Towards a Comprehensive Model of the Cognitive Process and Mechanisms of Individual Sensemaking

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This review introduces a comprehensive model of the cognitive process and mechanisms of individual sensemaking to provide a theoretical basis for:

- empirical studies that improve our understanding of the cognitive process and mechanisms of sensemaking and integration of results of such studies;
- education in critical thinking and sensemaking skills;
- the design of sensemaking assistant tools that support and guide users.

The paper reviews and extends existing sensemaking models with ideas from learning and cognition. It reviews literature on sensemaking models in human-computer interaction (HCI), cognitive system engineering, organizational communication, and library and information sciences (LIS), learning theories, cognitive psychology, and task-based information seeking. The model resulting from this synthesis moves to a stronger basis for explaining sensemaking behaviors and conceptual changes. The model illustrates the iterative processes of sensemaking, extends existing models that focus on activities by integrating cognitive mechanisms and the creation of instantiated structure elements of knowledge, and different types of conceptual change to show a complete picture of the cognitive processes of sensemaking. The processes and cognitive mechanisms identified provide better foundations for knowledge creation, organization, and sharing practices and a stronger basis for design of sensemaking assistant systems and tools.

Received September 5, 2012; revised August 21 2013; accepted August 23, 2013

 • Published online 23 April 2014 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/asi.23125

Introduction: Overview and Scope

Information science research and practice, including librarianship, has made much progress in understanding information behavior, especially information seeking, and in helping users to find and access information. Information retrieval has seen large advances, even though much still needs to be done to assist users with conducting meaningful searches; information and communication technologies provide access to huge amounts of information. Likewise, information-literacy education has focused on information-search and evaluation skills. But use of the information found and assisting users with such use has received less attention from system builders and information-literacy educators. The next frontier is building systems that assist users with making sense of all the information found and to educate students and users generally in the best ways of using and applying information, with or without the use of such next-generation systems. We need to bring together concepts and techniques from information science (broadly construed to include relevant areas of computer science), information design and visualization, education, instructional design, and learning theory to build systems and services that assist users with and prepare them for learning and sensemaking in an information-rich world (Neuman, 2011a,b).

As a contribution to this effort, this review introduces a comprehensive model of the cognitive process and mechanisms of individual sensemaking to improve our understanding of sensemaking and to provide a theoretical basis for:

- Empirical studies of the cognitive process of sensemaking and integration of the results of such studies
- Education in critical thinking and sensemaking skills

- The design of sensemaking assistant tools that support and guide users

Sensemaking is the information task of creating an understanding of a concept, knowledge area, situation, problem, or work task (application task; for definitions of information task and work task, see Ingwersen & Järvelin, 2005; Byström & Hansen, 2005) often to inform action. Sensemaking is a prerequisite for many work tasks such as problem solving, decision making, planning, and executing a plan. Sensemaking has also been defined as:

> A process of forming and working with meaningful representations in order to act in an informed manner (Stefik et al., 1999; Pirolli & Russell, 2011).

and as:

> Reading into a situation patterns of significant meaning (generalized from the original quote: individuals "realize their reality, by reading into their situation patterns of significant meaning; Morgan, Frost, & Pondy, 1983, p. 24").

An important part of sensemaking involves making clear the interrelated concepts and their relationships in a problem or task space.

As an example, consider a business analyst who is developing a marketing plan for a product, including a TV ad campaign and advertisements on other media such as print, radio, and the web. To understand the whole picture, she/he needs to gather information about the product and its competitors; conduct thorough research in trade and business presses and periodicals about the product, the company, and its competitors, potential users, and market shares and trends; and then develop multiple ideas for the marketing plan based on the research. The analyst is involved in a *sensemaking* task.

Sensemaking (Brenda Dervin, the originator of the sense-making methodology, prefers the spelling with a hyphen while the community in computer science and more technical people in information science [for example, SIG-CHI] use sensemaking without a hyphen) is a series of continuing gap-defining and gap-bridging activities between situations (Dervin, 1992, 1998). The sensemaker accomplishes each sensemaking "moment" by defining and dealing with the situation, the gap, and the bridge.

Sensemaking may be carried out by an individual or in a group or organization or it may be a societal endeavor. It involves both cognition and affect and interpersonal relationships and group/organizational dynamics. Dervin and Naumer (2010, p. 4696) distinguish work on sensemaking in four fields: "Human Computer Interaction (HCI) (Russell's sensemaking); Cognitive Systems Engineering (Klein's sensemaking); Organizational Communication (Weick's sensemaking; Kurtz and Snowden's sense-making); and Library and Information Science (Dervin's sense-making)." As can be seen from Figure 1, sensemaking by individuals or groups takes place in a rich context and has many influences. This paper focuses on sensemaking by individuals and within that on cognitive processes, drawing on literature from

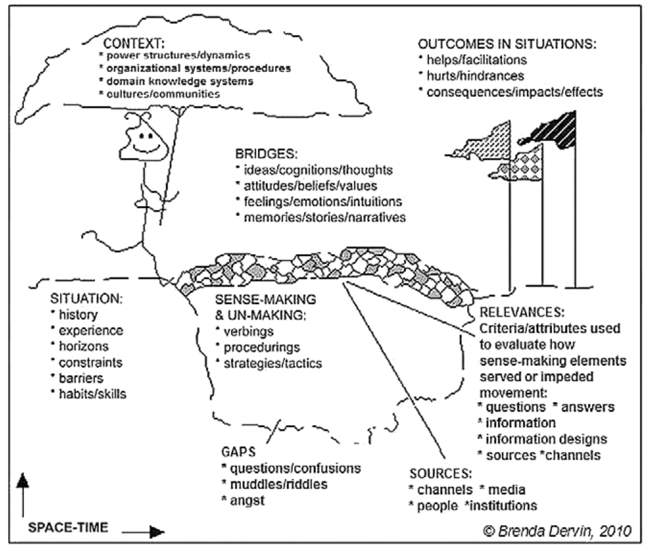

FIG. 1. The Sense-making metaphor (copyright, Brenda Dervin 2010 as published in Dervin & Foreman-Wernet, 2012, Figure 1, p. 156). Reprinted with permission.

human-computer interaction and cognitive systems engineering. Further, the paper addresses primarily conscious, deliberate, and often somewhat systematic processes of sensemaking that usually involve deliberate search for and use of information; but less conscious, experiential sensemaking falls within the general parameters of the sensemaking models presented. Parts of the model may apply to components of organizational sensemaking as well. In the remainder of the paper, sensemaking is used to refer to this limited scope.

There are several areas and literatures that overlap with sensemaking and that present models that are similar to the sensemaking models we discuss later in this paper: *Information seeking* and *learning* (we include a few representative models of both), *research methods* (which we have treated as kind of sensemaking and included in our review of models), *creativity* (Kaufman & Sternberg, 2010), *problem solving* (the classic Polya, 1945/1957/2004, Problem solving, n.d., and, as an example, one of many how-to books, Treffinger, Isaksen, & Stead-Dorval, 2005), and the many books on *writing* scholarly papers, theses, etc. Including models from these areas would have enriched our analysis of sensemaking and related activities (see Table 1 and the Supporting Appendix), but is well beyond the scope of this paper.

In the literature and in this paper, sensemaking has both a broad and a narrow meaning. Sensemaking, broadly defined, refers to the overall process of the following two subprocesses:

1. Seeking information, followed by extracting and filtering the information found; also called *sensing*.
2. Sensemaking, narrowly defined, which refers to iteratively creating and updating an understanding of the situation, especially connections (for example, between people, places, events, intentions, etc.), creating a representation that can support decisions or effective action (Klein, Moon, & Hoffman, 2006a). This can be

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TABLE 1. Elements of sensemaking.

Sensemaking is an iterative process that can include many activities in different sequences. They may iterate in several rounds until the goal is reached, intertwine with and influence each other, or spiral up to the final presentation. The activities are often defined by a combination of several characteristics. Different sensemaking models describe these activities at different levels of granularity. This figure presents a (faceted) classification of the activities and characteristics found in the models we reviewed.

0 **General control and command activities** applied at individual steps throughout the process
  0.1 Planning − .2 Defining − .3 Evaluating − .4 Interacting − .5 Feedback − .6 Monitoring − .7 Reflecting

A **Task analysis and determination of information gaps**
  Primarily for work tasks but also meta information tasks and learning tasks
  A0 Selecting a topic (for example, for an assignment or for research)
  A1 Preparing. Becoming familiar with the general or specific area of the work task / problem
  A2 Task / problem definition (could be considered part of developing the structure)
  A3 Identifying audience − A4 Establishing evaluation criteria for the research product and process.

B **Information Seeking. Searching for information / data / structure**
  B0 **Planning and carrying out the search process**
    B0.1 Determining information needs − .2 Search strategy − 2.1 Conceptual query formulation − .2.2 Selecting and sequencing sources. − 2.3 Source-specific query formulations − .3 Executing search strategy − .4 Reviewing results − .5 Editing results. − .6 Checking helpfulness of the results
  B1 **Searching for data versus Searching for structure**
    B1.1 *Searching for data*
      B1.1.2 Using structure to find data − .1 Searching for data guided by structure −.2 Inferring data
    B1.2 *Searching for structure (as contrasted with building structure)* = C1.1.1.3
      B1.2.1 Searching for structure based on problem / gap definition
      B1.2.2 Search or activation of structure prompted by data
  B2 **Scanning the environment versus specific search**
  B3 **Exploratory (pre-focus) versus focused search**
  B4 **Searching for sources versus extracting data or structure from sources**
  B5 **Searching in outside sources versus search in a data store or representation created for the sensemaking problem at hand**
  B6 **Evaluating and selecting information. Judging quality and relevance** NT B0.4, B0.5

C **Making sense of the information / data**: Analyzing and synthesizing the data. Creating a representation that fits the data into a structure or schema
  At the heart of sense making is the **interplay of structure and data**.
  C1–C3 approximate an umbrella process sequence.
  C4–C8 give many characteristics of activities in the interplay of data and structure arranged into a faceted classification

C1–C3 Approximate an umbrella process sequence

  C1 **Building / acquiring and instantiating structure**
    C1.1 *Building or acquiring structure or structure modification*
      C1.1.1 Mode of building or acquiring structure or structure modification
        C1.1.1.1 Building new structure or modifying structure
          C1.1.1.1 : C1.1.2.1 Building structure inductively from the data
        C1.1.1.2 Activating existing structure that is close at hand (in memory, external store)
        C1.1.1.3 Finding structure through search in outside sources = B1.2
      C1.1.2 Basis for building or acquiring structure (combine with C1.1.1)
        C1.1.2.1 Building or acquiring structure from data or prompted by data
        C1.1.2.2 Building or acquiring structure from problem definition
        C1.1.2.3 Building or acquiring structure from theory
        C1.1.2.4 Building or modifying structure influenced by predisposition and purposes
        C1.1.2.5 Building or modifying structure influenced by past experience
      C1.1.3 Comparing to other structure
      C1.1.4 Format of resulting structure (for example, a list of hypotheses)
    C1.2 *Instantiating structure / making data and structure fit. Organizing information*
      C1.2.2 Fitting data into the structure − .2 Discarding data −.3 Using structure to filter data
    C1.3 *Stage of Building / acquiring / instantiating structure or structure modification*
      C1.3.1 initially versus.2 Modifying, revising, replacing structure = C2.2
  C2 **Examining and revising structure. Determining whether completed** RT C3.2
    Strictly speaking, all part of C1 (in iteration); broken out for easier correspondence to other models
    C2.1 *Examining and questioning data and structure*
      C2.1.1 Examining data not yet fitted. leftover non-fitting data (residue) versus new data
      C2.1.2 Tracking anomalies − .3 Detecting inconsistencies. − .4 Judging plausibility
      C2.1.5 Gauging data quality (may be informed by structure)
    C2.2 *Modifying, revising, replacing structure*
      C2.2.1 To fit residue of non- or ill-fitting data, “representational shift” −.2 To fit new data
  C3 **Formulating the result in a report/presentation for a specific audience**
    May include recommendations for action, already starting D
    The sense-making process may continue in this step as problems surface in the writing
    This could also be a “report to self”, as an internal or external representation
    C3.1 Preparing draft report/presentation
    C3.2 Reflecting on the process so far and the resulting product
    C3.3 Revising / refining report/presentation as needed
    C3.4 Disseminating report/presentation

