone can publish virtually any information on the Web, the WWW is characterized by a large variability of information quality with information sources differing dramatically with regard to Web authors' expertise and motives. As a result, the trustworthiness of online information on topics like medicine or healthcare varies considerably, with many Web sites containing misleading or even false information (Eysenbach, Powell, Kuss, & Sa, 2002). Despite this variability, different Web sources (e.g., scientific and other institutions, journalists, lay people, or companies) are usually interspersed in the results lists returned by search engines. Moreover, in many cases popular commercial or social Websites (e.g., shops or forums) that

may be doubtful with regard to their motives or expertise fit exactly to search terms entered by users, so that they are listed among the highest-ranked search results on a search engine result page (SERP). Thus, even the information contained in the top search results of a SERP might turn out to be biased and one-sided, leading to premature or even wrong decisions. Accordingly, Web users may not only be required to critically evaluate the topical relevance of search results but also their quality (cf. Taraborelli, 2008) - especially when dealing with controversial issues such as the effectiveness of specific medical treatments. Contrary to this claim, however, most current cognitive models of information search on the Web focus on evaluating the topical relevance of search results, thereby neglecting issues of information quality.

In this paper, we propose an extension of one of the most influential theories of search and navigation on the Web - the Information Foraging Theory (IFT, Pirolli, 2007) - based on the results of two experimental studies. These results will be reviewed following a theoretical introduction of Web-search models and quality evaluations.

Topicality-oriented models of Web navigation

In the last decade, various computational cognitive models of Web navigation have evolved. These models are based on concepts like semantic similarity and topical relevance, such as SNIF-ACT by Fu and Pirolli (2007), CoLiDeS by Kitajima, Blackmon, and Polson (2000), MESA by Miller and Remington (2004), and CoLiDeS+ by Juvina & Van Oostendorp (2008). Although several models exist, they have all ignored the evaluation of information quality.

In this paper we will focus on the SNIF-ACT model, which is based on IFT. IFT postulates that the selection of hyperlinks (e.g., from a SERP or Web page) is determined by the strength of a so called "information scent". Information scent reflects the perceived semantic similarity between *proximal cues* (i.e., keywords or trigger words available in link labels or search results) and the current *search goal* of the user, which is defined by a desired distal information source (e.g., a Web page). A strong information scent of a hyperlink indicates a high likelihood that the source accessible via the hyperlink contains the desired information and thus increases the likelihood that the hyperlink will be selected. As IFT explains Web searching behavior based on this notion of information scent, the theory presupposes that Web searching is exclusively guided by the topical rele-

vance of Web information. The computational modeling of information search in SNIF-ACT uses spreading activation in semantic memory as a mechanism for determining semantic similarity. A strong information scent occurs when the encoding of proximal cues in semantic memory results in a substantial spread of activation to the representation of the current search goal. Activation spread according to the associative strength between concepts in memory is a standard measure to represent semantic similarity in the underlying ACT-R architecture. Figure 1 illustrates the concept of information scent (IS) for a user pursuing the goal of finding information about “medical treatments for cancer” (this is the desired distal information defining the search goal). It is assumed that the user encounters a search result like the one depicted in Figure 2, which includes the terms “cell, patient, dose, beam” (these are the available proximal cues). The arrows represent the spread of activation from the search result to the goal representation, which is used to calculate the information scent of the search result.

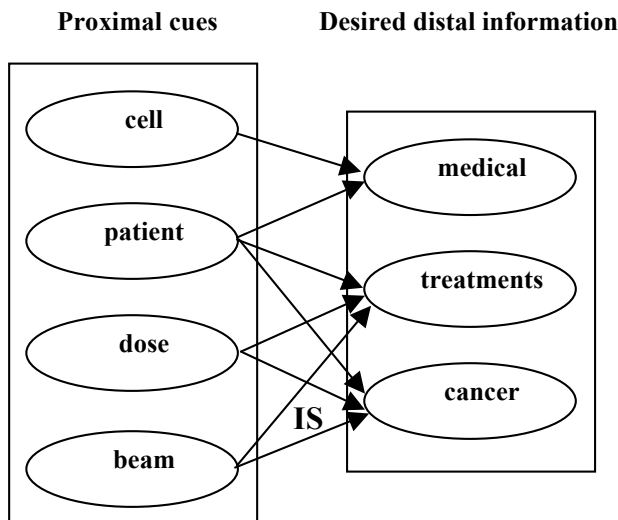


Figure 1: Illustration of information scent (IS), example adapted from Pirolli (2007).

