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Engineering Complex Human-Technological Work Systems - A Sensemaking Approach

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Abstract

This paper explores two underlying philosophical traditions that are relevant to the design and analysis of complex human-technological work systems –i.e., organizations of people and technology that deal with complex problem spaces in today's society. The first tradition (classical/positivist) dominates the design of information system technology. The second tradition (sensemaking/constructivist) enjoys a prominent place in the scientific study of human behavior at the individual and social level. These two traditions reflect radically different views of data, information, tacit knowledge, shared knowledge, and so forth. This paper explores these two traditions and summarizes their implications many of the core constructs that must be considered by the systems engineer. By adopting the latter tradition, the systems engineer is able to gain further insight into the nature and functioning of complex human-technological work systems.

Introduction: The Analysis of Work Systems

A system can be defined as a collection of entities—either real or abstract—that functionally interacts or relates with one another to form a meaningful whole. Because meaning can take on various forms and perspectives, the defined boundary of a system is somewhat arbitrary or subjective. In order to explore complex human-technological work systems at the different levels of systems analysis, we must first agree on what constitutes the system (or system-of-systems) under study. While this might seem a trivial question, it is one that requires careful consideration by the systems engineer. Deciding what set of physical entities, process activities, and epistemological constructs is included or excluded from this definition establishes the framework of the systems analysis and ultimately determines the scope of what the systems engineer (1) understands to be an important determinant of system performance and (2) believes to be capable of change and improvement. Further, one system can be declared to be a component of another larger system –thus giving rise to the popular term "system-of-systems." In short, the definition of what constitutes a system depends solely upon the perspective of the systems engineer and is not something that is universally given.

The more obvious types of systems dealt with in systems engineering studies include *technology systems* (*e.g*., machines, industrial plants, military weapon systems, computer hardware and software systems, information displays, and telecommunication systems and networks), *human and organizational systems* (*e.g*., machine operators, decision makers, work teams, social networks, communities of interest, and communities of practice) and *ecological systems* (*e.g*., biospheres, urban communities, multi-cultural societies, and military battlefields). During the industrial age, attention was primarily directed towards studying the physical aspects of these systems such as raw materials and physical commodities, the machinery used to produce finished goods and services, and the human operators and decision makers employed to oversee these resources. Correspondingly, engineers would typically focus on the physical description and representation of these entities in their analyses. Additionally, attention was also directed toward the representation of the physical processes and activities that functionally linked these resources within a system. Human operators and decision makers, if they were considered at all, were represented in a mechanistic manner that belied much of their inherent complexity. Thus, the analysis and engineering industrial age work systems largely focused on bringing together physical descriptions and process descriptions in some sort of predictive calculus that could illuminate key aspects of system performance.

However, with the advent of the information age, attention has increasingly shifted to studying the more abstract or epistemological nature of modern work systems. It is not just the representation of physical resources and processes that is of interest, but also the representation of relevant cognitive and social phenomena that demands the attention of the systems analyst. Here, the systems engineer must begin to consider various types of knowledge-based systems, including (1) *work control systems* that functionally link intent with action within an organization's

operational problem structure, (2) *planning systems* that define a sequence of both formal and informal activities and knowledge products through which an organization projects and guides its actions into the future, and (3) *knowledge management systems* that bring together relevant information and expertise within an organization to interpret the state of its operational environment and move the organization toward a desired set of goals. Focusing on the epistemological description of a work system provides the system engineer with deeper insight into the structures and activities associated with knowledge creation.