C4–C8 Further characteristics of activities in the interplay of data and structure

  C4 **Mechanisms for conceptual change. Sensemaking mechanisms**
    Data-driven or bottom-up versus structure-driven or top-down (Section *Sensemaking Mechanisms*)
  C5 **Degree of structure change when fitting data into structure** (Section *Types of Conceptual Change)*
  C6 **Internal versus external representation**
  C7 **Granularity of iterations by amount of information processed**

D **Consuming the instantiated structure. Applying the results to the work task: making a decision, executing an action, etc.**, by the sensemaker or the reader/listener of a presentation

E **Feedback**
  E1 Evaluative feedback. Did the report/presentation provide guidance for action? Action successful?
  E2 Requirement feedback: Additions or changes to requirements
  E3 Data feedback: New or corrected data found in application
  E4 Structure feedback: Changes in the structure discerned in application

F **Reflecting on the process and its results. Considering lessons learned. Updating individual and group store of knowledge, internal and/or external**

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> accomplished by relating information found to previous knowledge, creating structures, and fitting data into structures to create representations, thus arriving at an understanding of a situation or phenomenon (Russell, Stefik, Pirolli, & Card, 1993). Also called making sense.

Pirolli and Card's (2005) model shows this broad and narrow use very clearly (in the discussion of models, Figure 5). The outer loop encompassing all activities is labeled "Sense-Making Loop for the Analyst"; it includes an inner loop which contains the activities for the narrow meaning and is called "Sense-Making Loop." It is generally clear from the context which meaning is intended.

The first steps in sensemaking, broadly defined, are determining an information gap and seeking information; *sensemaking* and *information seeking and use* are closely intertwined in reality and commingled in terminology. Just as sensemaking, broadly defined, includes information seeking, so does information seeking and use include sensemaking, narrowly defined (in the use part). Thus, sensemaking, broadly defined, and information seeking and use refer to the same total process but emphasize different subprocesses. Information seeking and use can be viewed as a continuum of various levels of sensemaking, ranging from fitting information directly to its need (for example, a task like catching a plane that can be supported with a factoid answer—the departure time) to very complex sensemaking activities illustrated at the beginning of the paper. Sensemaking is particularly important when people are faced with new situations and complexity in work tasks such as decision making, strategy development, and policy making (Kurtz & Snowden, 2003).

Previous research on sensemaking, broadly defined, has examined the information-seeking aspects extensively, while research on the construction of the knowledge representations has been by and large descriptive. Several important questions about the creation and updating of the knowledge representations and about the cognitive process and mechanisms behind such changes still go unanswered. Research in learning and cognition and in task-based information-seeking and use behaviors all bring useful insights to sensemaking research. Through the development of a theoretical framework and a comprehensive sensemaking model this paper aims at providing some insight into the unanswered questions.

The purpose of this paper is to construct a comprehensive model of the cognitive process and mechanisms of individual sensemaking by fitting together components from sensemaking models, learning theories, and cognitive psychology, as they discuss sensemaking mechanisms. Table 1, itself a product of a sensemaking process, provides a listing of all the elements from the sensemaking and learning models discussed in the following in an integrated structure; thus, it provides a useful framework for the description and discussion of these models. The reader may also want to look ahead at the complete model in Figure 17 as a context for the discussion. The Online Appendix (www.dsoergel.com/ZhangSoergel2013Appendix.docx) has a full version of Table 1 (TABLE A-1) and two additional tables: Table A-2 lists for each model the activities and gives for each activity the combination of characteristics from this classification; Table A-3 gives for each element of the classification the corresponding activities from all models.

We base our analysis on a selection from the sensemaking and related literatures. We aimed to include all major sensemaking models. First we identified the interdisciplinary areas where research on sensemaking has been done, including HCI, cognitive system engineering, organizational communication, and library and information science (LIS). We then examined each area and identified major sensemaking models, whether so labeled or not, paying particular attention to models that added new features. We cast a wider net to include practical task areas for which sensemaking is discussed most often, for example, intelligence analysis, organizational practice, and criminal investigation, to add models we found useful. We decided not to include sensemaking models that did not further contribute to the formation of our comprehensive model (as the information-seeking and learning models did), for example, Snowden's multi-ontology sensemaking (Snowden, 2005), Vivacqua and Garcia's sensemaking state diagram (Vivacqua & Garcia, 2009), and Wu et al.'s spatial sensemaking model (Wu, Zhang, & Cai, 2010). As mentioned earlier, we consider conducting research and most of learning as forms of sensemaking; we also wanted to acknowledge the importance of information search for all these activities. So we added representative search and learning models selected for their intellectual appeal and their contribution to our overall model. For learning and cognition theories, we selected theories or models relevant to either the overall process or any components of sensemaking and useful in explaining the cognitive process and mechanisms inside the process and activities.

We used conceptual analysis to identify the main components of the sensemaking process. For each sensemaking model we identified the components (often referred to as "processes" or "steps") and how the components are combined (often referred to as "loops," "cycles," or "phrases"). Then we compared the components across all sensemaking models, identified processes that are common to many and sequences of processes that appear repeatedly; we also recognized variance in steps and sequences of sensemaking.

The remainder of the paper is organized as shown in Figure 2: We first review relevant theoretical and empirical research in many areas that contribute to our framework or model and then describe the comprehensive model. We conclude with a discussion of future sensemaking research directions. This paper is based on the first author's dissertation (P. Zhang, 2010) with appropriate updates.

Contributions From Sensemaking Models in HCI, Cognitive System Engineering, Organizational Communication, and Library and Information Sciences (LIS)

Several sensemaking models have been proposed for different purposes, such as:

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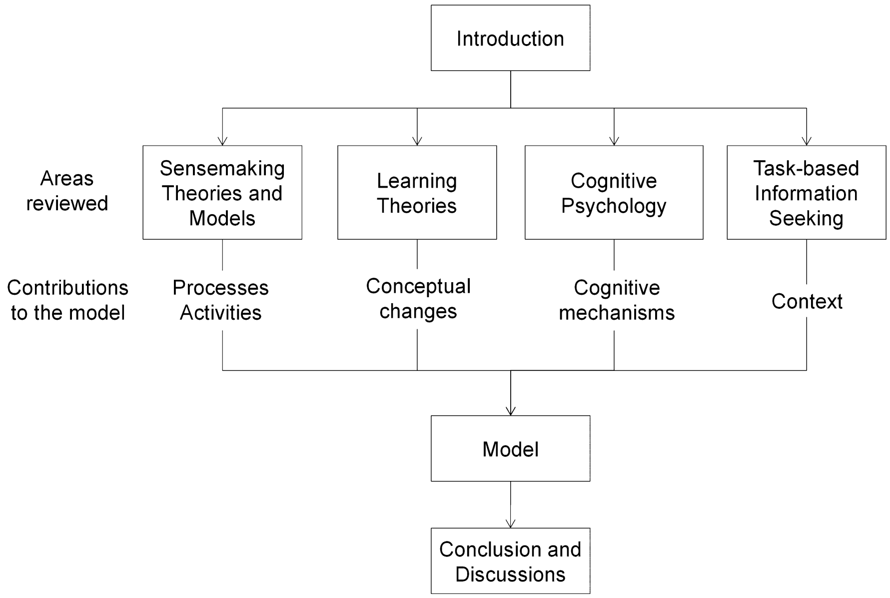

FIG. 2. Organization of the paper.

- To provide an analytical abstraction derived from empirical user studies (Russell et al., 1993; Klein et al., 2006b; Qu, 2003; Qu & Furnas, 2008);
- To describe the sensemaking processes, either of particular or generic user groups (Krizan, 1999; Pirolli & Card, 2005).

The existing models are by and large descriptive of the activities and processes involved in individual or collaborative sensemaking and do not explain the cognitive mechanisms the sensemakers use (see sections Contributions From Learning Theory and Contributions From Cognitive Psychology).

Norman and Bobrow's Model

This model comes from cognitive psychology but is quite similar to models in HCI. Figure 3 shows the schemata representation of the human information-processing system. Physical signals in the external representation get through the sensory system to become the data pool from which schemata are constructed to support communication and decision making (Norman & Bobrow, 1976).

Russell's Sensemaking Model

Through several case studies, Russell et al. (1993) explored the cost structure of sensemaking. They identified four main processes in sensemaking, shown in Figure 4.

1. Search for representation (structure or schemas; generation loop): the sensemaker creates both representations and the procedures that use them.
2. Create instances of representations (data coverage loop): the sensemaker identifies information of interest and encodes it in (fits it into) the representation.
3. Modify representation (representational shift loop): when some data do not fit well (or not at all) into the representation, the sensemaker modifies the representation (restructuring).
4. Consume instantiated schemas: the sensemaker uses the instantiated schemas in the task-specific information-processing step.

The schemas provide top-down or goal-directed guidance, by prescribing what to look for in the data, what questions to ask, and how the answers are to be organized.

Structural representation plays a crucial role in all processes. The generation loop represents the construction of a structural representation; the data coverage loop represents the fitting of data or evidence into the structure. When there is a mismatch between the representation and the data, a residue of data that do not fit remains, and the representational shift loop takes place to reconstruct the representation. As presented, Russell et al.'s model starts with representation, that is, in the structure-driven mode. The initial representation could also be generated from the data (data-driven). In either case, the representation is checked against the data and modified as needed.

