Collaborative Information Synthesis II: Recommendations for Information Systems to Support Synthesis Activities

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As the quantity of information continues to exceed our human processing capacity, information systems must support users as they face the daunting task of synthesizing information. One activity that consumes much of a scientist's time is developing models that balance contradictory and redundant evidence. Driven by our desire to understand the information behaviors of this important user group, and the behaviors of scientific discovery in general, we conducted an observational study of academic research scientists as they resolved different experimental results reported in the biomedical literature. This article is Part 2 of two articles that report our findings. In Part 1 (Blake & Pratt, 2006), we introduced the Collaborative Information Synthesis (CIS) model, which captures the salient information behaviors that we observed. In this article, we review existing cognitive and information seeking models that have inadvertently reported synthesis behavior and provide five recommendations for systems designers to build information systems that support synthesis activities.

Introduction

As the quantity of information available continues to exceed our human processing capacity, information systems must support users as they integrate information. This activity is best described as synthesis, "the dialectic combination of thesis and antithesis into a higher stage of truth" (*Merriam-Webster's Collegiate Dictionary*, 2004). Synthesis reflects the alternative viewpoints that often occur when multiple empirical studies explore the same phenomena. The synthesis activity results in an overall finding—a higher stage of truth—which scientists achieve by resolving conflicting evidence. Thus, the synthesis activity requires accurately weighing a body of evidence that comprises both *contradictions* (when the study results differ), and *redundancies* (when study results concur), which are inevitable when multiple studies explore the same natural phenomena. In this article, we consider synthesis activities that involve evidence reported in existing literature rather than synthesis activities requiring additional data collection through experimentation.

Synthesizing information is a time-consuming activity. For example, one survey of 37 groups of scientists who synthesized biomedical literature revealed a total mean time of 1,139 hr (Allen & Olkin, 1999). Assuming that our scientist could dedicate 8 hr a day exclusively to the synthesis activity, it would take approximately 7 months. Another survey revealed an elapsed time of 28 months between an initial review idea and its later publication (Petrosino, 1999). These scientists could reduce their effort by constraining the scope of the review; however, this reduction could introduce undesirable biases and thus reduce the validity of the entire synthesis activity.

The system recommendations reported in this article build the Collaborative Information Synthesis (CIS) model, which we described in detail in Part 1 of our findings. The CIS model captures the two information constructs (the hypothesis projection and context information) and four critical tasks (retrieval, extraction, verification, and analysis) that we observed when studying synthesis activities. The model also reflects the collaboration and iteration that we observed. In this article, we reflect on existing theoretical models from information science that have inadvertently identified synthesis behaviors and the systematic review process that played a major role in the work environment of our study population. We provide a comprehensive description of our study population and the mixed methods approach that we utilize to collect data in the study environment section as well as a set of five system recommendations to support this important user population.

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Background

Several existing information theory models have inadvertently identified synthesis activities. In this section, we reflect on general studies of information behaviors and on studies that explore the information behaviors of a similar user population. We then introduce the systematic review process, which scientists in a variety of disciplines employ to combine evidence reported in empirical studies.

Related Work

Several theoretical models suggest that synthesis activities play a role in enabling users to survive in an information-intensive world. From a cognitive perspective, personal construct theory emphasizes the importance of inconsistencies among information artifacts and between an information artifact and a user's mental model (Kelly, 1963). Kelly (1963) suggested that inconsistencies eventually force a user to either discard information that threatens their existing mental models or formulate a new, tentative hypothesis. From the personal construct theory perspective, our study de-emphasizes the early stages of confusion, doubt, and threat and focuses on hypothesis testing, assessing, and reconstruing. Our study explores the process scientists use to generate the new, tentative hypothesis.

Gardner's (1985) model of cognition also suggests that synthesis plays a fundamental role in information interactions. He stated that "the organism . . . manipulates and otherwise reorders the information it freshly encounters—perhaps distorting the information as it is being assimilated, perhaps recoding it into more familiar or convenient form once it has been initially apprehended." We also recognize the temporal nature of information assimilation, specifically that users assimilate information when it is "fresh." The user population in our study externalizes their assimilation processes, which enables us to observe the process directly and thus capture *how* users assimilate information rather than reverse-engineer their synthesized result. We posit that users in an information-intensive environment will assimilate only the overall finding into their mental models' contradictions rather than individually encoding every information resource.