Complex human-technological work systems can be analytically viewed in terms of three interacting levels: (1) the cognitive level of the individual operator, decision maker, or staff member; (2) the social level of the work system within which these individuals are organized to contribute; and (3) the ecological level of the environment within which the work system attempts to accomplish some meaningful purpose. In order to explore these different levels of analysis, it is useful to begin with a basic understanding of the major system elements to be represented at each level, defined here as *system goals*, *system objects*, *system processes*, and *system constraints*. System goals help the analyst to focus on the purpose being served by the system under study. System objects reflect the important constructs that give structural definition to the analysis –aspects of the real world that are conceptually bracketed (isolated) by the systems engineer and represented in terms of specific characteristics. Objects can either be concrete or abstract in nature. However, to be useful to the analysis, they must be defined in ways that are relevant to the purpose of the work system. System processes give functional definition to the analysis –that is, they describe something about the way in which objects are created, used, or modified within the work system. System process representations in an analysis are necessarily approximations of reality. They highlight causal relationships presumed to exist among what is considered to be variable (subject to change or modification), knowable (observable or measurable), and relevant (influential relative to system performance), while ignoring or assuming away other detail. System constraints specify additional conditions that limit the freedom by which the system is said to operate. The definition of system constraints depends, in turn, upon how the first three elements—goals, objects, and processes—are defined and represented. That is, goals, objects, and process definitions provide the analytical context within which to articulate important limitations on system behavior.

While these definitions might seem rudimentary or basic in nature, they are nevertheless important to consider when undertaking the analysis of a complex human-technological work system. Overlooking or failing to adequately represent important goals, objects, processes, or constraints in an analysis will ultimately limit—or even invalidate—the insight that can be developed by the systems engineer. Hence, it is important at the outset of a study to establish a general understanding of what must be considered at each level of systems analysis. In this regard, there exist two philosophical traditions that must be considered –one that underlies much of the physical sciences and that dominates the design and development of information system technology and another that underlies much of the behavioral sciences and frames our understanding of how humans engage in sensemaking and decision making at either an individual or social level. These traditions fundamentally differ in how they define concepts such as information, knowledge, awareness, understanding, and so forth. Consequently, adoption (either consciously or unconsciously) of one or the other tradition can have a profound impact on the analysis of complex human-technological work systems. Given the importance of this topic to the systems analyst, the following paper addresses a number of these important constructs and compares their treatment within each philosophical tradition.

Current Confusion Regarding Fundamental Constructs

In reviewing the current research literature on information management and knowledge management, one is struck by a pervasive ambiguity of definitions regarding the fundamental nature of human knowledge. Indeed, terms such as “tacit knowledge,” “explicit knowledge,” “information,” and so forth are often used by different writers to imply different meanings. Given this confusion, it becomes a challenge for the systems engineer to draw comparisons across this literature and to integrate their findings in any sort of comprehensible or unified manner. Accordingly, if we are to develop a systematic understanding of complex human-technological work systems, then we must first come to a basic understanding of what these terms mean. Otherwise, we have little chance of developing the analytical precision needed by the systems engineer.

In examining this current state of confusion, we note that ambiguity arises from two sources. The first type of ambiguity arises from the weaknesses of the philosophical foundation underlying much of current research in information science and management science today. This first type of ambiguity is compounded by a second type of ambiguity that results from addressing knowledge and knowledge creation at different levels of systems analysis – *i.e*., the cognitive level of the individual, the social level of the organization, the ecological level of the problem space, and the technological level of the tools employed in this regard. In each case, researchers focusing on a

specific aspect of knowledge analysis are likely to resemble a committee of blind men inspecting an elephant –with each describing a single phenomenon in terms of different paradigms and metaphors. Given these two sources of ambiguity, we devote the present paper to addressing the first source of ambiguity, namely, the weaknesses of the philosophical foundation underlying much of the current research in information science and management science today. At the same time, we contrast this foundation with an alternative philosophical tradition that is both old and new. This alternative philosophical perspective is rooted in the historical ideas of social constructivism; however, it has recently reemerged as part of the current writings on organizational sensemaking. This alternative perspective is also reflected in the more recent literature on knowledge management, writings that have begun to rethink the nature of knowledge at both an individual and organizational level of analysis.