Pirolli and Card: Notional Model of Sensemaking

Through cognitive task analysis (Chipman, Schraagen, & Shalin, 2000), Pirolli and Card (2005) proposed a detailed model of the steps in the sensemaking process, the variables involved, and a general flow of how they interact. Their model was developed to describe the work of intelligence analysts where the product of sensemaking is a presentation or report. The overall flow of sensemaking follows the path:

Information → schema → insight (hypotheses) → product

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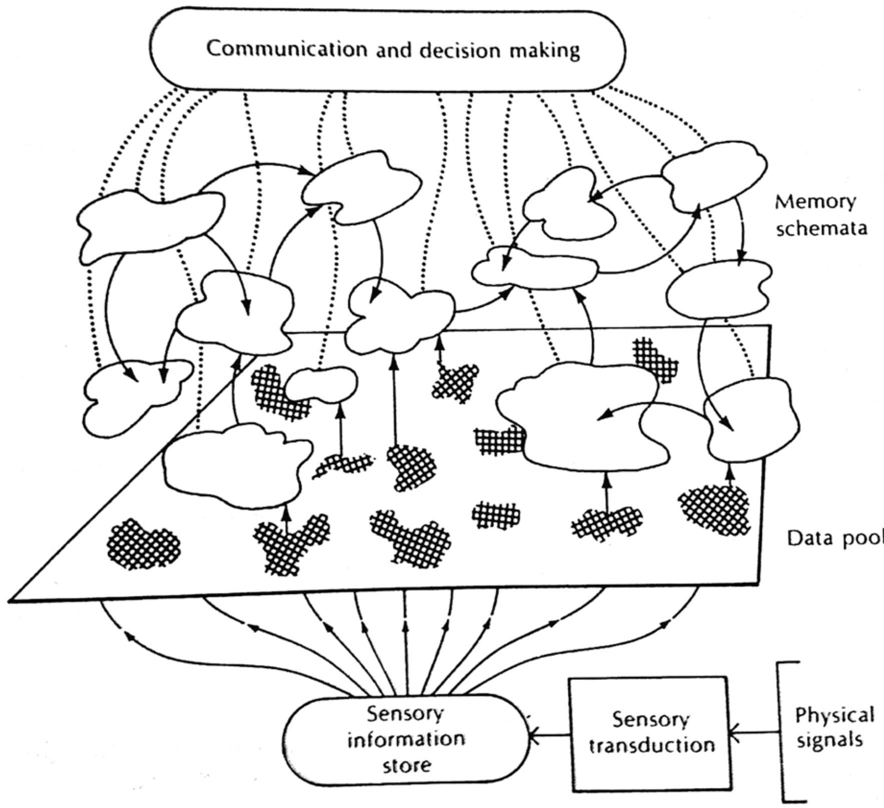

FIG. 3. The memory schemata view of the human information-processing system (Norman & Bobrow, 1976, Figure 6.2, p. 118). Reprinted with permission.

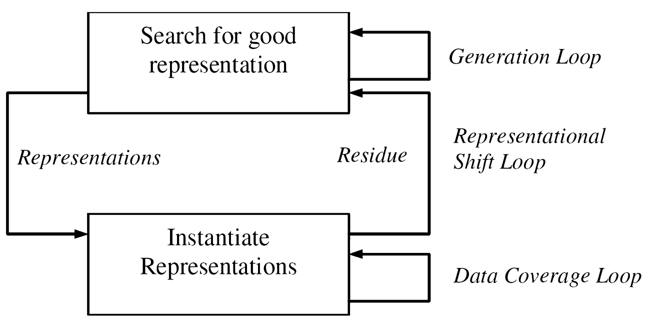

FIG. 4. Russell's sensemaking model (Russell et al., 1993, p. 271). Reprinted with permission.

Cognitive task analysis (CTA) identified two loops of activities:

- An information "foraging loop" that involves searching for documents in external data sources and filtering them for relevance and then "reading and extracting information into some schema," and
- A "sensemaking loop" that uses the schema to iteratively "develop a mental model (conceptualization) that best fits the evidence": The schema that aids analysis; the development of insight through the manipulation of this representation; and the creation of some knowledge product (a presentation) or direct action based on the insight.

This process starts out in a data-driven mode, but the analyst often goes back to a previous step as shown in Figure 5 through arrows in both directions. Figure 5 illustrates 10 processes and six representations (ranging from external raw data to the final task presentation) of the sensemaking process for intelligence analysts. External data sources are raw evidence, largely in textual form. The "shoebox" is a much smaller subset of the external data that is relevant for processing. The evidence file refers to snippets extracted from items in the shoebox. Schemas are the re-representation or organized marshaling of the information so that it can be used more easily to draw conclusions. Hypotheses are the tentative representation of those conclusions with supporting arguments. Ultimately, there is a representation in the sensemaker's mind or externalized in a report, based on which the sensemaker or (most likely in the intelligence context) the recipient of the report can make a decision and execute an action.

The Data/Frame Theory of Sensemaking

Klein et al.'s (2006b) data/frame theory (Figure 6) elaborates on Russell's data coverage loop and the representation loop as the two major cycles of sensemaking activities, including:

1. An elaboration cycle where the sensemaker elaborates the structural representation (frame) by adding detail,

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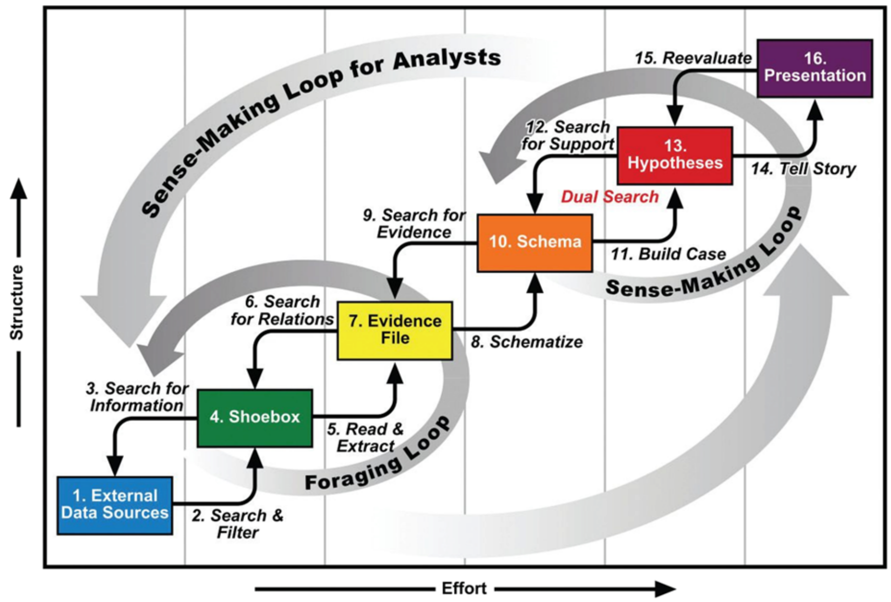

FIG. 5. Notional model of sensemaking loop for intelligence analysis (Pirolli & Card, 2005). Reprinted with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

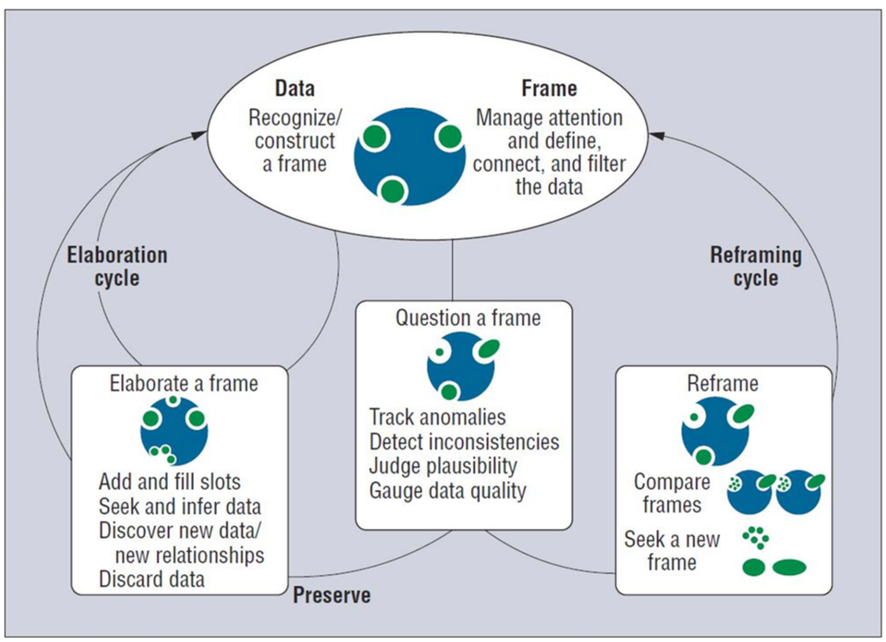

FIG. 6. The data/frame theory of sensemaking (Klein, Moon, & Hoffman, 2006b). Reprinted with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

questioning the frame and its explanations. Data that do not fit (Russell's "residue") may be explained away to preserve the frame, or it may result in

2) A reframing cycle (Russell's "representational shift loop") where the sensemaker rejects the initial frame and seeks to replace it with a better one.

Klein et al. (2006b) further pointed out that the elaboration cycle corresponds to Piaget's "assimilation," and the reframing cycle is similar to Piaget's "accommodation" (Piaget, 1936, 1976; see the section Types of Conceptual Change).

Krizan's Cyclical Model of the Intelligence Process

Intelligence analysis, a typical and intensive sensemaking task, has been investigated extensively. The process of

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intelligence creation and use (in government or business) follows a series of repeated and interrelated steps (Krizan, 1999). Each step adds value to the inputs and together they create a substantially updated report. The analysis (sensemaking) processes convert "information" into "intelligence" for planners and decision makers.

This model focuses on five critical steps, again in a data-driven mode (Figure 7):

1. Planning/tasking: intelligence needs are assigned or provided by customers (end users) to analysts. Intelligence needs are often complex and time-sensitive. Intelligence analysts need to interpret the customer requirements before the task can be processed.
2. In the collection step, analysts acquire information from various sources, including people and information systems.
3. Processing is the selection of raw information based on its plausibility, expectability, and support to intelligence issues.
4. In the analysis step, analysts try to make sense of the selected information and make higher-level analyses including giving descriptions of the task domain, establishing explanations of phenomena, and interpreting cause and effects.
5. In the production step, an intelligence report giving "value-added actionable information" is created by synthesizing the information extracted from all available sources, including the intermediate products of previous steps, to create a comprehensive assessment of an issue or situation.

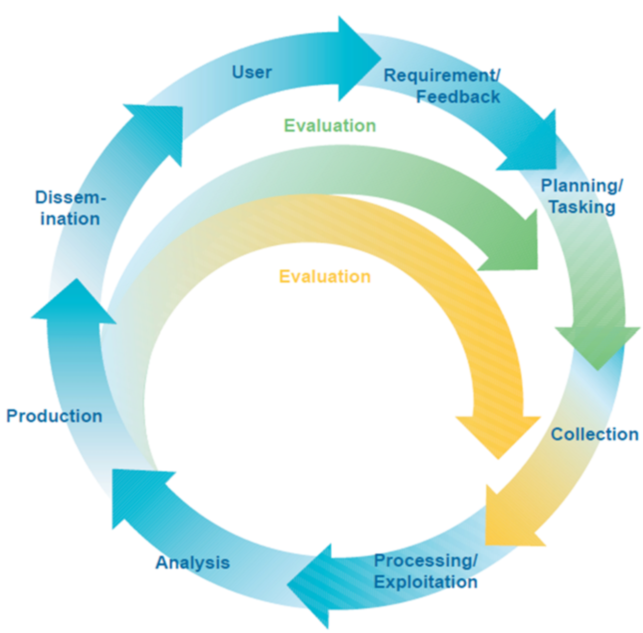

FIG. 7. The cyclical model of the intelligence process (Krizan, 1999). Reprinted with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

The intelligence report is disseminated to the customers for action and for evaluation and feedback; a next round of sensemaking activities may follow.

