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Concept Analysis of Cognitive Artifacts

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Cognitive artifacts—information displays that inform thought processes and increase knowledge—fulfill a fundamental role in distributed cognition. Cognitive work—the mental processes of selecting and evaluating data, reasoning, and making decisions—is guided and informed by cognitive artifacts, especially in clinical areas. The importance of cognitive artifacts to cognitive work suggests the need to study and comprehensively understand cognitive artifacts prepared and used by the clinical nurses and how these documents influence and guide nursing practice. This article identifies and describes the attributes of effectively constructed cognitive artifacts using the concept analysis process described by Walker and Avant.
Key words: , *cognitive artifact*, *concept analysis*, *distributed cognition*, *external knowledge representation*, *internal knowledge representation*, *nurse cognition*

Cognitive artifacts, or external knowledge representations, are purpose-driven[1] data displays created to communicate, augment, and influence human reasoning, understanding, and decision making.[2] The content of cognitive artifacts interacts with our knowledge, mediating our reasoning and shaping knowledge and understanding of our environment.[3] The interaction and interdependence of external knowledge representations and our personal internal knowledge representations are constructs of distributed cognition theory. Figure 1 is a model depicting the interaction between external knowledge representations (which include cognitive artifacts, other people, or other environmental factors) and the internal knowledge representations of an individual (formal and experiential knowledge). This interaction results in or creates the cognitive work space of the individual.[4,5]

Cognitive artifacts and cognitive work are highly interdependent constructs of cognitive science.[4–9] Reasoning processes are mediated by the interaction between internal knowledge representations and external knowledge representations, or cognitive artifacts, in the environment. For example, as you read this article your attention is directed by a cognitive artifact, regardless of whether you are reading a paper version or an online version of this journal. While reading this article you are evaluating the content in the context of your personal knowledge, assessing the information, and formulating an overall judgment of the accuracy and importance of the content you are reading. The experience of reading this article will prompt you to (1) reinforce your current knowledge

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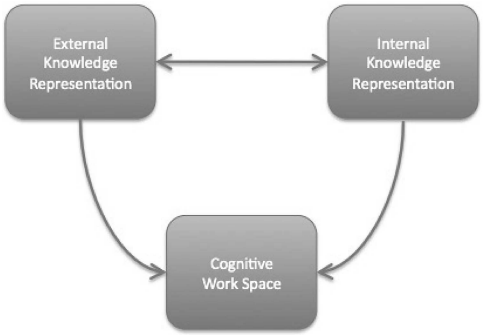

Figure 1. Distributed cognition model.

because you believe that the evidence is congruent with your current knowledge; (2) accept the evidence of the data presented and modify or replace your current knowledge; or (3) reject the information because you do not believe that the evidence presented is sufficient to change your current knowledge and understanding. Regardless of your final assessment of this article, you are actively engaged with a cognitive artifact that is influencing your thoughtfulness and cognitive processes.

Cognitive artifacts, such as roadside signs, restaurant menus, way-finding signage in public buildings, newspapers, the Internet, and television program listing guides, are deeply embedded in everyday life.[6,10,11] Intended for concurrent or sequential use by multiple people, each of these cognitive artifacts is an example of information present in the environment to guide or influence reasoning and action. In addition to cognitive artifacts developed for use by many people, we each create personal cognitive artifacts for a variety of purposes, such as task lists, grocery lists, snack and bedtime instructions for the babysitter, or a medical history form requested during a visit to our physician's office.

Cognitive artifacts are ubiquitous in health care settings. Table 1 lists examples of cognitive artifacts that are frequently found within health care environments. Nurses and other health care practitioners consult these external knowledge representations, or cognitive artifacts, multiple times each day. The information content of these cognitive artifacts directly influences critical thinking, clinical decisions, and the ongoing evaluation and individualization of the plan of care. Nurses review and document on paper medical record forms, information displays in electronic health records (EHRs), medication administration records, personal cognitive artifacts that are clinical summaries and task lists for patient care, and many other types of external knowledge representation.