The second source of ambiguity, the disconnectedness of knowledge research at one level of analysis from that of another level, begs the development of a unified model of sensemaking and knowledge management that spans four levels of analysis: cognitive, social/organization, ecological, and technological. By adopting a so-called "*sensemaking / constructivist*" perspective, we can arrive at a set of construct definitions that enable these four levels of analysis to be (1) developed more deeply and (2) linked in a consistent and coherent manner.

Two Philosophical Traditions

Underlying much of the current research in information science and management science today is a philosophical tradition that can be labeled "*classical / positivist*" in its characterization of human knowledge. As summarized in Figure 1, this tradition approaches the definition of knowledge from a *logical positivism* point of view that holds that meaning and truth must always be established in an empirical and rational manner. The creation of knowledge is based on the historical ideas of *reductionism*, *essentialism*, and *analytic philosophy*. Because this tradition serves as the epistemological foundation for much of the physical sciences, it is accepted unquestioningly by most systems engineers whose academic training comes out of the physical sciences. Indeed, the very concept of "the scientific method" comes out of, and is indistinguishable from, these ideas.

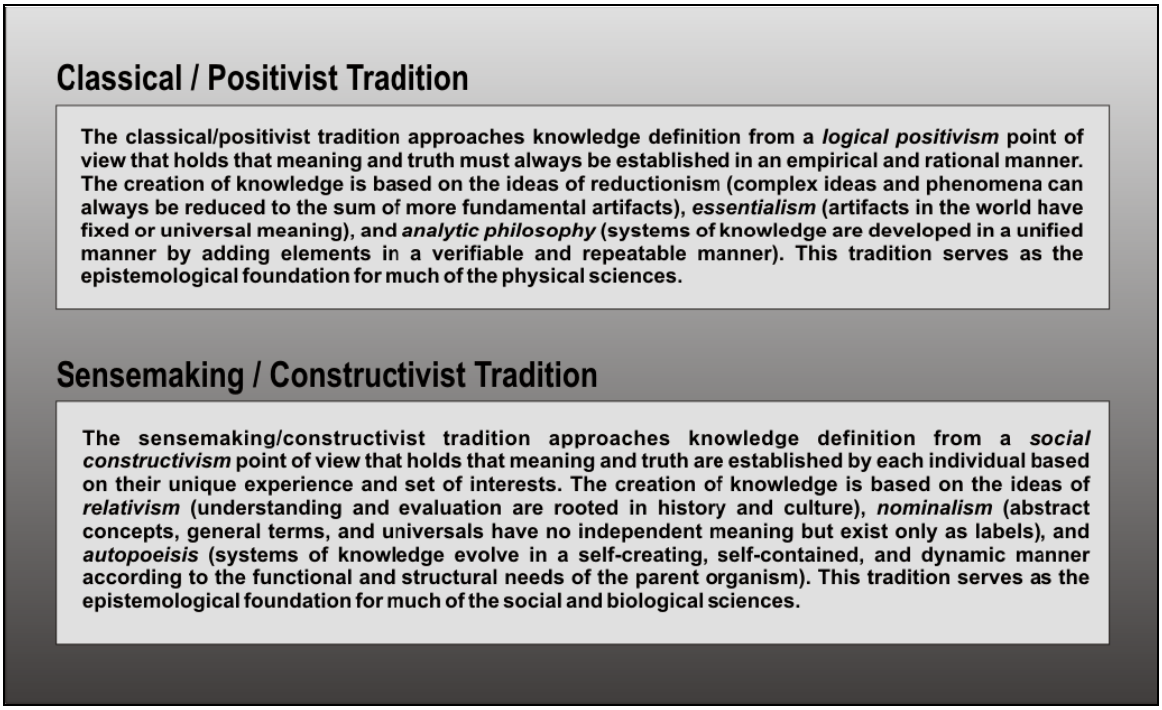

Figure 1 Philosophical Traditions Underlying Concept of Knowledge

By contrast, the philosophical tradition labeled "sensemaking/constructivist" approaches the definition of knowledge from a *social constructivism* point of view that holds that meaning and truth are established by each individual based on their unique experience and set of interests. This perspective holds that the creation of knowledge is based on the historical ideas of *relativism*, *nominalism*, and *autopoiesis*. While this tradition serves as the epistemological foundation of a major thrust in the social sciences, it is little understood or ignored by most

systems engineers. Yet, as is well known in some circles of both psychologists and corporate managers, the principles reflected in this alternative tradition often provide a better explanation or model of human behavior in everyday life.