Barrett's (2009) Sensemaking in Criminal Investigation

Criminal investigation and intelligence analysis share similar task complexity and data incompleteness. Making sense of terrorist or criminal actions involves generating, elaborating, and testing alternative plausible hypotheses, which is representative of complex sensemaking tasks. Investigative sensemaking activities (Figure 8) involve explaining the event behind the data collected, speculating about other possibly related events, and inferring plausible hypotheses that explain the situation. The sensemaker (such as a jury or detective) tries to create a meaningful understanding of the evidence gathered through witnesses, exhibits, and arguments at trial. Through constructive mental activity, possibly recalling earlier cases, the investigator creates one or more stories to interpret the evidence (Pennington & Hastie, 1991). (The stories are the structure in this case; this is initially a data-driven process.) The model describes the interaction of knowledge structure with investigative evidence in the environment to inform the generation and testing of stories/hypotheses.

This model adds a second way in which knowledge structure and data interact: The knowledge structure (activated by investigative goals) guides data collection. Some of the data collected may in turn activate knowledge structures already held by the sensemaker, and these knowledge structures added to the active set in turn guide the collection of still other kinds of data—an iterative process. The important points here are: (a) Data collection is not a "neutral" process; the attention of the sensemaker is focused and guided by knowledge structures active in the sensemaker's mind; (b) When data do not fit the active structure(s), the sensemaker can either change the structure (as in Russell's and many other models) or he/she can activate another structure he/she already knows to accommodate the new data. Such activation may also occur when a single data item is discovered. For example, when it is discovered that a member of a group suspected of terrorism is a specialist in making nail bombs, the structure for bombing at public gatherings is activated and guides the collection of a whole different set of data. If the sensemaker does not have the needed structures at hand this may trigger a search for structure (see Qu & Furnas, 2008).

Among the sensemaking processes illustrated (investigation, evaluation, and conclusion), the essential part, investigation of cues and knowledge via mental representations, includes activities such as:

- Generation of structure (hypotheses) to explain data
- Evaluation of completeness and coherence of structure and mental representation
- Evaluation of conflict within mental representation (alternative hypotheses)

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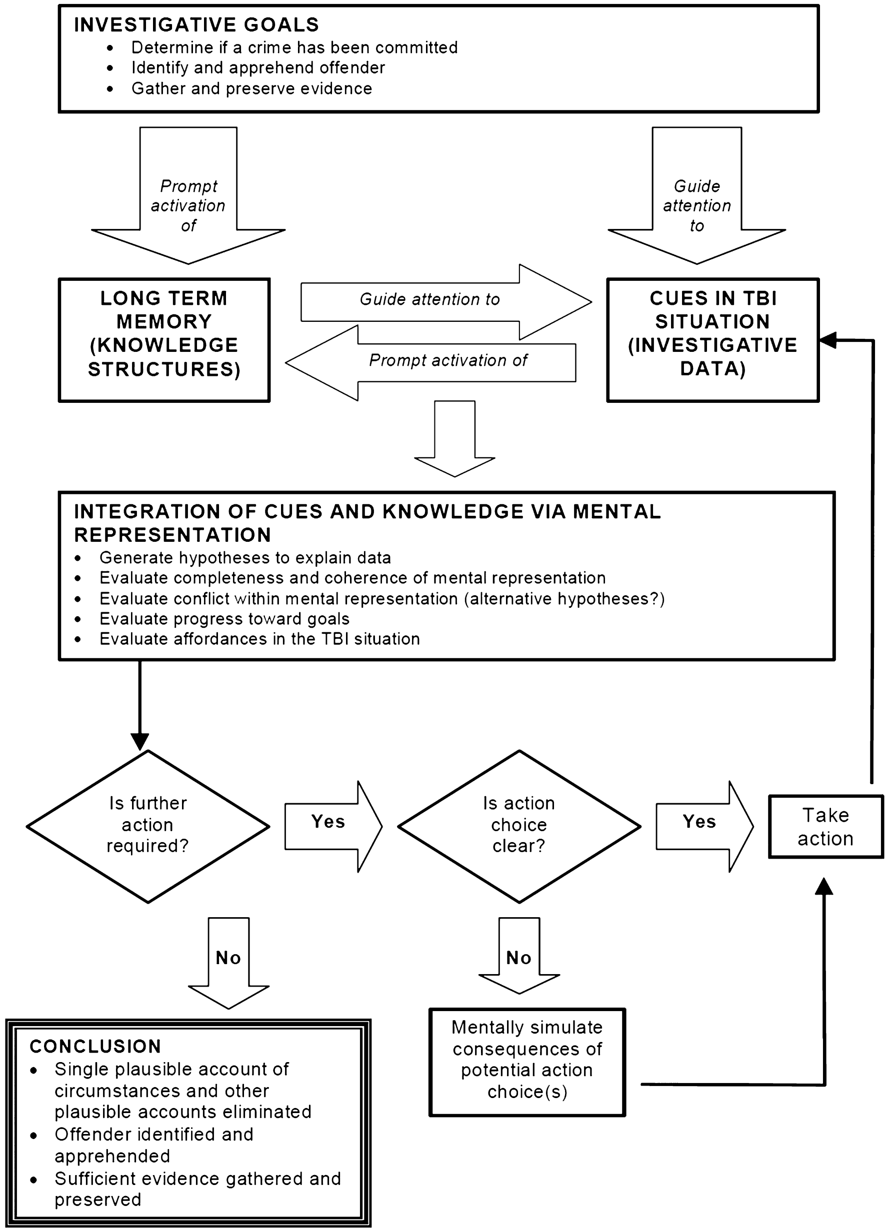

FIG. 8. Investigative sensemaking model (Barrett, 2009, Figure 1.2, p. 24). Reprinted with permission.

Louis (1980): Sensemaking in Organizational Entry

When a newcomer enters an organization, he or she needs to make sense of the new environment. Louis (1980) identified several inputs to such sensemaking, including other's interpretations, local interpretation schemes, and predispositions and purposes and past experiences (Figure 9). These inputs enter the sensemaker's interpretation process to attribute meaning, which leads to responding actions and an updated understanding. Data collection occurs in the process of interaction with others in the organization. Sensemaking, building a structure and understanding of how the organization works, occurs incrementally, with small updates often immediately guiding action in the moment.

Organizational Sensemaking

The study of organizational sensemaking has identified the same pattern of sensemaking as an iterative process of (a) searching and (b) sensemaking, narrowly defined (Weick, 1995; Weick, Sutcliffe, & Obstfeld, 2005; Choo, 1998, 2006). Choo (1998, 2006) frames the organization's adaptability in a dynamic environment into a twofold challenge: sensing and making sense. *Sensing* means noticing potentially important messages in the environment—acquiring information about events, trends, and relationships in an organization's external environment in which every part is interconnected with other parts in complex and unpredictable ways. *Making sense* means constructing meaning from

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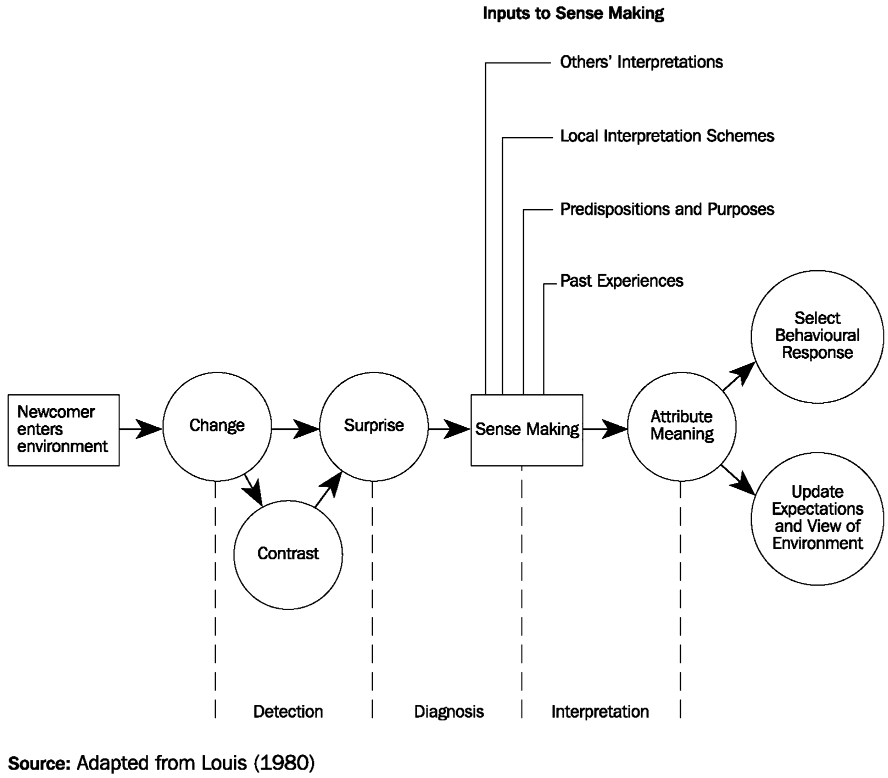

FIG. 9. Inputs of sensemaking in organizational entry (Louis, 1980). Reprinted with permission.

the data about the environment that have been sensed. The challenge for sensemaking is that there are multiple interpretations. Organizational sensemaking is inherently a "fluid, open, disorderly, social process" (Choo, 1998, p. 67).

Conducting Research as Sensemaking

Conducting research is a sensemaking process. Researchers start with a lack or discontinuance of knowledge, recognize the gaps to be filled (research questions), and conduct research using various methods to bridge the gaps.

Compared to sensemakers in other scenarios, researchers undertake a more systematic approach to identifying gaps; they explain specifically what they attempt to learn or understand, explicitly articulating a research topic and one or more research questions and subquestions (Creswell, 2003; Maxwell, 2005). Researchers then (a) collect data (search) and (b) analyze and interpret the data (sensemaking, narrowly defined).

Often the data do not exist anywhere to be "retrieved" (exceptions include secondary analysis, meta-analysis, and analysis of historical documents); researchers need to collect data in experimental or natural settings. Quantitative and qualitative methodologies take different approaches to making sense, answering the research questions. In general, the quantitative approach is structure-driven (deductive, or top-down), starting with a hypothesis, collecting experimental data (often in controlled conditions), and conducting statistical analysis to test if the data support the hypothesis (Kirk, 1995); however, there are also data-driven quantitative approaches such as exploratory data analysis and data mining. The qualitative approach, on the other hand, may use a combination of deductive and inductive data analysis (Potter, 1996). For example, a researcher may use the grounded theory approach, "grounded" in the data (data-driven) and developing increasingly higher-level concepts and theoretical models (Denzin & Lincoln, 2003). During this process new questions often emerge—data activating structure or leading to the construction of new structure.

The final product of research is usually a presentation describing the data and the sense made (findings and conclusions). Several intermediate products such as coding schemas, case reports, and researcher notes may be produced to assist sensemaking.

Research as sensemaking should also be seen in a larger context, not confined to individual studies but to the research program of a person or group or research enterprise in a subject domain. Much research is exploratory, creating structure to guide further research.