[Proton Beam Therapy with High-Dose Irradiation for Superficial and ...](#)
 Table 1 Patient characteristics, dose of irradiation, efficacy, and toxicity in superficial
 Supported in part by a grant-in-aid for Scientific Research (No. ... Earlam R., Cuhana-
 Oesophageal squamous cell carcinoma. ...
clincancerres.aacrjournals.org/cgi/content/full/9/10/3571 .

Figure 2: Example of a search result link.

Topically-oriented computational models like SNIF-ACT have been able to predict Web search and link selection in a wide range of different tasks. Thus, at first sight they seem to allow for a successful and precise modeling of Web navigation of any kind. However, we claim that all tasks that were used for modeling forced users to focus their attention on the topical fit of available information: Users either had to engage in simple fact-finding tasks or they had at their disposal a selection of Web information that was restricted to uncontroversial and consistent information of established

quality. For these types of task, quality evaluations are not an important issue. Moreover, previous studies used search environments that provided users with more or less salient topicality cues but not with salient cues pointing to the quality of search results.

Preconditions for quality evaluations on the Web

Given the search tasks and search environments used in previous studies on information scent, it seems plausible that users’ Web navigation in these tasks was mainly a function of the perceived topical relevance of available information (i.e., its information scent), because quality evaluation are neither required nor supported. However, we hypothesize that the role of quality evaluations on search behavior might change considerably when certain preconditions are given with regard to task characteristics, user prerequisites, and search interface. The hypothesized interplay of these preconditions, which is illustrated in Figure 3, will be used as a theoretical framework throughout this paper.

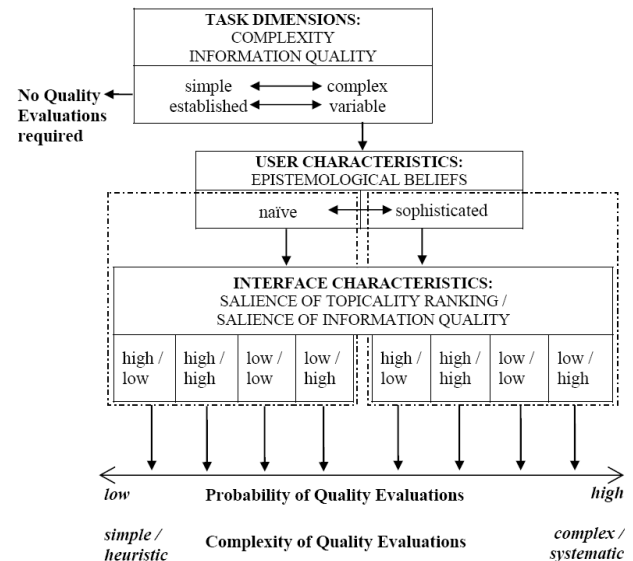


Figure 3: Preconditions of quality evaluations

Task complexity and variability of information quality

We assume that the evaluation of information quality (e.g., in terms of credibility, accuracy, and completeness) becomes of major importance (1) when the search task is sufficiently complex and, even more important, (2) when the available information is highly variable with regard to its quality. Search tasks loading high on these two task dimensions have become an increasingly important activity on the Web, for instance, when users search for controversial science-related topics or personal concerns like medical or health issues. In such search tasks, inconsistent and potentially contradictory Web information of variable quality is often encountered, so that searchers should not take the accuracy of the available information for granted. Despite the growing popularity of research on Web information quality in the last decade (for a review see Rieh & Danielson, 2007), to the best of our knowledge, the fit of topicality-

oriented models of Web navigation with users' search behavior in tasks that require the evaluation of information quality has not yet been investigated.