To better understand each of these traditions, we briefly outline the ideas underpinning the classical/positivist and sensemaking/constructivist positions, respectively.

Classical / Positivist Tradition

The classical/positivist tradition can be generally explained in terms of four fundamental ideas that are said to govern the way in which we develop knowledge about the world: reductionism, essentialism, logical positivism, and analytic philosophy. Accordingly, the concept of reductionism—originally introduced by Descartes in 1673)—asserts that complex objects, phenomena, theories, and meanings can always be reduced to a set of simpler or more fundamental things. Applied to the physical sciences (*e.g*., physical, chemistry), reductionism implies the existence of a finite number of basic substances from which more complex compounds and be made. While this idea might make sense for these fields, when applied to the fields of biology, linguistics, psychology, and sociology, the notion of hierarchical reductionism becomes problematic. More specifically, attempts in the late 1800s by Wilhelm Wundt to apply reductionism to the study of human perception and knowledge were dramatically unsuccessful –thus leading the field of psychology to momentarily abandon its study of internal mental phenomena for several decades thereafter. Nevertheless, the close association of reductionism with analysis (*i.e*., the breaking down of complex system phenomena into a set of constituent elements) has led many researchers and engineers to uncritically apply this principle to both information science and knowledge science.

Closely aligned with reductionism is the concept of essentialism. This idea holds that for any specific type of entity it is theoretically possible to specify a finite list of characteristics that can be used to establish group or type membership. Historically derived from the ideas of Plato, essentialism leads to the classification of objects, ideas, and other artifacts in the world according to a defined hierarchy of groups. For example, all objects possessing a specific set of characteristics are said to belong a group defined by those characteristics. The establishment of groups and hierarchies of groups supports reductionism by providing a universal classification scheme for organizing our understanding of objects, phenomena, theories, and meanings. As applied to information science and knowledge science, the ideas of reductionism and essentialism lead the systems engineer to believe that everything in the world can be known in terms of a finite, universal ontology of meaning. Thus, once an object has been defined and associated with a defined set of characteristics, it is presumed that this definition is sufficient to establish meaning in any context. Unfortunately, if such a task is handled by a machine, this implies the need for large and unwieldy ontology frameworks in order to account for the many possible contexts in which a given object might be considered.

Logical positivism reflects the idea that all knowledge must be based on the dual concepts of empiricism and logical rationalism. As historically introduced by Aristotle, Thomas Aquinas, Roger Bacon, John Locke, and (much later) Ernst Mach, empiricism posits that knowledge (in the form of hypotheses and theories) must be borne from empirical observation and testing of the natural world. Logical rationalism was developed conceptually by Rene Descartes, Immanuel Kant, and Ludwig Wittgenstein, and mathematically by Alfred North Whitehead and Bertrand Russell. Logical rationalism extends the concept of knowledge to include truths that can be systematically developed through logical reasoning. Together, the ideas of empiricism and rationalism formed the principle that knowledge comes about through a combination of verifiable observation and logical reasoning. An important objective pursued within this school of philosophy is the development of a unified science –*i.e*., a common language through which all scientific propositions can be expressed. Here, a unified science (or, *Einheitswissenschaft*) is best understood as a model of the world that integrates all relevant bodies of science into a unified understanding. Extending beyond the development of scientific knowledge, the concept of logical positivism has been applied more recently to all human knowledge and reflected in current data fusion research, information mining technologies, and semantic web technologies (*cf.* Steinberg *et al*, 1999; Davies (ed.) *et al*, 2003; Veltman, 2004; Seifert, 2006; Khriyenko & Terziyan, 2006).