In addition to Kelly's (1963) and Gardner's (1985) cognitive models, several information-seeking models capture synthesis activities. For example, Dervin and Nilan's (1986) sense-making methodology is motivated by the premise that users "actively construct" rather than "passively process" information (p. 24). In our study, we explore the construction processes in an academic setting and limit the study to the "collect, store, retrieve, and disseminate" stages proposed by Dervin and Nilan.

Kuhlthau (1991) stated that "since people have limited capacity for assimilating new information, they purposefully construct meaning by selectively attending to that which connects with what they already know" (p. 2). This perspective is consistent with our emphasis on synthesis. In contrast to the students who participated in Kuhlthau's study, members within our user group hold advanced degrees within their chosen disciplines. Thus, our model reflects well-tested methods designed by scientists to produce high-quality reviews.

Ellis and Haugan (1997) created a model of information seeking by studying multiple kinds of users; however, the physicists in Ellis's 1993 study are most similar to our user population. The scope of our study is constrained to the verifying, ending, extracting, and distinguishing stages identified by Ellis and Haugan after observing engineers and research scientists.

Both the cognitive and information-seeking models imply that users integrate incrementally new information into their existing mental models. Bates' (1989) berry-picking model also suggests that users integrate information incrementally: A user decides to keep or discard each new "berry" based on the berries that are already in the user's basket. Our intuition is that users in an information-intensive environment will synthesize information before updating their mental models. Continuing with the berry-picking model analogy, our study suggests that scientists first collect their berries and that they do not adjust their mental models until they organize the berries into different piles. In contrast to trying to capture the relationship between a user's mental model and information artifacts, we focus on how scientists resolve differences between information artifacts in the hope that this externalization of synthesis activities may provide insight into the unobservable cognitive processes.

Several studies explore information behaviors in the work environment. Those that relate most to our study include populations similar to the academic researchers we observed. Sonnenwald and Pierce (2000) studied scientists as they participated in interdisciplinary collaboration and found that scientists "collect, analyze, synthesize, and disseminate information throughout the work processes." Studies conducted by Florance and Marchionini (1995) and by Hersh and Hickam (1995) revealed that interactions between articles affect how physicians interact with information retrieval systems. An additional study by McKeown and colleagues (2001) found that users do not distinguish between the retrieval and extraction tasks. In each of these cases, researchers have shown the insufficiency of retrieval alone to satisfy a user's information need. We, too, emphasize postretrieval tasks conducted by users in an academic environment.

In addition to our focus on synthesis activities, our study differs from many information-seeking studies because our unit of study is a group rather than an individual. Although traditionally neglected, the information science community has recently focused on group behaviors and, in particular, collaboration. The National Science Foundation funded a joint project comprising staff from the University of Washington, Microsoft, Boeing, and the Risø National Laboratory to explore collaborative information seeking in engineering and software-development teams (Bruce et al., 2003). Prior to this work, researchers had focused on collaboration between an individual seeking information and an experienced searcher (e.g., a librarian) to address the

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information seeker's need (Fowell & Levy, 1995). In contrast, we observed collaboration among equally experienced members of medical research teams and the medical librarian. Patient-care teams also have promoted such close collaboration with a medical librarian (Davidoff & Florance, 2000).

The Systematic Review Process

This section provides the background necessary to interpret our findings and understand the challenges faced by scientists during synthesis activities. Medical experts use a clearly defined systematic review process to balance contradictory and redundant findings from a collection of empirical studies. Davies and Crombie (1998a) stated that "High-quality systematic reviews take great care to find all relevant studies published and unpublished, assess each study, synthesize the findings from individual studies in an unbiased way and present a balanced and impartial summary of the findings with due consideration of any flaws in the evidence" (p. 1). By summarizing salient aspects of existing studies, a systematic review provides medical professionals with a valuable resource to reduce information overload. For example, recommendations within a high-quality, on-topic, current systematic review can remove the scientists' need to conduct their own synthesis.

A cornerstone of the systematic review process is that the review include the search strategy, inclusion and exclusion criteria, and the methods used to integrate findings (Davies & Crombie, 1998b; Hunter & Schmidt, 1990). In one review, for instance, the search strategy included articles "from MEDLINE from 1980 [that] were considered if they (1) had either 'impotence' or 'erectile dysfunction' in the title; (2) were not reviews, letters, comments, editorials or news; (3) involved human, not animal, subjects; (4) were published in 1980 or later; and (5) described studies performed in the United States" (Tengs & Osgood, 2001, p. 2). Integration of findings in this study utilize meta-analysis techniques. Each of these information components enables a scientist not involved in the review to assess the review with respect to the topic, recency, and objectivity.