External knowledge representations, or cognitive artifacts, influence perception and understanding. Changes to the content or structure of an external knowledge representation will change perception and understanding.[12–14] Thus, the content of cognitive artifacts directly influences nurse perception, reasoning, decision making, and practice. The purpose of this concept analysis is to clearly establish the attributes of cognitive artifacts. These attributes are fundamental principles to guide the design of cognitive artifacts to assure they support nursing theory, knowledge, and practice.

A review of the literature failed to disclose a concept analysis of cognitive artifacts. Yet, the presence of so many cognitive artifacts in the clinical and nursing environments implies that we must understand the cognitive artifacts to understand their impact on nursing practice. The process of concept analysis will identify the theoretical and operational definition of cognitive artifacts and enable them to be accurately identified and included in new research.

METHODS

Our concept analysis of cognitive artifacts was conducted using the 8-step concept analysis process developed by Walker and Avant.[15] This process involves examination of the attributes of a concept to identify how the concept is similar or dissimilar to other concepts. This process includes the following:

Table 1. Examples of Cognitive Artifacts Prevalent in Healthcare Environments

Assignment boards or sheets	Fall precaution signage
Automated vital sign equipment	Intravenous infusion pumps
Barriers to freshly mopped floors	Lab flow sheets
Chalk boards	Medical records/charts
Clinic appointment schedules	Medication dose calculators
Clinical pathways or guidelines	Nursing care flow sheets
"Do not awaken for vital signs" signs	Physiologic monitors
Electronic or paper medication administration records	Physician orders
	Surgery schedules
Electronic or handwritten bed-boards	Way-finding directional signage
Employee identification badges	Work lists or other reminders of clinical tasks to be completed

1. selecting a concept,
2. determining the aims or purposes of the analysis,
3. identifying all uses of the concept,
4. determining the defining attributes,
5. identifying a model case,
6. identifying borderline, related, contrary, invented, and illegitimate cases (invented and illegitimate cases are optional and may be included when their addition provides clarification of the concept),
7. identifying antecedents (which must occur before the concept exists and cannot be a defining attribute) and consequences (which must occur in response to, or as a result of, the occurrence of the concept), and
8. defining empirical referents or concrete examples that demonstrate an occurrence of the concept. Empirical referents support content and construct validity and are frequently equivalent to the defining attributes.

We will describe the concept analysis of cognitive artifacts and discuss the importance of thoughtfully and comprehensively understanding the role of cognitive artifacts in the cognitive work of nurses and other health care practitioners.

CONCEPT ANALYSIS OF COGNITIVE ARTIFACTS

Identify uses of the cognitive artifact concept

The term *cognitive artifact* was coined by Norman to characterize information-display objects as "artificial devices designed to maintain, display, or operate upon information in order to serve a representational function and that affect human performance."[7] Generally, cognitive artifacts are physical objects designed for a specific purpose, and they facilitate thinking, evaluation, and consequent responses or actions.[16] Bang and Timpka[17] characterized cognitive artifacts as tangible objects intentionally created to aid, enhance, or improve thinking and reasoning.

Several examples of cognitive artifacts were cited earlier in this article (restaurant menus, roadside signs, way-finding signage in public buildings, newspapers, the Internet, television program-listing guides). Additional examples of cognitive artifacts include textbooks, automobile dashboards, financial statements, and instruction manuals. Cognitive artifacts frequently used by nurses include online clinical resources (eg, Micromedex Thomson Reuters, New York), skills reference systems (eg, Mosby's Nursing Skills, Elsevier, Amsterdam, NL), and organizational policy manuals. Each is an example of specific information prepared to guide behavior or modify

current knowledge. It is not possible to list all of the cognitive artifacts present in the environment because of the volume and the ongoing development of new cognitive artifacts.