User prerequisites: Personal epistemology

Once the user is confronted with a search task that requires quality evaluations, both the probability and the complexity of these quality evaluations will strongly depend on the searcher's cognitive prerequisites, for instance on his or her personal epistemology. In line with dual-process theories (e.g., Chen & Chaiken, 1999), quality evaluations can range from simple, non-elaborated, intuitive, and spontaneous "heuristic" evaluations, on the one hand, to complex, cognitively elaborated, conscious, and reflected "systematic" evaluation processes on the other hand. In order to systematically evaluate the quality of Web information, searchers need to consider how credible a source of information is, how certain and consistent with other sources the information itself is, and how strongly the information might be influenced by the motives of the information provider. According to Hofer (2004) this kind of reasoning is closely connected to a person's epistemological beliefs (EBs), that is, to one's personal beliefs about the nature of knowledge and knowing. EBs have been shown to guide users' cognitive and metacognitive activities during Web search (Hofer, 2004). For instance, it has been demonstrated that users with naïve EBs are less critical Web searchers and that EBs influence search techniques and the ability to recognize authority (Hofer, 2004; Whitmire, 2003). Certainly, there exist other important cognitive prerequisites beyond EBs that support systematic quality evaluations of Web information, such as domain expertise or Web expertise. These prerequisites were, however, not investigated as factors in the studies reviewed in this paper and will therefore not be discussed in greater detail.

Search interface: Salience of topicality and quality

A third precondition for quality evaluations – beyond task requirements and user prerequisites – is related to the affordances and information provided by the search interface. We assume that even if a user is able to engage in quality evaluations required by a search task, the concrete enactment of these processes during Web search might depend on two aspects of the search interface: first, whether the search interface affords quality evaluations and second, whether it comprises quality-related information. In our opinion, the interface of popular search engines usually does not support quality evaluations with regard to these two aspects.

First, search engines usually present search results in a list, with the most topically relevant and most popular Web pages being the highest-ranked ones (cf. Cho & Roy, 2004). This list format provides a strong affordance for users to start reading at the top of the list and to follow the strict and non-ambiguous order when reading and selecting the search results presented. Thus, no affordances are provided for users to take over the responsibility for evaluating and selecting search results on their own. Rather, searchers' aware-

ness of the ongoing selection process is hindered by the SERP layout.

Second, search engines usually display only very little information for each search result (e.g., a title, an excerpt from the respective Web page, a URL) on which evaluation processes aimed at deciding which search results to select for further inspection must be based. Moreover, the search result descriptions are typically confined to topical information, whereas quality-related source information is sparse and non-salient. Accordingly, the interface design of standard search engines does not support users to engage in quality-related evaluation processes on their own.

It can be expected that (1) the salience of topicality rankings of search results and (2) the salience of proximal cues in search results pointing to the quality of information are two important factors that determine whether quality evaluations take place or not. We assume that a search interface that provides salient proximal cues for information quality and refrains from making the topicality ranking of search results the most salient feature will stimulate more quality evaluations than a search interface without these characteristics. Thus, within the limits of users' individual cognitive prerequisites, a proper search interface might lead to navigational decisions that are based to a substantial degree on evaluating information quality in addition to evaluating topical relevance.

Hypotheses and review of experimental studies

Based on the framework describing the preconditions of quality evaluations during Web search (Figure 3), a couple of hypotheses were derived and tested in two studies reviewed in this section. In both studies, fine-grained process data (combination of eye-tracking methodology and log file data) were used to test the relationship between the probability and complexity of quality evaluations in a science-related search task and the design of the search interface and users' EBs. The task of both studies addressed a controversial medical topic. The collection of Web pages made available in the studies represented the variability of information quality on the Web and included Web pages provided by official institutions, scientific authorities, journalists, companies, and lay people (e.g., discussion pages). All Web pages were topically relevant to the respective search topic. We hypothesized that a search task with these characteristics would cause users to engage in quality evaluations, at least when their cognitive prerequisites and the search interface used would allow for these processes. Users' EBs were measured to test whether users with naïve and sophisticated EBs differ in the quality evaluations they engage in.