Finally, the term analytic philosophy combines logical positivism with logical atomism to define the doctrine and methods of knowledge creation within the physical sciences. Doctrinally, logical positivism defines empirical observation and logical reasoning as the way in which we come to know the world. Logical atomism applied reductionism to language and defines the way in which we articulate this knowledge. Methodologically, analytic philosophy places emphasis on precise definition and universal meaning so as to avoid ambiguity and

provide the basis for creating a unified framework for all knowledge. As a formal framework for scientific knowledge promoted by Wittgenstein, Russell, and other continental philosophers, analytic philosophy is the dominant academic tradition of most Western countries. And, given its roots in the physical and mathematical sciences, it is not surprising that current systems engineering methods are implicitly shaped by this tradition.

The tenets of reductionism, essentialism, logical positivism, and analytic philosophy (what we define here as the classical/positivist tradition) have served well the needs of the industrial age where emphasis was placed on physical science theories and the design and analysis of mechanical systems. Unfortunately, the classical/positivist tradition does not characterize knowledge as it is created and applied in the complexity and wickedness of everyday life. Thus, as society has moved from the industrial age to the information age (and, as stated by some writers, to the knowledge age), the classical/positivist tradition no longer serves as a fully adequate framework for studying work systems. As rule sets, ontologies, and other artificial devices for coping with the fluidity of knowledge across different contexts have grown to unmanageable size, researchers have begun to look for an alternative framework – one more closely aligned with the nature of human mental and social behavior. In short, we have reached the point where, according to Thomas Kuhn, systems engineers must shift to another paradigm in order to further deepen their understanding of the phenomena (Kuhn, 1975).

Sensemaking / Constructivist Tradition

The sensemaking/constructivist tradition approaches the definition of knowledge from a social constructivism point of view. As originally conceived by Georg Wilhelm Friedrich Hegel in the early 1800s and later developed by Emile Durkheim in the early 1900s, social constructivism argues that meaning and truth are established by each individual based on their unique experience and set of interests. More specifically, Peter Berger and Thomas Luckmann introduced the idea that all knowledge, including the common sense knowledge of everyday life, is derived from and maintained by social interactions (Berger & Luckmann, 1966). In contrast to the unified frameworks of truth assumed to exist by the classical/positivist tradition, the sensemaking/constructivist view holds that truth and the meaning of language (*i.e*., types, categories, and definitions) are negotiated by human actors. Thus, it can be said that human actors socially create the reality within which they work.

In contrast with the ideas embedded within the classical/positivist view of knowledge, the sensemaking/constructivist tradition argues that the creation of knowledge is based on the ideas of relativism, nominalism, and autopoiesis. In this regard, relativism implies that humans always understand and evaluate specific beliefs (*i.e*., facts, assertions, and theories) in terms of their historical and cultural context. Thus, the roles of truth and language are reversed from that posited in the classical/positivist tradition. The classical/positivist view begins with the idea that truths exist in the world and await discovery by man. Language is then shaped to provide a unified means of articulating this truth so that it can be shared. In contrast, the sensemaking/constructivist tradition begins with the existence of language that is acquired through personal experience, and then argues that it is language that shapes our individual understanding of truth.