The characteristics of cognitive artifacts may extend beyond data and information representation. Cognitive artifacts often influence the interaction between an individual and a task, both the nature of the task and how the individual understands the task. Performance of a task may be facilitated or impeded by the content of a cognitive artifact in combination with the knowledge, skills, and experience of an individual.[16] For example, the assembly instructions that accompany a child's bicycle may significantly influence how well and how quickly a parent is able to assemble the bike. Language complexity, diagrams, and assumptions about the user's skill each influence the effectiveness of the cognitive artifact to simplify the task.

Cognitive artifacts are context dependent, with context defined as person, place, and/or time. For example, a list of yesterday's entrée specials at your favorite restaurant is not relevant to selection of an entrée this evening. Similarly, a report containing the laboratory work of a patient discharged 72 hours ago is not a relevant cognitive artifact while identifying the care needs over the next 12 hours for a group of hospitalized patients. And as important as roadside directional signage is when driving to an unfamiliar city, signs rarely influence our behavior while driving to work via the same route we have traveled for the past 2 years because we have "automated" the process and no longer pay attention to the street signs even though they are present. In each of these instances, the document contained information that was not relevant to the context and did not serve as a cognitive artifact.

Health care has many cognitive artifacts that support clinicians to deliver safe and effective patient care. According to Nemeth et al, cognitive artifacts have various physical forms—such as paper, whiteboards, and schedules—that support visualization of temporal data, provide insight into the nature of the work of clinicians, and illuminate important interactions and relationships in the clinical setting.[6,18-20]

Defining attributes of cognitive artifacts

The purpose of cognitive artifacts is to communicate information that will aid understanding and augment our abilities. We use cognitive artifacts to interpret our environment and help us create meaning . . . so that we know where, when, and how to do our jobs as nurses. This enables us to evaluate and accept or reject new data, modifying our current knowledge as appropriate. Cognitive artifacts have specific properties, originally described by Zhang[21] and refined by Zhang and Patel.[14] Table 2 lists these attributes and is amended by the addition of contextual relevancy. These attributes illustrate that cognitive artifacts are more than memory aids or data repositories—they also serve as aids to critical thinking and decision making while reducing distractions created by abstractions and the effort of data recall.

Table 2. Attributes of Cognitive Artifacts[a]

1. Relevant in the context
2. Reduce memory load of the user
3. Guide recognition and understanding of inferences, supporting rapid assimilation of data
4. Augment user knowledge and internal representations
5. Support user perceptions and cognition without requiring conscious effort of the user
6. Promote more efficient and effective user action
7. Limit abstraction
8. Make "transient" or "invisible" data visible and sustainable
9. Facilitate critical thinking
10. Channel decision making by maximizing accuracy and minimizing user effort
Numbers associated with the attributes are referenced in the cases that are subsequently discussed in the text

[a]From Zhang and Patel[14]

A model case of a cognitive artifact

Model cases are examples of a concept that demonstrate all of the defining attributes of the concept.[15] Figure 2 is a model case of a cognitive artifact that [1] is relevant to a care provider, and [2] reduces memory load by presenting a graphic representation of the temporal relationship of furosemide administration (a potassium-wasting diuretic) and a patient's serial serum potassium (K^+) levels. The graph [3] guides understanding of inferences by illustrating an incremental decline in the patient's serum potassium following furosemide administration, with a subsequent increase in the serum potassium level after potassium infusion and furosemide dose reduction, [4] reinforcing clinician knowledge and [5] and [6] channeling perception and action. The graph [7] limits abstraction, [8] makes the relationship between serum potassium and furosemide administration visible, [9] prompts critical thinking about the relationship between the potassium wasting drug and serial serum potassium levels, and [10] channels decision making.

The graph could further enhance clinical insight with the addition of serial serum digoxin levels and indications of the patient's cardiac rhythm, as well as symptoms reported by the patient. The relationship between the data of this simple graph and a clinician's knowledge, experience, and skill assists data assimilation and facilitates clinical decision making. In this model case, a knowledgeable clinician could quickly recognize the relationship between furosemide and serum potassium, define potentially minor and more serious complications, and intervene appropriately.