Two organizations play an active role in establishing the methodology used to conduct a systematic review. The Cochrane Collaboration (www.cochrane.org) is a collection of experts who, on a voluntary basis, provide both methodological advice (Higgins & Green, 2005) and access to systematic reviews. The Health Technology Assessment Program (http://www.hta.nhsweb.nhs.uk/) also provides methodological guidance (Sutton, Abrams, Jones, Sheldon, & Song, 1998). Both organizations' methodologies describe a five-stage systematic review process that includes the following: (1) Define a research question; (2) search the literature; (3) assess study quality; (4) combine findings; and (5) place the findings in context. Although each of these steps are important to the systematic review process, Steps 3 to 5 are of most interest in this study because they provide insight into the synthesis activities employed by scientists in medicine and in public health.

TABLE 1. Evidence levels for combining findings in decreasing order of reliability (Hunter & Schmidt, 1990).

1. Meta-analysis
2. Counting positive and negative significant results
3. Counting positive results
4. Counting positive significant findings
5. Vote counting methods yielding estimates of effect size
6. Vote counting methods yielding only significance levels
7. Statistically correct vote counting
8. Cumulation of *p* values
9. Voting method

From an information science perspective, Bates' (1976) also emphasizes the importance of clearly defining the inclusion and exclusion criterion of a rigorous systematic bibliography. The quality scores assigned during Step 3 correspond with the differentiating stage in Ellis's (1989) model of information behaviors. The scientists' well-defined metrics in our user community enable them to assign a numeric value capturing article quality. In addition to assigning numeric values, users group articles on a study-design basis to reflect known study-design biases. Thus, authors typically report multiple synthesized results. For example, they present a synthesis of findings reported in randomized clinical trials separately from their synthesis of findings reported in cohort studies.

Scientists combine findings using a variety of quantitative methods, which are shown in Table 1. Hunter and Schmidt (1990) ranked each method in decreasing order of reliability. Thus, if two independent scientists conduct a meta-analysis on the same topic, their findings are more likely to be the same than if they cumulated the *p* values of each study. Meta-analyses is the most reliable form of synthesis in medicine (Bartolucci, 1999; Davies & Crombie, 1998b; DerSimonian & Laird, 1986; Glass, 1976; Ingelfinger, Mosteller, Thibodeau, & Ware, 1994; Lipsey & Wilson, 2000; Petitti, 2000).

In addition to the nine quantitative synthesis techniques listed in Table 1, researchers can combine evidence using a qualitative approach. In a qualitative systematic review, researchers employ the same rigorous methods to identify and assign quality scores to each article as in a quantitative approach; however, in a qualitative review, scientists group studies using the quality scores assigned in Step 3 and then discuss the findings with respect to each quality cluster. The scientists discuss redundancies and contradictions with respect to quality clusters and emphasize findings from studies with the highest quality.

Study Environment

In this section, we introduce the study environment, the scientists studied, and our data-collection methodology. Our intuition is that the information-intensive environment in which a scientist operates requires an externalization of synthesis behaviors, and thus provides a rich environment in which to study synthesis activities. With 14 million bibliographic references (National Library of Medicine, 2006a)

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already in Pubmed, and 571,000 new references in 2004 alone (National Library of Medicine, 2006b), it is easy to characterize the environment of academics in medicine and in public health as information intensive. Although the general review process is well documented (see preceding section), our interests lie in the information behaviors surrounding the application of that review process and during synthesis in general. To explore these behaviors, we collected qualitative data in a naturalistic setting. In the second part of this section, we describe our data-collection methodology and instruments.

User Population

This study explores synthesis activities of two user groups, the medical group and the public health group. Our work complements the many studies that have investigated information behaviors in the domain of medicine, including studies of physicians (Smith, 1996), nurses (Lange, 1993), and patients (Leydon et al., 2000) in settings as diverse as rural clinics (Bowden, Kromer, & Tobia, 1994) and academic medical centers (Woolf & Benson, 1989). In contrast to these medical populations, our users operate in an academic setting and are actively involved with synthesizing medical literature. Although the well-defined processes employed by the user population of scientists will not generalize to all populations, their information-intensive environment suggests that these users are likely to suffer from overload and thus deserve our attention.

The medical group possesses expertise in systematic review methodologies, library science, biostatistics, health services, clinical research, and clinical content. The group comprised 2 domain experts in the area of spinal manipulation (the focus of the review), 4 experts in other areas of complementary and alternative medicine, a medical librarian, and a biostatistician.