Two different interface design approaches were implemented to test whether they stimulate quality-related evaluation processes. In study 1 (Kammerer, Wollny, Gerjets, & Scheiter, 2009) participants either used a standard Google search result list or an augmented search result list additionally containing source categories for each search results (cf. <http://www.clewwa.de/>). This approach aimed at providing salient quality-related cues. In Study 2 (Kammerer & Ger-

jets, 2010) a standard list format was compared to a grid format with search results arranged in multiple rows and columns (cf. www.viewzi.com). This approach aimed at decreasing the salience of the topicality ranking and at increasing users' awareness of the selection process.

We hypothesized that both experimental interfaces would lead to more and better quality evaluations than a standard search interface with a high salience of the topicality ranking and a low salience of information quality.

Study 1: Display of search results with source categories

In this study (for details see Kammerer et al., 2009) participants were confronted with a fictitious request from an overweight friend, who wants to lose weight by changing her diet. Participants were asked to conduct a 20-minute Web search to make an informed decision between low fat and low carb diets in order to recommend one of the two diet methods. Participants were provided with three prearranged Google-like SERPs with ten search results each.

Method. Thirty university students participated in the experiment by either using a standard Google search result list or an augmented search result list (15 participants per group). The augmented list additionally contained source category labels printed in bold next to the URL. The labels indicated to which of five different source categories a search result belonged. The five source categories were Science/Institutions, Portals/Advisors, Journalism/TV, Readers' Comments, and Shops/Companies. We assumed that these source categories provided users with cues regarding the quality of the respective Web pages without changing the topical information available for each search result. Furthermore, searchers' EBs were obtained with the Epistemic Beliefs Inventory (EBI; Schraw, Dunkle, & Bendixen, 1995). In order to study participants' evaluation processes, their eye movements and mouse clicks during Web search were captured. We assumed that the amount of attention (i.e. total fixation duration) spent on a search result reflected evaluative processes with regard to this search result. As the topical information did not differ between the experimental conditions we assume that group differences in the amount of attention indicate differences in quality evaluations. Similarly, selection differences between groups cannot be traced back to differences in topicality but indicate that searchers evaluated the quality of sources differently.

Results and discussion. The results showed various differences between the two search interfaces and between naïve and sophisticated users with regard to the attention distribution on SERPs and the selection of search results. First, augmenting SERPs with source categories resulted in less linear viewing sequences than standard SERPs. Second, the availability of source categories influenced students' evaluation and selection behavior, such that they gave less attention to commercial search results ("Shops/Companies") and were more likely to select search results from the category Portals/Advisors. Third, beyond these effects of the interface design, the results revealed that source categories stimulated users with sophisticated EBs to pay more atten-

tion than naïve users to search results that were rather ambiguous with regard to their information quality (Portals/Advisors, Journalism/TV, and Readers' Comments) compared to the remaining categories Science/Institutions (high quality) and Shops/Companies (low quality). Fourth, with regard to EB effects on standard SERPs, the results indicated that sophisticated users paid less attention than naïve users to search results linked to social or commercial Websites. A possible explanation is that searchers with sophisticated EBs might be able to identify such search results as being of rather low quality by having only a quick look on the search result descriptions (e.g., the URLs). To conclude, Study 1 revealed several effects of (1) enriching search interfaces with salient quality-related cues and (2) of the personal epistemology searchers bring to the task. These two factors would be difficult to model with topicality-oriented theories of Web navigation like the IFT because the differences in attention distribution and selection behavior were not associated with differences in topical relevance.

Study 2: List interface versus grid interface

In this study (for details see Kammerer & Gerjets, 2010) users had to decide between two competing therapies for Bechterew's disease. They were given eight minutes to conduct a Web search regarding the pros and cons of both therapies and to make an informed decision between them. Participants were provided with two prearranged SERPs, one for each therapy, with nine search results each.