Supporting the idea that language shapes the understanding of truth is the work of linguist and anthropologist Edward Sapir and his student and colleague Benjamin Whorf. The resulting *Sapir-Whorf Hypothesis*, developed in the early 20th century, reflected two key ideas: linguistic determinism and linguistic relativity (Whorf & Carroll, 1956). Linguistic determinism states that there is a systematic relationship between the grammatical categories of the language a person speaks and how that person uniquely conceptualizes the world. Linguistic relativity states that people who use different languages will conceive of the world differently. A classic illustration of these two ideas is seen in the Inuit language that has multiple words for snow, with each word denoting a particular state or condition of snow that is relevant to the survival of this Artic people. By contrast, English-speaking people—who have only the single word “snow”—are generally incapable of interpreting these types of distinctions. As applied to software development, the Sapir-Whorf hypothesis is supported by the observation that programmers skilled in different programming languages (*e.g*., Fortran, C++, Ada, Prolog) will often conceptualize problems from different perspectives, with each limited by the principal paradigms and grammatical constructs of their familiar language. Likewise, within the military, each specialized community of practice—air-to-air combat, ground force maneuver, logistics, intelligence, civil-military affairs, *etc*.—have evolved their own special jargon to represent specific, relevant aspects of the operational problems they face. As a consequence, each of these communities will perceive different significant aspects of an operational situation, aspects that remain obscured for others that do not share usage of a specific jargon.

Extending this same idea, George Lakoff and Mark Johnson argue that much of our thinking is metaphorical in nature as we attempt to interpret current experience in terms of previous experience (Lakoff & Johnson, 1980). While some individuals might view metaphorical thinking as being limited to poetic imagination and rhetorical flourish, Lakoff and Johnson have found that it plays a central role in how people mentally structure their perception of the world around them, how they get around in the world, and how they relate to other people in the world. Although we cannot directly inspect our internal conceptual system, we are given glimpses of it through the language we use to communicate and act in the world.

Closely related to relativism is the idea of nominalism. This concept rejects the classical/positivist position that objects and other artifacts in the world can be objectively assigned to specific types and groups on the basis of commonly shared characteristics. By contrast, nominalism holds that objects labeled by the same term have nothing more in common except their assigned –*i.e.*, each person attaches their own meaning to it. In short, nominalism denies the existence of universals. Such an idea fits with the tradition of social constructivism since it philosophically argues that the described characteristics of objects and other artifacts have no place to exist other than in the minds of individual perceivers. In a more practical sense, nominalism underscores the need for different actors to establish a common ground of understanding (*i.e.*, similarly highlighted and labeled frameworks of mental artifacts) before they can effectively interact.

Finally, the concept of autopoiesis comes to us from the work of biologists Francisco Varela and Humberto Maturana. As noted by these authors, an autopoietic system is one that is organized as a network of self-sustaining processes that continuously regenerate the system as a self-contained entity –*i.e.*, one that cannot be described by using dimensions that define another space (Varela *et al*, 1974). Examples of an autopoietic system include the biological cell that is made up of various nucleic acids and proteins, and is organized into bounded structures such as a cell nucleus, cell membrane, and cytoskeleton. These structures, based on an external flow of molecules and energy, produce the chemical components that, in turn, maintain the organized structures that give rise to these components. As a result, the concept of autopoiesis has attracted attention within the field of computer science as it provides an important and distinctive framework for building computational models of artificial life (McMullin, 2004). However, in a later paper, Maturana and Verela extended this concept to the structure and organization of human knowledge (Maturana & Verela, 1980). Specifically, the concept of autopoiesis is said to define the dynamics of non-equilibrium systems operating in a larger open system. In the case of knowledge, the state of understanding of an individual actor is considered to be in non-equilibrium as the actor operates within the world (the larger, open system). Thus, to say that an individual actor's state of understanding is autopoietic is to highlight the self-referent and self-sustaining nature of that mental framework –*i.e.*, it is self-adjusted on the basis of personal experience in order to enable the actor to maintain a cohesive and functional identity. This has important implications for our definition of knowledge. In the classical/positivist tradition, to have knowledge of something, say an object, implies that the object will functionally behave in the manner defined by our knowledge of it. That is, the behavior of the object in response to our actions against it is predetermined. However, we know that this is not always true in the real world since objects sometimes behave in unpredictable ways. This leads researchers in the classical/positivist tradition to append additional contextual qualifiers onto their existing knowledge of the object –a strategy that quickly results in an unmanageable set of contextual qualifiers to account for all possible situations. From an autopoietic viewpoint, we would simply say that our self-referent knowledge of the object is, by definition, limited and not definable in any sort of universal manner. Thus, the concept of autopoiesis tells us something useful about the individual and limited nature of knowledge in the real world.