The medical group formed specifically to conduct nonbiased, rigorous reviews of the literature relating to complementary and alternative approaches to medicine. We base the information behaviors model presented in this article on data collected by the first author during her direct observations of the medical group as they conducted a systematic review of literature on the reliability of spinal manipulation.

In contrast to the medical group, the majority of members in the public health group had worked together for several years before our study began. Students were the only exception to this rule: Each graduate student had worked in the group for less than 1 year, and the majority of undergraduate interns had worked in the group for less than 1 month. The public health group comprised a domain expert in public health (the director), a statistician, a research programmer–statistician, a staff research assistant, 3 graduate students, and 4 undergraduate interns.

In contrast to the medical group, where data was drawn from only one project, we collected data related to the information behaviors of the public health group from three different projects. Their projects included (a) a systematic review that explored the relationship between smoking and impotence, (b) a meta-analysis on utility estimates and AIDS, and (c) an ongoing project that centers on the creation and maintenance of a database comprising lifesaving and cost-effectiveness data. Each project was in a different stage of completion and comprised a different subset of the total public health group. The domain expert, statistician, and research programmer participated in the systematic review project, which was completed and published before our study began. Only the domain expert and the statistician participated in the meta-analysis that was in progress during our observations. The domain expert, research assistants, and student interns participated in the groups' ongoing database project. The differing stages of completion for each of the three projects required that we use differing data-collection methods. We believe that these differences enabled us to triangulate their information behaviors better than if we had studied one project in isolation.

Data-Collection Methodology

We used qualitative methods in a naturalistic setting to explore information behaviors surrounding the synthesis activities of scientists. Our collaborative synthesis model draws on our direct observations, meeting minutes, extraction worksheets, e-mail communications, analysis spreadsheets, interviews, and the final manuscripts developed for each of the medical and public health groups' projects.

Each member of the medical group provided us with permission, via e-mail, to directly observe and record their meetings. The group partitioned their meetings to discuss the organization of their review, their search strategy, and methodological issues associated with the review. We attended their first organizational meeting on July 10, 2001. Based on the discussion at that meeting, the first author decided that of the three meetings, the methodology meetings would provide us with the most insight into the medical group's information behaviors. Thus, the first author attended, observed directly, and recorded the methodological meetings of the medical group between July and September 2001. In addition to our observations, we asked short clarification questions that addressed the medical group's search criteria and analysis methodologies. The first author interviewed the domain expert using an open-ended question format. The previous meta-analytic experience of both the domain expert and our recorded data provided us with a rich collection of qualitative data on which to base our analysis.

We supplemented direct observations and interviews with information artifacts from the medical group, including (a) minutes from methodology meetings produced by the group as part of their process; (b) minutes from search strategy meetings, also produced by the group; (c) bibliographic references collected during the group's initial search; (d) methodology literature recommended by the group; and (e) literature in the library and online.

The elapsed time of a typical review is 28 months between the initial idea and its later publication (Petrosino, 1999). In a typical review, scientists volunteer their time and thus must balance the review process with their other commitments. In contrast, members of the medical group were conducting the review as part of a grant and were on a strict timetable. Thus, the time frame for the medical group's systematic review was much shorter than that for a typical review.

In contrast to the prospective nature of our data-collection methods with the medical group, our methods for the public health group were primarily retrospective due to the public health group's project work progress prior to the initiation of our analysis. Our data from the public health group comprised interviews, observations, and information artifacts to capture their information behaviors. We conducted an open-ended, face-to-face interview with the director and a separate open-ended, face-to-face interview with the director and the statistician. The research programmer–statistician had left the group, so we interviewed him by telephone and e-mail, and had a short, face-to-face interview. The first author worked from the public health group office 2 days a week during Summer 2001. During that time, she observed and conducted open-ended discussions with interns who were developing the group's cost-effectiveness database. Thus, our observation of the public health group was more immersive than that for the medical group. Although we observed multiple concurrent studies during the summer, the analysis reported in this article includes only three projects: two systematic reviews and the ongoing database maintenance project.

We did consider collecting data using a survey questionnaire. Our objection to using a survey approach alone is best captured by Forsythe and Buchanan (1989), who stated that "There is a great deal more to understanding what an expert says and does than one can obtain from interview material alone, or from interview material supplemented by textbooks" (p. 437). Our own observations of a scientist as she prepared an article for publication reflected the difficulty in capturing behaviors from this user population. When probed for details regarding how she came up with the finding, she stated that an upcoming conference deadline had prompted the analysis and that the findings just "jumped out." She was quick to add that this was not *really* how scientists work. This encounter motivated us to triangulate user behaviors using multiple data-collection methods, the most important of which was direct observation.