Related, borderline, and contrary cases of a cognitive artifact

A related case is very similar to the concept but does not have all of the defining attributes of the concept.[15] A related case of cognitive artifacts in health care is the record maintained during cardiac resuscitation. Typically, a resuscitation event comprises a small team of clinicians that includes a physician who directs the event, members who fulfill the physician orders, and a "scribe." The scribe records the time of each event (eg, medication administration, cardio version, and other interventions), the dose/nature of each intervention, and the patient's response to the intervention. Thus, in cardiac resuscitation events, the team responsible for assimilating data and planning the next stage of care and intervention is often unable to evaluate the composite data except through the interpretive lens of the scribe.

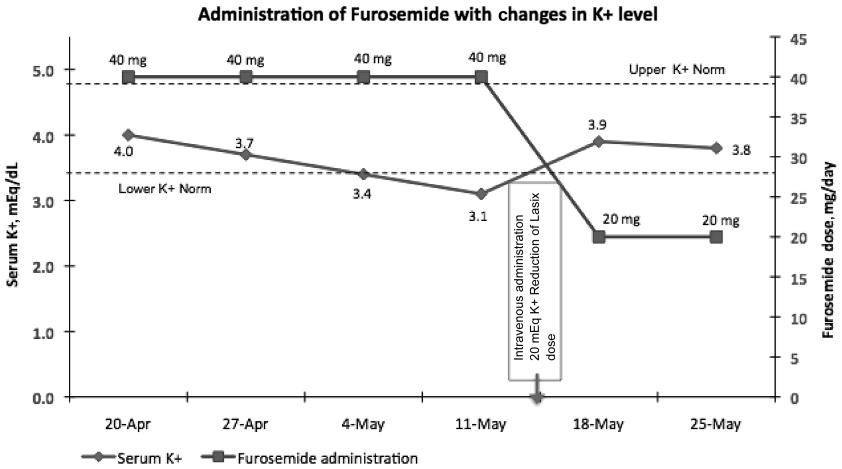

Figure 2. Example of a model case of a cognitive artifact.

While the recorded data are [1] relevant to the resuscitation team, team members experience [2] memory load burden, and [3] difficulty identifying, understanding, and assimilating data in the context of their [4] internal knowledge representations because they cannot directly assess the data. Team member [5] perceptions and cognition require conscious effort, which [6] may slow identification and implementation of the most effective responses. Abstraction [7] is significantly increased as the members of the team create mental models of data relationships and [8] attempt to "visualize" audio data and the implications of the data. Decision accuracy [9] and [10] may be reduced in response to efforts to collate and assimilate information gathered from the scribe's verbal responses to queries. The record maintained by the scribe during a cardiac resuscitation exhibits many of the attributes of a cognitive artifact for the scribe, but the ability of the record to serve as a cognitive artifact for the resuscitation team is limited. The utility of the resuscitation record after the event may be limited for members of the team due to unique notations (eg, abbreviations, acronyms, visual cues, and so forth) recorded by the scribe.

Borderline cases are similar to related cases, having many of the attributes of the concept, but at least one characteristic is significantly different from the study concept.[15] An example of a borderline case would be a 24-hour fluid balance record of patient intake and output. Such a record would [1] be clinically relevant to the clinician, [2] reduce memory load due to the summary of all fluid intake and output for the previous 24 hours, [4] augment the clinician's understanding of the patient's fluid balance, [5] support perception of the daily fluid balance of the patient, [6] position the clinician for effective action, [7] minimize abstraction regarding daily fluid balance [8] eliminate "invisible" data by defining the various sources of intake and output, [9] provide important data for decision making, and [10] create accuracy for decision making. Assessment of fluid balance generally encompasses periods that are longer than 24 hours. Fluid balance records are often limited to data from the past 24 hours. Without 48-hour, 72-hour, and 96-hour cumulative intake and output balances, the clinician is [3] expected to assimilate the data, which increases the load on [2] working memory, [5] increasing the need for conscious effort, [6] reducing efficient action, [8] reducing the visibility of "invisible" data, and [10] reducing accuracy and increasing user effort because of the need to perform mental math.