Qu and Furnas (2008): Structural Information-Seeking Model

A common theme of the comprehensive models discussed in this section is the interaction between structure/frame and data. Qu and Furnas (2008) focus on a

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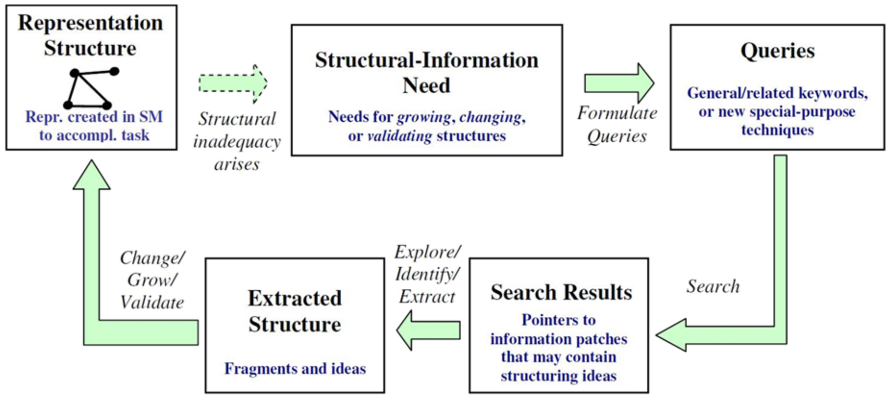

FIG. 10. Structural information seeking (Qu & Furnas, 2008). Reprinted with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

subprocess, searching for structures. They highlight the need for finding structure as an information need in its own right when the representation is inadequate, incomplete, or ill-formed and the need for changing, growing, or validating structures arises or when a piece of data "calls for" a structure into which it fits. This is related to the observation by Barrett (2009) that pieces of data may activate structures, except that they think of structures that the sensemaker already has at hand while Qu and Furnas (2008) talk about new structures to be acquired. Qu and Furnas analyzed and developed a model for the process of seeking structures (Figure 10).

Information-Search and Use Models and Learning Models

In this brief section, we present, by way of comparison, representative models of information search and use and models of learning. Together they roughly describe the same overall process as defined in the broad meaning of sense-making from a different perspective.

Soergel's (1985) search process model (Figure 11) is a very general normative model. Kuhlthau's (1991, 1993, 2004) information-search process (ISP) model (Figure 12) was developed primarily in the context of students' searching for information needed for school assignments; it identifies the affective, cognitive, and physical behaviors. Nesset's (2013) preparing, searching, and using (PSU) model (Figure 13) captures the information-related activities in the conduct of an instructional unit in a school. It identifies positive and negative feelings that accompany the activities in each stage. It adds the preparation stage, which is useful in general, not just for students. Neuman's (2011a,b) I-LEARN model (Figure 14) describes the process of learning with information. It is a normative model that draws on information-seeking behavior models and theories of learning/instructional design. The Alberta Inquiry Learning Model (Alberta Learning. Learning and Teaching Resources Branch, 2004; Figure 15) was developed as a guide for learning and instruction.

The notes in () refer to the corresponding general systems analysis functions

1	Recognize and state the need (define objectives).	**7**	**8**
2	Develop the search strategy (design):		
	a formulate the query conceptually;	I	M
	b select and sequence sources;	N	O
	c translate the conceptual query formulation into the language of each source	T E R	N I T
3	Execute the search strategy (system operation).	A	O
4	Review search results (evaluation 1).	C T	R
5	Edit search results (system operation).	during the entire search.	
6	Check helpfulness of the results (evaluation 2).		

FIG. 11. General search process model (Soergel, 1985, p. 343). Reprinted with permission.

Summary

Sensemaking is an individual or collective construction of knowledge. The models discussed in this section all attempt to describe the process whereby knowledge is created. Despite the differences, the basic pattern of iterative interaction between search for data and creating a structure that makes sense of the data (see Figure 17) is in common to all models. They differ in detail, in what aspects they emphasize in defining subprocesses, and often in the sequence of steps. Table 2 compares different sensemaking models and illustrates the common processes.

Several important points are raised in the sensemaking literature:

Sensemaking is comprised of iterative information seeking (the acquisition of data, sensing) and sensemaking (the creation of a knowledge structure, making sense) processes. For the information-foraging/seeking loop, the evolution of a user's interests depends upon the changing characteristics of the information context. New information gives users new ideas and directions to follow. Users use information from the current situation to decide where to go next (Bates, 1989; Ingwersen & Järvelin, 2005). Researchers have identified the important role of exploratory search and developed systems to support it (Baldonado & Winograd, 1997; Qu, 2003). The sensemaking loop, on the other hand, including activities such as summarizing, organizing, and identifying patterns, is not as well supported. A key task in sensemaking is to identify patterns of concepts and relationships to build on.

Data and structure play different roles in creating knowledge representations. Russell et al.'s model (1993) illustrates that the major cost of sensemaking is related to the structural representation, including the cost of finding or building a representation to support required operations in the target task, and the cost of instantiating the representations. Research indicates a separation of data and structure in sensemaking tasks and the use of external representations for tasks where information processing is complex (J. Zhang, 1997, 2000).

Data and structure are intertwined. The sensemaker may select and activate structures based on the knowledge required for the work task, either from the sensemaker's memory or through search for structure. Active structures may guide the acquisition of data. Or, the sensemaker acquires data largely unguided. Data may lead to structure in two ways: A piece or configuration of data may activate an existing structure—from the sensemaker's memory or acquired through search for structure (for example, based on cue extraction, Seligman, 2006) or the sensemaker creates a new structure that accommodates the data. Regardless of how the structure is created and activated, the sensemaker tries to fit data into active structures (instantiate the

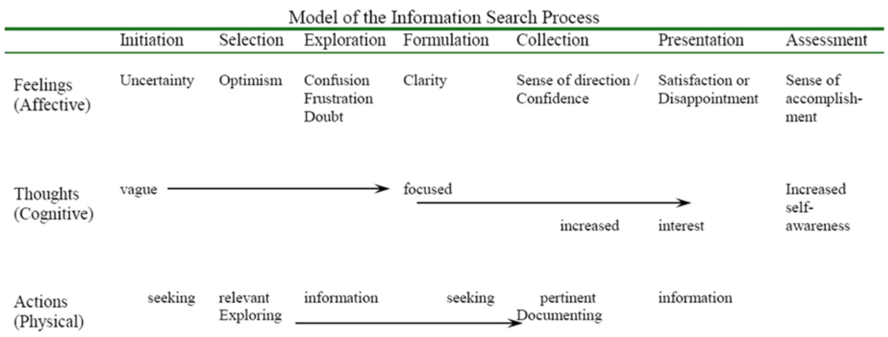

FIG. 12. Model of the information-search process (Kuhlthau, 2004, p. 82). Reprinted with permission. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

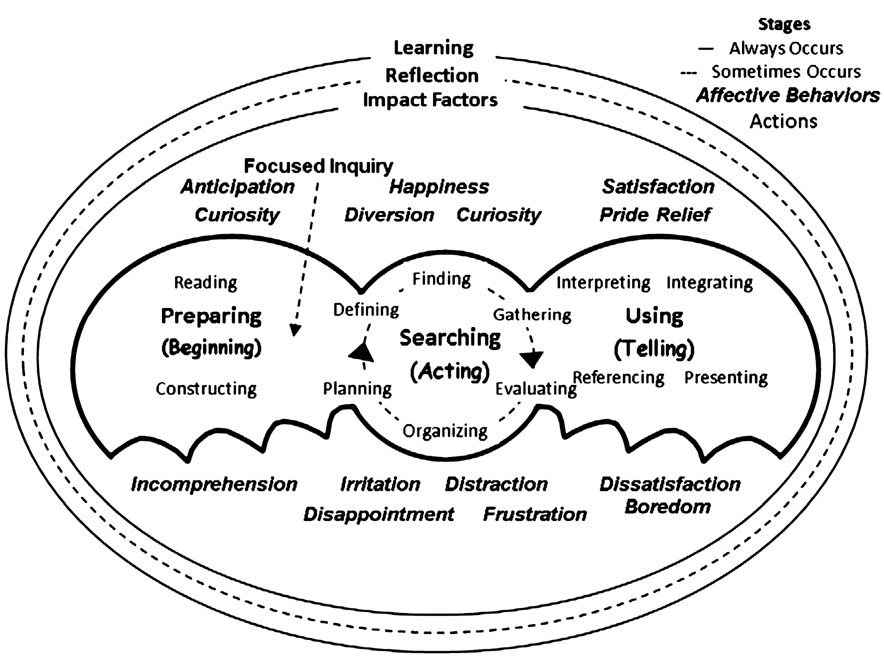

FIG. 13. Model of the information-search process (Nesset, 2013, p. 100). Reprinted with permission.

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TABLE 2. Elements in selected sensemaking models (the sequence of elements in the model may differ).

		Dervin, 1992, 1998	Krizan, 1999	Pirolli & Card, 2005	Russell et al., 1993	Qu and Furnas, 2008	Klein, et al., 2006b	Maxwell, 2005; Kirk, 1995
Task analysis		Gap identification	Task planning					Research goal and questions
Search	**Exploratory search**	May include both gap identification and gap bridging	Data collection	Search for & filter information		Determine structural information need	Recognize a frame	Search for theoretical framework
	Focused search • Finding sources • Extracting data & structure			Search for evidence	Search for representation	Search for structures	Elaborate a frame	Data collection
Sense-making (narrow meaning)	**Fitting data into structures**		Interpretation and analysis	Search for support	Create instances of representations		Define, connect and filter the data	Data analysis
	Building structures			Schematize	Search for representation	Explore / identify extract structure	Construct and question a frame, reframe	
	Updating knowledge	Gap bridging		Build-case	Consume instantiated schemas	Change, grow, validate structure	Preserve a frame or reframe	Interpretation & conclusion
				Reevaluate hypotheses	Modify representation			
Preparing task output			Production and dissemination	Tell story				Writing papers, reports, or books

structures data); put differently, the sensemaker tests the structure against data by judging plausibility and detecting inconsistencies (Klein et al., 2006b). Data that do not fit lead the sensemaker to modify structures or activate additional existing structures. In short, structure guides data acquisition, sensemakers fit data into structures, nonfitting data may activate existing structures or lead the sensemaker to build or update structures. Thus, sensemaking does not always have clear beginning and ending points. The simplified waterfall or cyclical model rarely applies; rather, there is often a back-and-forth between several steps before moving on, as shown through empirical evidence about several sensemaking tasks, for example, expert decision making (Klein et al., 2006a).

To summarize, previous research has identified important processes involved in sensemaking, involving the interrelated activities of the search for data and the creation of an understanding. The importance of structure associated with the processes is recognized: not only do structures influence how people seek for information, they are critical to the creation of an understanding. It seems quite clear that sensemakers seek structures in sensemaking tasks and their sensemaking processes are closely related to the structural representation of task situations. However, the sensemaking models discussed in this section are by and large descriptive of the activities and processes involved in individual or collaborative sensemaking; they do not delve into the cognitive process and mechanisms that contribute to the creation, modification, and update of structures when existing external structures are not available or ready to use. They do not address questions such as:

- What types of conceptual changes occur during the sensemaking process and how do they occur?
- What mechanisms trigger the changes and enable the assimilation of new information and the creation of a structural representation?
- What are the cognitive processes and structures by which knowledge is created and stored during the sensemaking process?

This paper aims to enhance existing sensemaking theories by incorporating ideas from learning and cognition to gain a more in-depth understanding of sensemaking.

Contributions From Learning Theory

Learning is more than the collection of inputs and the production of outputs. The mind has the ability to extract, analyze, synthesize, and formulate received information and stimuli and then to produce abstractions and representations that go beyond what can be directly attributed to the input given (Gredler, 2008). Much learning is sensemaking, especially using recorded information or systematic discovery to learn concepts, ideas, theories, and facts in a domain, such as science or history. We do not deal with rote learning, drill, and practice for mental or physical skills, or other forms of learning where sensemaking is not central.