While each of these tenets—relativism, nominalism, and autopoiesis—offer us general insight into the constructive nature of knowledge, it is the more recent concept of sensemaking that applies these ideas to an organization and shows more explicitly how knowledge relates to action. Sensemaking as a concept has principally evolved through the work of Karl Weick that began in the 1970s and has continued through the present (*cf.* Weick, 1977; Weick, 1993; Weick, 1995; Weick & Sutcliffe, 2001). In its most simplified form, sensemaking can be defined as an ongoing process by which actors within an organization consensually construct and coordinate a system of understanding and action. The classical/positivist tradition sees knowledge as an accumulated, but static framework of propositions, meanings, facts, and truth values. By contrast, current theories of sensemaking view knowledge as a dynamic, ongoing, and negotiated achievement that is distributed among a set of actors.

It is difficult to define the notion of sensemaking—or its implications for knowledge creation—in a single phrase or sentence. In a more recent paper, Weick and other organizational strategists highlight several ideas that have been emphasized in this philosophical tradition over the past several decades (Weick *et al*, 2005). These ideas, paraphrased in terms of knowledge creation, include the following:

- Knowledge creation is a form of social organization that deals with equivocality and ambiguity. People organize (in both a social and cognitive sense) to make sense of a stream of equivocal or ambiguous world events, and then enact this understanding back into the world to make that world more orderly.
- Knowledge creation is about noticing and labeling. Sensemaking starts with bracketing, the deliberate differentiation and fixation of specific phenomena out of an ongoing flux of raw experiences. These bracketed experiences are then labeled and categorized so that they can become the common currency for exchanging ideas among a set of actors.
- Knowledge creation serves to link the abstract with the concrete. Sensemaking interprets or frames the current situation in terms of past experiences that have been abstractly organized in an actors' memory.
- Knowledge creation is motivated by the need to enact the world. As sensemaking constructs and assigns meaning to the current situation, it provides a mental framework for planning intentional action.
- Knowledge creation creates plausible understanding, not absolute truth. Sensemaking involves the continual redrafting of an emerging story so that it becomes more comprehensive, incorporates more of the observed phenomena, and is resilient to criticism or alternative explanations of a situation.
- Knowledge creation serves to shape organizational identity. Sensemaking is not just about developing mental explanations of a situation. Rather, it also shapes an organization's identity within the world as others react to its formed actions.

Thus, in comparison with the classical/positivist view, it can be seen that the concept of sensemaking moves us closer to understanding the role of knowledge within an organization. The classical/positivist position sees knowledge principally as an intellectual exercise –a framework of universal truths that are accumulated and organized within a specific field of study. By contrast, the sensemaking/constructivist tradition explicitly associates knowledge with organized action –action taken in order to bring about some intentional change in the world.

Analytical Implications of Adopting the Sensemaking/Constructivist Tradition

In the remainder of this paper we briefly explore the implications of adopting a sensemaking/constructivist perspective on a number of construct definitions: data, information, tacit knowledge, focal knowledge, explicit knowledge, and shared knowledge.[1] The order in which we discuss each of these constructs is guided by the classical/positivist view that data, information, individual knowledge, and collective knowledge somehow exist within a prescribed hierarchy. Thus, we discuss these constructs in an order that is familiar to the reader who comes out of the classical/positivist tradition. However, as will be seen, the sensemaking/constructivist view replaces this notion of a hierarchy with the idea that data, information, individual knowledge, and collective knowledge are mutually defined as part of a holistic system.