Contrary cases are examples of what is not an instance of the concept.[15] A contrary example of a cognitive artifact is a personal clinical summary prepared by a clinician for personal reference and incorporating, for example, extensive use of personally created acronyms and abbreviations, variable use of highlighter markings and colored ink, and handwriting legible only to the author. The acronyms, abbreviations, and use of color have specific meaning and purpose for the clinician who prepared this cognitive artifact. However, this document is a contrary instance of a cognitive artifact to any other clinician because they are unable to interpret and assign meaning to the acronyms, abbreviations, use of color, and illegible handwriting. While the document has and will continue to serve as a meaningful cognitive artifact for the author, the document is unable to communicate information to others because of the highly personal manner in which notations were made. The document is unable to fulfill the attributes outlined in Table 2 for any clinician except the author. Thus, a clinical summary prepared for personal use and employing unique personal notations lacks the element of communication for others.

Antecedents and consequences of cognitive artifacts

Antecedents, events or conditions that precede the instance of a cognitive artifact, may not be a defining attribute.[15] In the health care environment, an example of an antecedent of a clinical cognitive artifact may be entry of the patient into the health care

system, usually referred to as a patient admission or a client visit. Admission initiates the development of clinical data repositories such as history and physical, nursing assessment, laboratory result data, radiographic data, electrocardiographic data, and so forth. Diagnostic testing and history information create the foundation for cognitive artifacts that subsequently are accessed by clinicians as they seek to develop an understanding of the clinical picture of a patient and formulate or modify a plan of care.

Consequences occur as a result of the presence of a cognitive artifact. In a health care environment, examples of the consequences of a cognitive artifact may include knowledge of the patient's clinical condition and development or modification of the plan of care. An additional consequence of cognitive artifacts may include development of a personal cognitive artifact, a summary of clinical data that the user finds important to have immediately available while responsible for the care of a patient. Review of shared clinical cognitive artifacts provides the clinician with the most recent information to guide decisions about continuation or modification of the care plan, and to support or inform clinical discussion about the patient's condition with colleagues.

Figure 3 depicts the antecedents and consequences of a cognitive artifact, and the attributes that qualify a cognitive artifact.