Method. Eighty university students participated in the experiment by either using a standard Google search result list or a grid interface with search results arranged in three rows and three columns. Furthermore, the trustworthiness order of search results on a SERP was experimentally manipulated in order to test participants' sensitivity to information quality (cf. Pan et al., 2007). The trustworthiness order of the search results presented in this study was obtained empirically in a pilot-study. Based on these data, the nine search results per SERP, which were all of high topical relevance, were either presented in an *optimal* order, with the most trustworthy search results presented first and the least trustworthy ones presented last, or in a *reversed* order, so that the least trustworthy search results were presented first. For the grid interface, trustworthiness of search results was arranged line-by-line, that is, from left to right in each of three rows. Twenty participants were assigned to each of the four conditions with trustworthiness order (optimal vs. reversed) and search interface (list vs. grid) varied as between-subjects factors. Searchers' epistemological beliefs were obtained with the Internet-Specific Epistemology Questionnaire (ISEQ, Strømsø & Bråten, 2010). Searchers' eye movements and mouse clicks were captured during Web search. Additionally, retrospective verbal protocols were obtained by asking participants post-hoc to think aloud while watching a replay of their own eye movements during search.

Results and discussion. The results showed numerous differences between the two search interfaces, between the two

trustworthiness orders, and between naïve and sophisticated users with regard to the attention distribution on SERPs, the selection of search results, and the occurrence of quality-related verbal utterances. First, the grid interface caused less homogenous and less linear viewing sequences on SERPs than did the list interface (for both trustworthiness order conditions). Second, when using the list interface most attention was given to the search results on top of the list – independent of their trustworthiness. In contrast, with a grid interface, nearly all search results on a SERP were attended for equivalent durations. Consequently, when search results were presented in a *reversed* order, participants using the list interface attended significantly longer to the least trustworthy search results and selected the most trustworthy search results significantly less often than participants using the grid interface. Third, with regard to verbal utterances, the grid interface stimulated quality-related utterances compared to the list interface, although these utterances mostly reveal simple and heuristic quality evaluations rather complex and systematic ones. Fourth, EB results showed that, with regard to searchers’ selection behavior, sophisticated users better identified trustworthy sources than naïve users. With regard to verbal data, naïve users reflected less on the type of sources they had encountered. With regard to attention distribution, naïve users paid less attention to the URLs of the search results. To conclude, Study 2 revealed several effects of (1) the presentation format and presentation order implemented in the search interface and (2) of searchers’ personal epistemology. These factors influenced verbal behavior, attention distributions, and selection behavior, providing evidence that at least sophisticated searchers using an interface with a low salience of the topicality ranking (i.e., the grid interface) substantially engaged in quality evaluations to guide their web navigation. Again, because the search results displayed in all experimental conditions were equivalent with regard to topical relevance, the findings obtained would be difficult to model with topicality-oriented theories of Web navigation like the IFT.

Extending Information Foraging Theory

Based on the theoretical framework illustrated in Figure 3 we predicted that – given certain preconditions – Web navigation would be substantially guided by quality evaluations in addition to topicality evaluations. The two experimental studies reviewed confirmed these expectations. Searchers in different experimental conditions were presented with search results that were equivalent with regard to topical relevance. Experimental manipulations involved the presentation format (list versus grid), the trustworthiness order (optimal versus reversed) and the availability of quality-related proximal cues (source categories). Additionally, we distinguished searchers with naïve and sophisticated EBs. The results yielded various effects of quality-related manipulations and of searchers’ EBs on attention distribution, selection behavior, and verbal utterances. IFT and other topicality-oriented models of Web search would not have predicted these effects, because the topical relevance of

search results remained unaffected by the manipulations. We propose to extend IFT in three ways to account for the data we obtained. Our suggestions are illustrated in Figure 4, which refers to the example introduced in Figures 1 and 2 (medical treatments for cancer).