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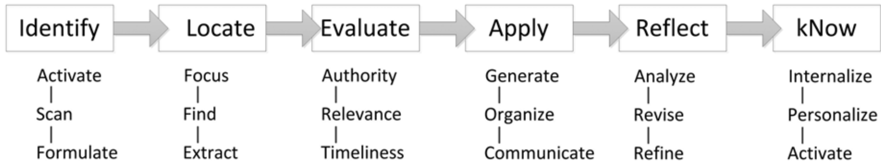

FIG. 14. I-LEARN stages and elements (Neuman, 2011b, p. 97). Reprinted with permission.

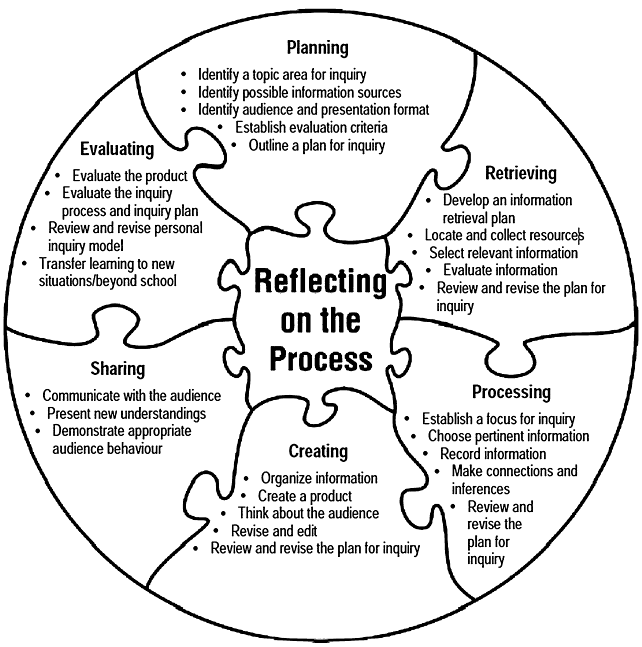

FIG. 15. Inquiry learning model (Alberta Learning. Learning and Teaching Resources Branch 2004, p. 10). Reprinted with permission.

Experiential learning, while not the focus of this section, falls within the broad parameters of the learning models presented earlier and the learning theories reviewed here. In this section, we review learning theories that elaborate on sensemaking and the types of conceptual changes that occur in sensemaking. Learner and sensemaker are used interchangeably.

Learning Theories as Theories of Sensemaking

All the learning theories that will be discussed here revolve around the same basic idea: fitting new information into an existing or adapted structure; they differ in emphasis and nuance. For a summary comparison of learning theories, see Grabowski (1996).

Assimilation theory (theory of meaningful learning) (Ausubel, Novak, & Hanesian, 1978). In meaningful learning a new piece of information is assimilated to an existing relevant aspect of the learner's knowledge structure:

- The development of new meanings is built on prior knowledge, that is, relevant concepts and relationships. Structure plays a crucial role in meaningful learning.
- When meaningful learning occurs, relationships between concepts become more explicit, more precise, and better integrated with other concepts and relationships.

Rote learning and meaningful learning are on opposite ends of a continuum (Novak, 1998). Some direct fitting of facts into existing knowledge structure without understanding its relationships may be similar to rote learning.

Schema theory (Rumelhart & Ortony, 1977; Rumelhart & Norman, 1981a,b; R.C. Anderson, 1984). Schema theory posits that knowledge is stored in human memory as schemas (interconnected concepts and relationships) that are actively constructed by the learner and organized in a meaningful way. Schema theory implies that sensemaking is facilitated by prior general knowledge and generic concepts (about the task and the domain). When new information is acquired, the sensemaker needs to actively construct a revised or entirely new knowledge structure. When new information is ill-fitted (Russell et al., 1993; Klein et al., 2006b), sensemakers feel internal conflict and need to filter the data or refine the structure. When the mismatch between data and structure or the difference between competing structures is too great, the sensemaker may experience *cognitive dissonance* which needs to be resolved (Cooper & Carlsmith, 2001; Festinger, 1957).

Generative learning theory (Wittrock, 1990; Grabowski, 1996). The learner is actively engaged in the learning process, working to construct meaningful understanding of information found in the environment. Much of what is learned is grounded in the situation where learning takes place (Lave & Wenger, 1991; J.R. Anderson, Reder, & Simon, 1996). Two types of meaningful relations are important for learning to occur:

- Among the parts of new information and
- Between new information and experience (prior knowledge)

Comprehension occurs by formulating connections between concepts, rather than simply "placing" information into memory or "transforming" information in memory. Wittrock (1990) (p. 354, cited from Grabowski, 1996) gives examples of the results of generative activity: "titles, headings, questions, objectives, summaries, graphs, tables, and main ideas" (with a focus on "organizational relationships between different components of the environment") and "demonstrations, metaphors, analogies, examples, pictures, applications, interpretations, paraphrases, and inferences"

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TABLE 3. Types of conceptual change.

Piaget, 1936, 1976	Chi, 2007	Rumelhart & Norman, 1981a	Vosniadou & Brewer, 1987
Assimilation	Adding new knowledge Gap filling	Accretion	(deals only with structure changes)
Accommodation	Conceptual change	Tuning Restructuring	Weak-revision Radical restructuring

(with a focus on the "relationships between the external stimuli and the memory components").

Structural Knowledge Acquisition. Perhaps the central concept related to learning and sensemaking is structural knowledge. Structural knowledge plays a key role in the creation of new understanding or reframing of existing knowledge. For example, learners who were given the task of creating a semantic network performed significantly better on other learning tasks such as relationship judgments (Jonassen & Wang, 1993).

Structural knowledge supports higher-order thinking in the form of analogical reasoning. The acquisition of structural knowledge may be a direct result of structural information seeking (Qu & Furnas, 2008) or may be taught, or it may be a result of generative activities described by the learning theories discussed in this section. The construction of personally relevant knowledge structures is the key to individual sensemaking. Structural knowledge acquisition improved significantly by focusing the learner's attention on structural aspects of the information in the environment. Visual tools help the acquisition of structures. The best task performance on analogy was achieved by learners who work with visual support of a graphical browser and focus on structural relationships (Jonassen & Wang, 1993).

Types of Conceptual Change

Learning theory postulates types of conceptual changes in the mental representation of knowledge in learning/sensemaking. Piaget (1936, 1976) identified two types of cognitive/conceptual change in knowledge acquisition:

- Assimilation: the addition of information to existing knowledge structures
- Accommodation: the modification or change of existing knowledge structures

Following Piaget, the schema theorists distinguished three ways in which existing schemas can be modified by new experience or information (Rumelhart & Norman, 1981a,b; Vosniadou & Brewer, 1987):

- Accretion (Piaget's assimilation): the gradual addition of factual information within existing schemas without schema change. Accretion may add new data when prior data are completely missing or fill gaps when prior data are incomplete (Chi, 2007).

Piaget's accommodation is refined according to the degree of structure change:

- Tuning: Evolutionary conceptual change in the schemas for organizing and interpreting information, or weak revision, the modification of existing knowledge structures. These changes may involve "generalizing or constraining the extent of a schema's applicability, determining its default values, or otherwise improving the accuracy of the schema" to best fit the data (Vosniadou & Brewer, 1987, p. 52).
- (Radical) restructuring: conceptual changes that involve the radical change of existing structures or creation of new structures. Such radical changes often take place when prior knowledge conflicts with new information. New structures are constructed either to reinterpret old information or to account for new information.

Table 3 shows a comparison of conceptual change recognized in the literature.

For accretion to occur, sensemakers need to recognize how well new information fits into an existing schema in their knowledge. For weak revisions, the concepts themselves are not radically changed; they may be broadened or their definition otherwise slightly changed. Similarly, the nature of links may change slightly, and a few connections may change without changing the basic structure that connects the concepts. Such change can result from the concepts having acquired more attributes, certain attributes becoming more or less salient, and so forth. Radical changes or abrupt changes, on the other hand, occur when new concepts and relationships are introduced to either complement or replace the existing concepts and relationships in the knowledge structure.

Contributions From Cognitive Psychology

This section reviews theories in cognitive psychology that deal with internal and external representations of knowledge structure and with the mechanisms that trigger conceptual changes in such structures.

Knowledge Representations

Choosing the right knowledge representation is extremely important for sensemaking, problem solving, and learning. Sensemaking uses internal representations (or mental models) and external representations (J. Zhang, 1997; Richardson & Ball, 2009), perhaps best viewed as one

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TABLE 4. Three-dimensional classification of types of knowledge.

1 *Declarative versus procedural knowledge*
 1.1 *Declarative:* knowledge about what is (or was or could be)*
 1.2 *Procedural*: knowledge about how to (procedures and processes; J.R. Anderson, 1976, 1983; ten Berge & van Hezewijk, 1999)*
2 *Propositional versus analogical knowledge*
 2.1 *Propositional*: knowledge structure represented as a set of symbols. Most knowledge stored in long-term memory falls into this category. Examples include symbolic logic, semantic networks, schemas, and frames*
 2.2 *Analogical:* knowledge structure that has a direct correspondence between the external world and the internal representation, such as a mental picture of a street view*
3 *Implementation of knowledge representations*
 3.1 *Parallel* and *distributed* representations: knowledge structure that is distributed over a large set of units, also called neural networks*

Note. *From Rumelhart and Norman (1988).

integrated representation consisting of coupled internal and external parts. Internal representations are constructed by the sensemaker and worked on through internal mechanisms. External representations are constructed by the sensemaker or other people or computer programs or the sensemaker working with computer programs; they are worked on by the sensemaker or by computer programs using external mechanisms which are often prescribed. The processes and representations of sensemaking migrate to wherever cost is the lowest (Kirsh, 2009). External representations may be internalized by the sensemaker and become part of her or his internal structures, or manipulated without becoming part of the internal structure. Conversely, internal representations may be elicited and stored as external representations. Tools for externalizing internal representations such as graphic organizers (Ausubel et al., 1978) and tools for generating external representations automatically (computer visualizations) in various application domains are developed to support sensemaking tasks (Gaines, 2010) A sensemaking support tool must help sensemakers to form good representations.

Table 4 shows a classification of types of knowledge and forms of representations (content and form are not clearly distinguishable here), which is based primarily on Rumelhart and Norman (1988). Multiple representational formats may exist at the same time in the representation system, for different pieces of knowledge or the same piece of knowledge (Rumelhart & Norman, 1988).

Different aspects of the world may be represented through different representational formats that map best into the sets of operations one wishes to perform. Propositional representations form the largest part of the knowledge structures that focus on meaning (Rumelhart & Norman, 1988). Many theories in cognition (for example, Rumelhart & Ortony, 1977; Carley & Palmquist, 1992; Jonassen & Henning, 1996) and many data models and theories of text structure agree that representations of propositional knowledge can be seen as built from:

- Entities / concepts
- Relationship types, binary or n-ary relationships
- Statements/propositions connecting two or more entities with a relationship (relationship instances)

Several statements can be connected into maps or networks (concept maps, semantic networks). People use map-like structures to make sense of information (Hoffman, 1992). Schema/frame theory (Wertheimer, 1938; Minsky, 1975, 1977; Rumelhart & Ortony, 1977) views personal knowledge as stored in schemas that comprise mental constructs for ideas. A schema is a package of several propositions, integrated information on a topic. A schema is a structure template (a frame, the definition of a class in object-oriented programming). A schema/frame instance is an instantiated structure (a frame with the slots filled, an object belonging to a class).