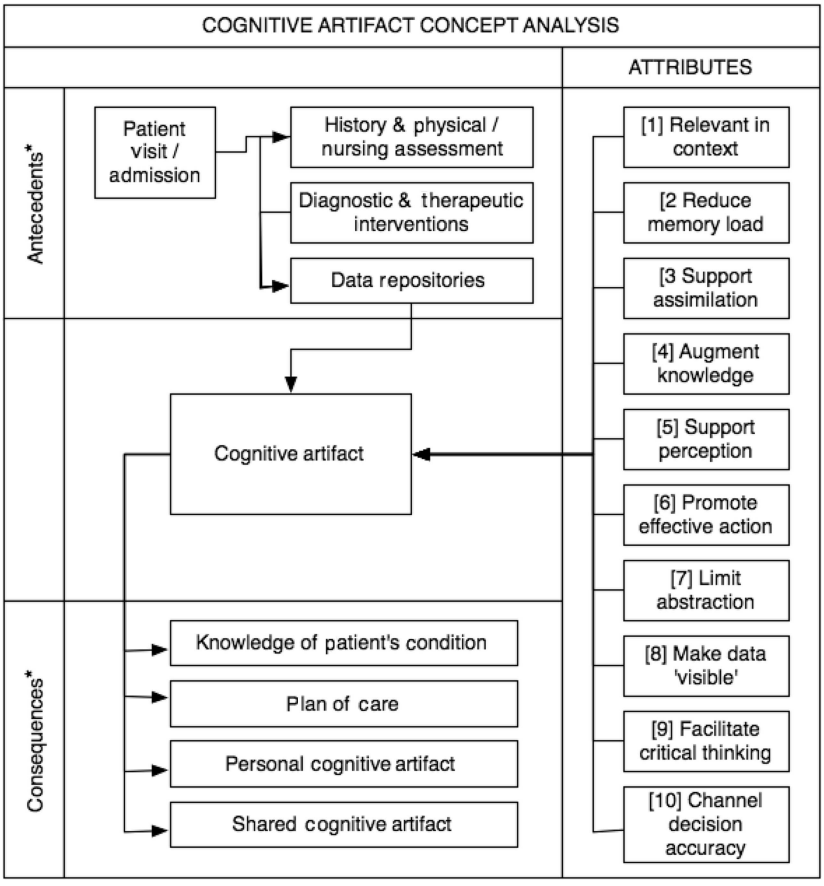

Figure 3. Cognitive artifact concept antecedents and consequences. *The antecedents and consequences depicted in this model are exemplars of events that precede or follow an instantiation of a cognitive artifact in the clinical environment.

The examples of antecedents and consequences depicted in Figure 3 are exemplars that may be more approachable to practicing clinicians.

Empirical referents of cognitive artifacts

Empirical referents are indications of the existence of a concept.[15] Phenomena that enable identification of a cognitive artifact are the attributes identified in Table 2. For example, clinicians create or use cognitive artifacts to reduce the burden of storing data in working memory. Another example is the plan of care, which demonstrates a clinician's understanding of the clinical data and how the patient's care should be planned in response to clinical information.

DISCUSSION

External knowledge representations, as exemplified by cognitive artifacts, influence perception, reasoning, knowledge, and decision making. Furthermore, Turley,[12] Coiera,[13] and Zhang and Patel[14] clearly identified that changing a representation will change perception and understanding. Thus, embracing the external knowledge representation component of distributed cognition theory has powerful implications for integration of nursing theory and nursing knowledge into the daily practice of nurses. Configuration of EHRs, and in particular screens frequently used by nurses, presents compelling opportunities to support the nurse and incorporate nursing theory, models of nursing care, and nursing knowledge at the bedside.[22]

Workflow reengineering may be a component of implementing an EHR. An example of workflow reengineering is replacement of the clinical summary (cognitive artifact) that nurses prepare as their shift begins with an automated clinical summary from the EHR. Prior to embarking on the development of automated clinical summaries, thorough study of nurse-prepared summaries is critical. In addition to the data the nurse records on the summary, developers need to understand the purposes of the summary as well as when and how the nurse uses the summary. Research has disclosed that the clinical summary is integral to the cognitive work of the nurse, supporting care planning, working memory, reflection and reflexivity, critical thinking, and decision making. Furthermore, this research indicates that data proximity, spatial placement, addition of personal notes, use of visual cues, and the contribution of the summary to organization and prioritization are significant factors that often highly individualized and thus need to be explored and defined.[23] Only after the knowledge representation of the clinical summary has been fully studied and understood should the process of exploring an automated alternative be explored. The attributes of cognitive artifacts (Table 2) provide a framework to guide analysis of cognitive artifacts.

Modification of a cognitive artifact to meet the needs of clinicians is another example of using cognitive artifacts in the clinical environment to communicate information. The employee identification (ID) badge generally includes, at a minimum, the full name of the employee and the job classification (eg, RN = registered nurse, CNA = certified nurse assistant). The ID badge facilitates identification of a staff member when in close proximity, but at a distance job roles cannot be identified. When physicians, pharmacists, patients, or family members need to locate an RN, for example, staff members need to be individually approached until the correct job classification can be visualized on the ID badge. The problem of assisting rapid and accurate location of the appropriate job classification has been resolved in some hospitals with the addition of a color-coded badge with the job classification printed in a large font that can be seen from a distance. This additional badge is worn behind the employee ID badge, and clinicians and visitors quickly discern the codes and are assisted in rapid location of the appropriate individual.