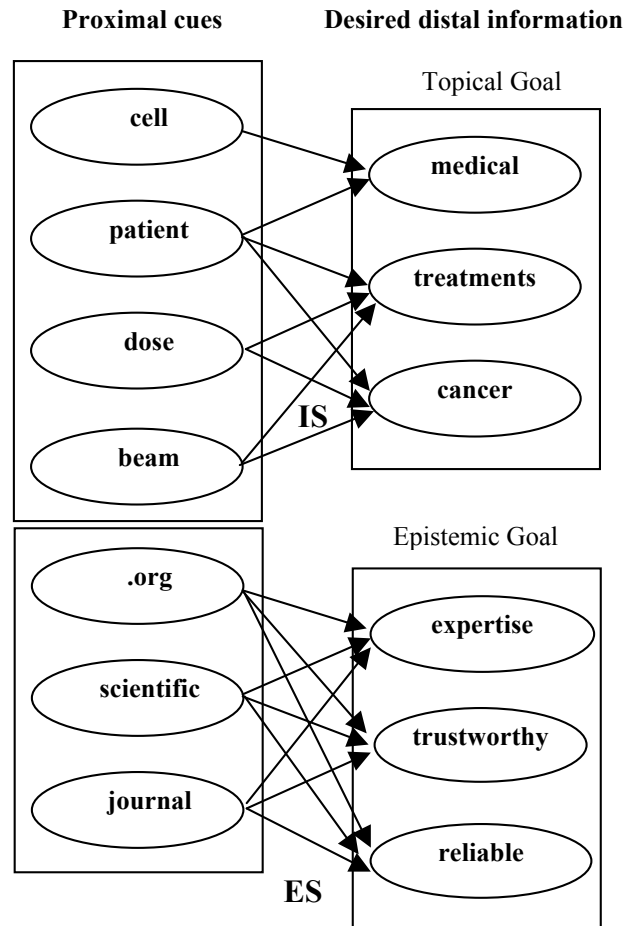


Figure 4: Extension of Information Foraging Theory

Tasks that require quality evaluations. IFT claims that Web search is guided by a topical goal, namely the goal of finding topically relevant information irrespective of its quality. In order to account for our data, however, it is necessary to introduce more complex goal structures that comprise an additional epistemic goal component (e.g., find *trustworthy* information of topical relevance). In order to decide which tasks require an epistemic goal component leading to quality evaluations, additional procedural knowledge is necessary to trigger the epistemic goal component (e.g., in cases in which contradictory information or information of variable quality is encountered during Web search).

Epistemic scent as a guiding parameter. When an epistemic goal component is active due to the characteristics of the search task and the nature of the search results encountered, a second scent parameter becomes available, namely the spread of activation from proximal cues for information

quality (e.g., the words “scientific”, “journal” or “.org” in a search result description) to the representation of the current epistemic goal component (e.g., reliable and trustworthy information provided by experts). This epistemic scent (ES) based on information quality, can be taken into account in addition to the topicality-based information scent for guiding Web navigation. An open issue might relate to the integration of information scent with epistemic scent (e.g., by summing up activations, applying “metacognitive” rules).

Epistemic knowledge: Concepts and rules. To account for effects of EBs and quality-related cues on SERPs we suggest not only to model searchers’ domain knowledge but also their epistemic knowledge. Epistemic knowledge comprises conceptual knowledge (e.g., knowing that information in a scientific journal provided by experts is trustworthy, see the lower part of Figure 4). Conceptual epistemic knowledge is necessary to interpret quality cues on SERPs and to judge the epistemic scent of search results. Epistemic knowledge also comprises procedural rules that guide systematic quality evaluations (e.g., recognizing good and unbiased Web information) and allow to handle information of variable quality (e.g., selection and attention behavior). These procedural rules will, however, strongly depend on whether search interfaces provide the information necessary for their application. Conceptual and procedural components of epistemic knowledge together can be used to model the influence of searchers’ EBs on Web navigation. The proposed extensions of IFT would broaden its scope to include search tasks that require quality evaluations. Based on these extensions, IFT could be used to model aspects of users’ Web navigation behavior that are not determined by topicality alone. Furthermore, these extensions are in line with the general assumptions of IFT and with our framework on the preconditions of quality evaluations (Figure 3). Moreover, they are consistent with the pattern of results obtained in the two experimental studies reviewed in this paper. Finally, they would allow for novel predictions on how domain and epistemic knowledge in combination can affect quality evaluations due to their associations in semantic memory.

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