No method of data collection is without limitations. For this study, the first author's presence at the initial medical group's methodology meetings could have influenced the information behaviors that she observed, and recall bias could have influenced the answers provided by the public health group members in response to interview questions.

Information System Recommendations

Observations, interviews, notes, our literature review, and information artifacts collected from both the medical and the public health groups provided us with a rich collection of qualitative data on which to develop information system recommendations that would support the well-defined processes used by scientists. Although these processes do not generalize to all user populations, the time required to synthesize evidence and the important role that synthesis activities play in discovery suggests that this user group deserves our attention and information systems that support their work practices. Furthermore, by studying experts, we can gain insight into the ideal information behaviors surrounding synthesis activities, from which other user populations might learn. Developing the CIS model has required that we reflect on the material collected during this observational study (see Blake & Pratt, 2006). This reflection revealed a set of recommendations that an information system requires to best support this important user population.

Recommendation 1: Integrate the Retrieval, Extraction, Verification, and Analysis Tasks

Despite their advanced qualifications and experience with the systematic review process, both user groups iterated within and between the retrieval, extraction, verification, and analysis tasks. Thus, to be consistent with existing work practices, information systems should integrate the retrieval task with the extraction, verification, and analysis tasks. Our study provides several examples where integration would be advantageous. If a system integrated the retrieval and extraction tasks to exclude articles that did not report risk-factor rates, then the public health group would have been required to read a greatly reduced number of articles. The same integration would have enabled the medical group to establish the set of analysis techniques used within existing literature. Integrating the extraction and verification tasks would have enabled the medical group to identify only those articles where their extracted information differed.

Recommendation 2: Improve Document Management Capabilities

Scientists in this study continually updated the articles considered and articles collected, prompting new hypothesis projections. Our second recommendation is that an information system should enable users to manage the full text, citations, and accompanying meta-data associated with an article. In both study groups, scientists required articles from one project for the next. This finding is consistent with Barreau and Nardi's (1995) personal information management models and Erdelez's (1999) model of accidental information discovery. A system also should ease the task of sharing references from existing articles and during manuscript preparation.

It is important that the document management system include full text because, typically, information required during the synthesis activity is located only in the full text of an article and not in the title or the abstract. This can be problematic when the full text is not available. As publishers continue to increase their offerings of journals available in electronic format, we envision that this limitation will fade over time, although issues of copyright have yet to be fully resolved.

Recommendation 3: Provide Support for Collaboration and Information Sharing

We observed that both groups collaborated with other group members and with individuals who were not group members. Although most of the intragroup collaboration that we observed was co-located and synchronous, a tighter integration of tasks would enable scientists to work together remotely. A variety of systems have been developed to support collaborative activity (Procter, Goldenberg, Davenport, & McKinlay, 1998), but few support teams partnering to search for, as well as use, documents. A few exceptions are for systems that support collaborative browsing among many individuals, such as a system developed by Twidale and Nichols (1998) that enables a user to see a trace of all the documents that other users have visited, and the Magpie suite of tools that overlays visited pages with semantic information (Domingue, Dzbor, & Motta, 2004). In contrast, scientists have well-defined information needs and require techniques that support searching rather than browsing activities.

Reaching consensus was an important motivator for developing the extraction checklists. A variety of other initiatives requires that members reach consensus. For example, consensus building is an important consideration in recent efforts in bioinformatics to annotate scientific articles with terms from the gene ontology (www.geneontology.com). In both the systematic review and bioinformatics examples, scientists have developed hierarchies of evidence that reflect the annotator's confidence in the final category assignment. In a systematic review, the stated study design reflects the level of evidence while in bioinformatics, scientists have invented a set of evidence codes[1] including "inferred from assay" and "inferred from genetic interaction" to measure their confidence. Another example is the category assignment to online health-information resources by different catalogers. In the study of annotations from the NC Health Info portal (Blake, West, Luo, & Marchionini, 2005), annotations enabled catalogers to reach consensus around the meaning of an existing information source, an activity that is not new in medicine. These processes enable groups to establish norms and verify the accurate extraction of information from each article.