Cognitive artifacts may be limited to use by a single individual, as is often the case when clinicians create clinical summaries to guide

care for the course of a shift. Cognitive artifacts are also used in community, fulfilling a role for successive individuals in a workflow process or serving different purposes for different groups.[18] For example, an operating room (OR) schedule generally includes considerable and diverse data, such as the start time of each case, procedure to be performed, assigned surgical suite, and the age of the patient. This document serves as an important cognitive artifact to a large number of people at varying points in the day. Anesthesiology uses the data to plan staff assignments, OR nursing staff use the data to provide appropriate instrumentation for the case, transportation service plans when to send transport staff to the operating room through the course of the day, and the postanesthesia care unit (PACU) can adjust staffing to assure that the appropriate number of staff are available when each patient is expected to be transferred from the OR to the PACU. Changes to the OR schedule or its distribution without an understanding of how this cognitive artifact is used and by whom could result in major disruption for the OR and patient care.[19]

Electronic health records have introduced the opportunity to collect, store, display, and retrieve patient data in ways that were previously not feasible. The process of developing applications for data entry in an EHR is exciting, challenging, and complex. As requirements are developed for applications, and current and future workflow are documented, the clinical environment needs to be carefully assessed to assure identification and understanding of cognitive artifacts. If we are not mindful of the relationships of external knowledge representations to workflow and clinician cognition, the final design will not be optimum and may introduce unexpected risks to patient safety. In the absence of patient safety concerns, clinicians may create workarounds because of previously unrecognized cognitive relationships.

Cognitive artifacts influence and are influenced by human cognition, shaping and informing our understanding of the world in which we live and work. Study of cognitive artifacts frames a new and more robust understanding of the role that cognitive artifacts serve in the clinical practice of users. However, the study of cognitive artifacts must include study of the culture in which the cognitive artifact is used. Culture includes the physical setting, values, mores, workflow, and similar factors that define the environment and agents that comprise the setting in which the cognitive artifact is used. As exemplified by the taxonomy hierarchy discussed earlier, care must be taken to assure that the study of cognitive artifacts includes the cultural environment in which they are used. Failure to understand the. Implementation of new workflow processes without first identifying and studying existing cognitive artifacts within the cultural context may introduce dissonance to the cognitive work of clinicians, create unplanned and unexplained disruption for clinicians, and potentially add new and unanticipated risks to patient safety.

Health care represents a unique culture that shapes the value, purpose, meaning, and role of the cognitive artifacts used by clinicians. With recognition and understanding of cognitive artifacts in the health care environment, informaticists, engineers, process improvement specialists, and others can develop systems and processes that will more effectively assist the clinician's cognitive work and support safe patient care.

Cognitive artifacts, and personal cognitive artifacts in particular, are integral to nursing practice. Cognitive artifacts shape and support critical thinking, decision making, and the plan of care developed by nurses for the delivery of patient-centered care. Understanding the purposes of a cognitive artifact, how and when it is used, and the cognitive interplay when recording information or consulting a cognitive artifact requires thoughtful study. Identification and study of cognitive artifacts used in nursing practice will enlighten researchers of the role and influence of the cognitive artifact to nursing practice. A richer understanding of these knowledge representations will increase our insight and appreciation of the

cognitive work and the practice of nurses, thus allowing us to build cognitive artifacts that support clinical practice rather than hinder practice. Equipped with this knowledge, nursing researchers and educators will have data critical to the development of new approaches to orientation of the novice nurse and advance practice nurses, more effective mentoring programs, and clinical decision support systems for clinical nurses. Another important application of a deeper understanding of knowledge representation and knowledge structure, as evidenced by cognitive artifacts, is the design of the EHR to support nursing practice. How, when, where, and why nurses use the cognitive artifacts present in the clinical environment needs to be understood prior to transition of these artifacts into the EHR. In absence of this knowledge, important supports to the practice of the nurse may be significantly modified or eliminated.

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