Many sensemaking and problem-solving tasks, such as comparing products (in order to choose one) or determining a product price that will maximize profits, require more data than most people can easily manipulate in their minds, so an external representation suitable for the sensemaking task at hand is needed (Faisal, Attfield, & Blandford, 2009). External representations can serve as memory aids to extend working memory, form permanent archives, and allow memory to be shared (J. Zhang, 2000; Kirsh, 2010).

There are many forms of external representation: text, formatted text (as in hierarchical outlines), tabular arrangement of text, diagrams, maps showing relationships between entities (concept maps, semantic networks), tables and graphs of numbers, databases, simulation models, photographs and schematic representation of various objects, just to name a few. They can be mixed and combined in various ways. They are suitable, to varying degrees, to present the different types of knowledge shown in Table 4. Especially diagrammatic and map representations support cognitive mechanisms to recognize features more easily and make inference directly. Spatial, argumentational, faceted, hierarchical, sequential, and network representations are seen in various sensemaking tasks and sensemaking support systems (Ausubel et al., 1978; Faisal et al., 2009). Different forms of representations are found useful at different stages of sensemaking (Attfield & Blandford, 2011). There is a vast literature on the use of external representations in data analysis and sensemaking, for example, Tufte's books on visual display, especially Tufte (2006), Arnheim (1969), books on visual thinking tools and graphic organizers (Hyerle, 2008; Hyerle & Alper, 2011), and books on

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qualitative (e.g., Miles, Huberman, & Saldaña, 2013) and quantitative research methods and statistical analysis.

Sensemaking Mechanisms

Searching and sensemaking processes involve cognitive mechanisms that result in the accretion, tuning, and restructuring of knowledge. Researchers in the areas of reasoning (Toulmin, Rieke, & Janik, 1979; Arthur, 1994; Johnson-Laird, 1999) and reading comprehension (Kavale, 1980), and learning (Vosniadou & Brewer, 1987) reported mechanisms that are important to the understanding of information and creation of knowledge. The mechanisms can be envisioned as falling into two broad categories: data-driven (inductive, bottom-up) and structure-driven (logic-driven, top-down; akin to unsupervised and supervised machine learning). While, in general, the mechanisms tend to belong to one category or the other, the distinction between data-driven and structure-driven mechanisms is not absolute. Some mechanisms may be used in both ways and some mechanisms may not belong to either category.

Data-driven (inductive) mechanisms involve recognizing patterns from data and building on the patterns of similarity and differences to generalize to the abstract structure of knowledge. In complicated problems where little structured knowledge is available, sensemakers look for patterns and use the patterns to construct temporary internal models or hypotheses or schemas to work with (Arthur, 1994). Primarily data-driven mechanisms include:

- Key item extraction: processing text to identify key concepts as expressed by words or phrases (Kavale, 1980).
- Schema induction: the discovery of the regularities in the co-occurrence of certain phenomena (Rumelhart & Norman, 1981a; Vosniadou & Brewer, 1987; Riloff, 1996; Patwardhan & Riloff, 2006).
- Generalization: making claims about groups based on a sufficiently representative sample (Toulmin et al., 1979; Chi, 1992).

Structure-driven/logic-driven mechanisms involve using knowledge schemas and logic to make arguments or reach conclusions. Primarily structure-driven mechanisms include:

- Definition: defining different aspects of a concept, such as purpose, function, and use (Kavale, 1980) or using existing definitions.
- Specification: specifying as conditions or requirements of a problem or task (Vosniadou & Brewer, 1987).
- Elimination: eliminating concepts that do not meet certain criteria in certain attributes (Kavale, 1980).
- Explanation-based mechanisms, or reasoning from cause: examining the causal connections of two phenomena (Toulmin et al., 1979).
- Inference: drawing a conclusion or making a logical judgment on the basis of available evidence and prior conclusions (Johnson-Laird, 1999).

Mechanisms spanning both categories: Some mechanisms can be used either bottom-up or top-down:

- Comparison: the comparison of facts, concepts, or relationships (Kavale, 1980)
  - Similarity: the recognition of common features or attributes shared by concepts (Vosniadou & Ortony, 1989)
  - Differentiation or discrimination: the recognition of different features of concepts (Vosniadou & Brewer, 1987; Chi, 1992)
- Classification: relating a concept to a broader conceptual category and grouping of sufficiently similar concepts (Kavale, 1980); classification is based on comparison. Classification may be manifested through bottom-up approaches such as clustering or unsupervised learning, or through top-down approaches such as assigning items to pre-established categories or supervised learning.
- Analogy and metaphor: concepts from different domains that are alike in some ways, especially in the structural relationships they express, may share common features or belong to a common abstract category and may exhibit other common characteristics (Toulmin et al., 1979; Vosniadou & Ortony, 1989; Gibbs, 2008).
- Semantic fit: examining the reasonableness with which a concept appears to fit a certain slot as it relates to the meaning of the knowledge structure as a whole (Kavale, 1980).

Other mechanisms that do not belong to either the data-driven or logic-driven approach:

- Questioning: asking questions to oneself can be used to assess knowledge levels; asking questions to others can be an effective strategy to bridge gaps in knowledge (Flavell, 1979).
- Socratic dialogue: critical dialogue to facilitate the recognition of inconsistencies in the current schema. Recognition of anomalies can serve an important function in initiating schema restructuring (Vosniadou & Brewer, 1987).

Research found that these mechanisms were used in intelligence analysis (P. Zhang et al., 2008), spatial sensemaking (Wu et al., 2010), and other information-use scenarios related to decision-making and choice-making (Savolainen, 2009).

Contributions From Task-Based Information-Seeking Research

While this literature does not contribute specific elements of the model, it provides important context for sensemaking. Sensemaking as an *information task* is often required for and carried out in the context of a *work task* (application task; Ingwersen, 1992; Ingwersen & Järvelin, 2005; Byström & Hansen, 2005). Some information tasks require a "meta information task," such as making sense of the information landscape before carrying out a search for information; thus, in some cases what is said about work tasks in this section may apply to an information task that is prepared through a meta information task; in other words, a meta information task is to the corresponding information task as an

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information task is to the corresponding work task. Furthermore, the distinction between information task (gathering information, making sense of information) and work task (applying information found or applying the sense made in sensemaking) is somewhat fluid. There are work tasks, such as many decision-making tasks, that consist primarily of manipulating information.

Requirements for sensemaking come from the characteristics of the work task. Ultimately, sensemakers or their "customers" need to complete a work task based upon sense made in the sensemaking task. The internal and external representations constructed during the sensemaking process need to fit the work task, or they must be updated (Russell et al., 1993).

Task-based, information-seeking research examined work tasks with various complexities, such as routine information-processing tasks that require very little case-by-case consideration during the task performance; normal information-processing tasks that require predictable case-by-case consideration; and decision tasks that are most complex and require several decisions specific to each case (Byström & Järvelin, 1995; Vakkari, 1999; Byström, 2002; Vakkari & Hakala, 2000). Among several work task characteristics discussed in the review paper by Kim and Soergel (2005), the work tasks that require at least some degree of sensemaking often involve:

- New situations or problems
- Complex, less structured situations or problems
- A new domain
- An unclear information need

Findings suggest that at different stages of the work task different types of information (domain information, general information about how to solve a problem, and information specific to the work task) were sought; for example, background information, information that is relevant in general terms, is sought at the beginning (prefocus) stage, whereas information that is more specific, more pertinent to a chosen focus, is used at the end of the work task (White, 1975; Kuhlthau, 1991, 2004). Sensemaking tools should provide information organization mechanisms that are flexible enough to support different stages of a work task.

Research in topical relevance (Huang & Soergel, 2006) reveals different ways in which a piece of information may be useful to a work task. For example, a piece of information may be useful to the sensemaking task because it provides information about a similar work task or topic, allowing the sensemaker to transfer solutions to the work task at hand.

A Comprehensive Model of the Cognitive Process and Mechanisms of Individual Sensemaking

Our comprehensive information-seeking and sensemaking model takes account of the iterative nature of sensemaking and emphasizes the creation of instantiated structure elements of knowledge. Building on previous sensemaking models, a few representative information-seeking and learning models, and theories of cognition and learning, the model shows the cognitive processes of sensemaking and provides explanatory power by incorporating the underlying mechanisms and different types of conceptual change. An earlier version of the model was presented in P. Zhang et al. (2008).

Figure 16 shows the elements involved: processes, activities, mechanisms, and outcomes of sensemaking. These

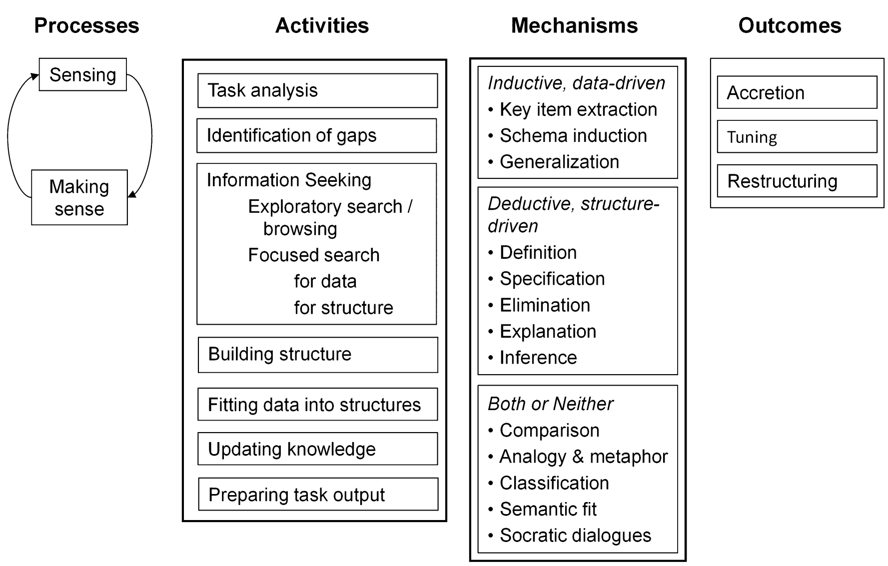
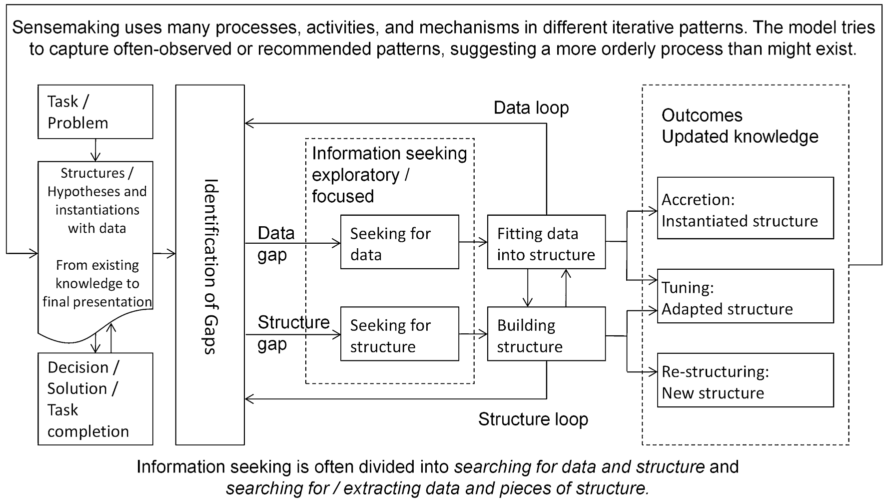


FIG. 16. Sensemaker's toolbox.