Recommendation 4: Improve Precision and Recall of Both Retrieval and Extraction Systems

Our data suggest that existing information retrieval systems provide neither the precision nor the recall necessary to support collaborative information synthesis. The public health group sifted through hundreds of articles to overcome precision limitations, and the medical group employed five alternative search strategies to overcome recall limitations. These findings suggest that precision and recall should be adjustable parameters of an information system rather than the "one-size-fits-all" solution currently embedded in systems. One way to achieve this goal would be to provide a user with a slider that balances precision and recall performance.

Recommendation 5: Provide Visual Interfaces to Verify and Explore Findings

Existing document summarization systems operate by first transforming text into an alternative representation and then generating new text that captures salient findings. In contrast, our study suggests that at the end of the synthesis activity, scientists expect both a visual and quantitative summary of information. Our fifth recommendation is that an information system should provide a variety of interfaces in which a user can explore extracted information. Thus, our position is consistent with Simon, Valdés-Pérez, and Sleeman's (1997) position that "Discovery systems which solve tasks cooperatively with a domain expert are likely to have an important role" (p. 180).

The validity of synthesis activities is dependent on accurately extracted information from each full-text article. Both groups that we studied went to great measures to verify the results of the extraction task. We therefore recommend that an information system must enable users to verify extracted information. In addition, we recommend that the system allow users to associate meta-data such as their own qualifications, the date of annotation, the project, and their confidence in the annotation.

Conclusion

In this article, we have reported our study of scientists in medicine and public health as they synthesized evidence from medical literature, and provided five recommendations for an information system design that would support this important user population. The synthesis activities that we observed capture just one of the day-to-day activities that consumes a scientist's time; however, the effort required to conduct this activity as well as the important role that current, accurate synthesized evidence plays in reducing information overload and in identifying new discoveries suggest that the study of synthesis activities demands our immediate attention. Furthermore, we must consider the scalability of the manual techniques currently used by scientists to synthesize evidence in the contexts of soaring quantities of new information.

Although our study considered only biomedical scientists, the agricultural industry developed the meta-analytic techniques now used in medicine, which suggests a similarity of information behaviors among some scientific populations. By observing an expert- rather than a novice-user population, we have captured ideal synthesis behaviors, and anticipate that non-scientific-user populations who operate in an information-intensive environment will find such a system valuable.

The information behaviors observed were both consistent with and in conflict with existing cognitive and information science models. The consistent information behaviors include the data-capturing, assessing, and reconstruing stages

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[1] A complete list of evidence codes are available from http://www.geneontology.org/GO.evidence.shtml.

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identified by Kelly (1963) and the manipulating and reordering of information proposed by Gardner (1985). In addition, we observed the distinguishing, filtering, extracting, and ending stages introduced by Ellis and Haugan (1997). Indeed, Ellis (1993) reported a similar verification task during his study of physicians, who are more similar to our user population than other populations included in his report.

Some observed information behaviors we observed also conflicted with previous cognitive and information models. Our qualitative data do not, for instance, support the confusion, doubt, or threat stages within Kelly's (1963) model nor the surveying, monitoring, or browsing behaviors proposed by Ellis and Haugan (1997). We do not challenge the existence of these stages because the scope of our study did not allow direct observation of these phases. For example, confusion or doubt may have occurred during the formation of either group. However, direct observation of such behavior was impossible due to group formation prior to study initiation. We did observe that the medical group members frequently brought new articles to their meetings, which suggests that the behaviors proposed by Ellis and Haugan did occur prior to our observations. We did not include these phases in our CIS model because they do not relate directly to the problem of synthesizing information.

Although our findings are consistent with Kuhlthau's (1991) model, we posit that the addition of a synthesis stage between the collection and presentation stages of her information seeking process (ISP) model would resolve a discrepancy that Kuhlthau noted in academic, public, and secondary-school libraries. She observed that "only 50% of the participants made focused statements of their topic at the close of their search" (p. 369). Our findings suggest that scientists must balance contradictory and redundant information within their collection of articles before they create a focused topic statement.

In contrast to an optimal retrieval system that provides a user with all relevant documents, an optimal synthesis system provides a user with an accurate overall finding that will enable the user to identify and explore contradictory and redundant evidence. As the quantity of information at our fingertips continues to exceed human processing capacity, the need for information systems that integrate findings will continue to increase in importance. The CIS model introduced in Part 1 provides a model of information behaviors that surround the synthesis activity and one mechanism used to resolve conflicting evidence. The system recommendations reported in this article provide the detail necessary to operationalize the CIS model. Together, these articles motivate the need to shift our focus from information retrieval to information synthesis.

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