DOI: 10.1002/asi



Most sensemaking processes involve both external and internal representations, and the interplay between them. In each process, the cognitive mechanisms listed below can be used as applicable.

Inductive (data-driven, bottom-up)	**Structure-driven (logic-driven, top-down)**	**Both or Neither**
Key item extraction	Definition	Comparison
Restatement	Specification	Analogy
Judgment or evaluation	Explanation-based mechanisms	Classification
Summarization	Elimination	*Stereotyping*
Schema induction	Inference	Semantic fit
Generalization		Questioning
		Socratic dialogues

FIG. 17. A comprehensive model of the cognitive process and mechanisms of individual sensemaking.

elements can be combined in many ways; the activities can be executed in many different sequences, using different mechanisms, and leading to any of the outcomes.

Figure 17 shows a framework in which often-observed patterns can be easily identified but which also allows for many different paths. The sensemaking process consists of several iterative loops of information seeking and sensemaking. The sensemaker starts with her/his existing knowledge (or the lack of knowledge) of a problem or work task situation and ends with an updated conceptual structure, different parts of which may be updated through accretion, tuning, or restructuring.

Sensemakers may start with an exploratory search and identify gaps in the existing knowledge, or identify gaps directly by analyzing the problem or planning the work task. Exploratory search is the pre-focus stage of seeking for information. During this process, sensemakers identify a problem, realize they need more information, and, through exploring or browsing or broad search, learn about what information they need to update their knowledge. During exploratory search, sensemakers may look for both data and structure and move through the structure loop and data loop in an embryonic form.

Focused search is a process in which sensemakers search for information about specific aspects of the work task situation, having specific questions in mind. The questions represent the gaps identified through problem analysis and through exploratory search and browsing.

The identification of gaps occurs at various stages with different levels of specificity. At the very beginning, the identified gap is a loose notion of lack of knowledge on some topic or problem. As searching and sensemaking continue, more specific gaps may be identified, including data gaps and structure gaps.

If a structure gap is identified, sensemakers may, in varying proportions:

- Search for structures created and described by others and put together a structure from what they found combined with what they already know.
- Examine the relationships of various parts of the internal structures in their existing knowledge, look for patterns in the data, and build their own structure or structure modification.

If a data gap is identified, the sensemaker conducts focused search looking for the particular pieces of data, and fits the data found into the previously built structure (instantiating representations). If the data needed are not available from an existing source, the sensemaker needs to either do without the data or conduct original data collection.

There are two mini-loops involved: the data loop and the structure loop (depending on the focus of a particular iteration of the sensemaking process), both of which are embedded in a larger loop of sensemaking in which knowledge is consistently updated. Sensemakers may take various paths, and the loops may be closely intertwined.

DOI: 10.1002/asi

Information seeking/search, whether for data or for structure, can be characterized from three perspectives:

1. Scanning and monitoring the environment versus specific search for information from the environment triggered by problems or work tasks at hand, possibly guided by a representation that needs to be instantiated with data, a representation derived from analyzing the work task.
2. Pre-focus, exploratory search and browsing for structure and data versus focused search.
3. Searching *for* sources versus searching *in* sources (information extraction).

Instantiating structures may result in accretion (the data fit with the existing structure), or in tuning (the sensemaker makes minor modifications on the structure so it fits the data), or in radical restructuring. Using structures created by others (usually found through a search for structures) may result in tuning (the gradual change in knowledge structure) or in restructuring (the radical change in knowledge structure). Different pieces of the structure may remain unchanged or changed through accretion, tuning, or restructuring.

Some sensemakers may start top-down, create structures and then search for data to fit in; others may start bottom-up from the data, and any changes in the structure may be accumulated from observing new data. Accumulated accretion may result in tuning, and accumulated tuning may result in restructuring.

Sensemaking activities use several mechanisms, each serving different functions in the structuring of a conceptual space. The bottom of Figure 17 gives a preliminary list compiled from the literature amended with findings from an empirical user study (P. Zhang, 2010). Cognitive mechanisms may be used alone or in combination. For example, a sensemaker may use the key item extraction mechanism to extract key entities/concepts and relationships as the basic structure elements to build on. He or she may then use specification to specify different aspects or requirements of an extracted concept. Both data-driven mechanisms and structure-driven mechanisms serve to come up with or validate structure; they belong to the structure loop.

We applied this model in an empirical study of sensemaking processes (P. Zhang, 2010). The model proved helpful in understanding sensemaking processes of journalism and business students working on news writing and business plan development assignments, respectively. The analysis of these sensemaking processes led to many refinements of the model.

The ultimate product of sensemaking is an updated knowledge representation, which consists of instantiated structures (or schemas). The mechanisms described earlier influence the creation of instantiated structures and the knowledge update. The sensemaker incorporates the relevant data found in information seeking in the schema; put differently, the final schema accounts for the relevant data. Once the sensemaker incorporates the instantiated structures into his/her existing knowledge and possibly produced a report, the sensemaking is accomplished.

Limitations of the Model

The framework and model presented in Table 1 and Figure 17 is the result of a sensemaking process carried out by the authors working on the inputs discussed. Such theoretical analysis depends always on who does it; thus, our model may be limited by our ability to interpret the input models, clearly identify their component elements, and arrange these elements in an integrated structure that makes sense. This limitation could be overcome by a consensus process among a larger group, but this would be well beyond our means for this analysis.

There are other limitations as well. Sensemaking is often a social process, but our model is limited to individual sensemaking. While affect clearly plays an important role in sensemaking, we focus strictly on the cognitive component. Our model is based primarily on secondary analysis, to a much lesser extent on our own empirical work. It is limited by the selection of input models; models we missed may have contributed additional aspects, especially to Table 1. The model needs to be applied in many different situations to establish its usefulness. Perhaps a general model is not possible, only models for specific sensemaking tasks. Sensemaking in specific practice areas may follow certain patterns (i.e., sequences of steps that sensemakers go through) and the general model may not be most useful in analyzing task-specific activities.

Conclusions and Discussion

The model proposed in this paper provides a framework for analyzing and describing the cognitive process and mechanisms of individual sensemaking; it focuses on the changes to the conceptual space and the cognitive mechanisms used in achieving these changes. It affords a better understanding of sensemaking and provides a basis for:

- Empirical studies: Table 1 can be used as a scheme for coding the elements of a sensemaking process that is observed. The comprehensive model presented in Figure 17 can guide a researcher in producing process diagrams to analyze user processes and activities.
- Interpreting empirical user studies and integrating their results using the framework established in Table 1 and Figure 17.
- Education in critical thinking and sensemaking skills. Students from an early age can be taught an overall approach to sensemaking that includes the elements and subprocesses of sensemaking most suited for the sensemaking task at hand. They can be taught the general flow with the knowledge that they often need to go back and forth. They can be taught which approach (for example, top-down or bottom-up) is most appropriate in a given situation or discover which approach is best suited for their own cognitive style.
- The design of sensemaking assistant tools that support and guide the users—from K–12 students to university students to practitioners and researchers at the highest levels—in arranging data and thoughts and creating a wide range of external representations and provide automated support for some

DOI: 10.1002/asi

functions, such as information extraction from text, visualization of relationships between entities and of quantitative data, automatic inference, and conversion from one representation to another, for example, from a concept map to an outline.

The framework also sheds light on research in information seeking and use from a perspective of the creation of structured representations. The processes and cognitive mechanisms identified provide better foundations for knowledge creation, organization, and sharing practices. By characterizing the overall process of sensemaking as iterations of "information seeking–sensemaking" that are linked with iterative updates of the conceptual space triggered by a set of cognitive mechanisms, the model shows how sensemakers move along from one knowledge state to the next, and what requisites are needed to enable such movements.

Researchers in LIS have been studying task-based information seeking and use, and they made a useful distinction between information task and work task (Vakkari & Hakala, 2000; Byström, 2002). Sensemaking, as an information task, is needed for many work tasks, such as problem solving and decision making. The representations constructed during the sensemaking process need to fit the task, or they must be updated (Russell et al., 1993). In fact, examining information use as gap-bridging under a sensemaking framework provides insights to information-behavior research (Savolainen, 2006). Task-based, information-seeking and use research can benefit from the analysis of creation and use of structured representations for tasks and problems. In addition to the compound nature of information tasks and work tasks, the examination of the concepts and relationships in the knowledge space of users suggested that task structure and topic structure are often intertwined and work together to best serve the functional demands of the task.

Researchers have sometimes avoided talking about internal representations and cognitive aspects of sensemaking because of the difficulty in assessing what is in a user's mind (Cacioppo & Petty, 1981; Chi, 2006; Das, Naglieri, & Kirby, 1994) and the limitations of using verbal reports and observations as data to interpret mental process (Nisbett & Wilson, 1977; Ericsson & Simon, 1993; Hoffman, Shadbolt, Burton, & Klein, 1995). However, the cognitive processes and mechanisms are fundamental to information-behavior research and need more attention in the field.

Tools have been developed to support sensemaking in various ways, mostly to capture intermediate products of sensemaking such as insights (Gersh, Lewis, Montemayor, Piatko, & Turner, 2006) and analytical thoughts (Lowrance, Harrison, & Rodriguez, 2001), and to provide a workspace of the intermediate representations (Wang & Haake, 1997; Hsieh & Shipman, 2002; Wright, Schroh, Proulx, Skaburskis, & Cort, 2006). However, there is less support for connecting intermediate products to the conceptual structure that users develop. A sensemaking tool should support the ability to "flexibly arrange, re-arrange, group, and name and re-name groups" (Hearst, 2009, p. 169) of raw information and intermediate products of sensemaking. The comprehensive information-seeking and sensemaking model provides the basis for developing sensemaking tools that support users' structuring a conceptual space using various sources, including search results and intermediate structured representations (which can themselves be part of the concept space) such as concept maps, templates, and outlines. With the growth of computer-based information systems, computer-generated displays as external representation can help the quality of complex information-processing tasks for many types of tasks. Much prior work on the role of external representations in individual problem solving used well-structured problems. Further studies need to investigate ill-structured, open-ended problems.

We need good sensemaking assistant tools to help users learn and to make best use of large amounts of information. To design such tools we need a better understanding of the sensemaking process, both of what people actually do and what they should do to achieve better results. Our comprehensive model of the individual cognitive processes points toward arriving at such an understanding. The model would be even more useful if it were augmented to consider affective, social, and organizational factors; we are interested in working with others on such an expansion.

Acknowledgment

We were formerly at the College of Information Studies, University of Maryland. This work was partially supported by the Eugene Garfield Dissertation Fellowship from the Beta Phi Mu Library & Information Studies Honor Society. The first author also received support from the Beijing Key Discipline Construction Fund. We thank the editor and two anonymous reviewers for their constructive comments, which helped us to significantly improve the article.

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Appendix A classification of sensemaking activities linked to a number of sensemaking models.

Table A-1. Elements of Sensemaking. A faceted classification (expanded version of Table 1).

Table A-2. Sensemaking, search, and learning models linked to sensemaking activities classified in Table A-1.

Table A-3. The sensemaking activities classified in Table A-1 linked to the elements of sensemaking, search, and learning models (a much expanded version of Table 2).

DOI: 10.1002/asi