The Concept of Data

From a classical/positivist tradition, data are considered to be the lowest, most elemental component of knowledge. This is not surprising, given the atomistic perspective imposed by this tradition. As summarized in Figure 2, data are defined as any collection of numbers, words, images, or other signs that symbolically represent observed facts or abstracted assertions about the world[2]. Data are typically defined within an established or fixed ontology of categories and entity types that are presumed to hold for all situations. One difficulty with the classical/positivist tradition is that is fails to provide a precise distinction between data and information. However, many writers consider data to be the more rudimentary building blocks of information. Conversely, information has been described as somehow being more "interpreted" or "defined" than data. What is meant by these terms is usually not made clear.

According to the classical/positivist tradition, data are reflected in the content of all reports received by a work system. Hence, additional processing is required to identify the subset of data considered relevant to an organization's work system. Here, it is not surprising that many studies speak of the issue of "data overload" or "information overload" –a reference to the significant workload often required within a work system to sort out relevant from irrelevant data provided by its many reporting systems. Since work systems are typically viewed in

[1] These are other constructs relevant to the study of work systems are addressed more fully along with illustrations of specific cognitive, social, ecological, and technological models of sensemaking in a forthcoming systems engineering book by the authors of this paper (to be published by John Wiley & Sons).

[2] There is also a definition of data that that does not involve the use of symbolism. From a signal processing point of view, a signal (energy pattern) is data when it is detectable by some sensor. If further processing allows classification or categorization of this data, it can now be said that information has been created out of the data.

terms of classical economic theory, data are treated as a universal commodity that can flow into, be stored within, and selectively used by a work system to produce information.

Classical / Positivist Tradition

Data are defined as any collection of numbers, words, images, or other symbols that symbolically represent *empirically observed facts or abstracted assertions*. Data are universally defined within an *established or fixed ontology of categories and entity types*. The classical/positivist tradition fails to provide a precise distinction between data and information; however, data are often considered to be the more *rudimentary building blocks of information*. Data are reflected in the content of all reports received by a work system; hence, additional processing is required to identify the subset of data relevant to an organization's work system. In this regard, data are treated as a *universal commodity* that can flow into, be stored within, and selectively used by a work system to produce information.

Sensemaking / Constructivist Tradition

Data are defined as a collection of numbers, words, images, or other symbols that symbolically represent *bracketed artifacts of a situation*. Bracketed artifacts reflect observed facts or abstracted assertions that are singled out for attention based on their perceived relevance to a dynamic framework of understanding. Hence, data are *defined relative to a dynamic framework of understanding* -not a universal or fixed ontology of categories and entity types. Data are communicated in messages, but only if the sending and receiving actors have established *consistent symbolic and bracketing conventions*. In this regard, data are treated as a *measure of effectiveness by which situational reports contribute to awareness and understanding* within a work system.

Figure 2 The Concept of Data

By contrast, the sensemaking/constructivist tradition defines data as a collection of numbers, words, images, or other signs that symbolically represent bracketed artifacts of a situation. Bracketed artifacts reflect observed facts or abstracted assertions that are singled out for attention based on their perceived relevance to a dynamic framework of understanding. Thus, the sensemaking/constructivist tradition defines data relative to a dynamic framework of understanding held by a specific actor or organizational component, and not as a commodity defined by some universal or fixed ontology of categories and entity types[3]. This distinction is crucial for the analyst: what constitutes data for one actor or organizational component might not represent data for another actor or organizational component. Conversely, the established framework of understanding held by an actor or organizational component can be seen to significantly shape or guide the search for meaningful data within the world.

Given the relative nature of data, data are said to be communicated only if the sending and receiving actors have established consistent symbology and bracketing conventions. Keith Devlin, a mathematician at Stanford University's Center for the Study of Language and Information speaks of this issue in terms of placing constraints on data in order that it becomes meaning information for someone (Devlin, 2001). Because symbology and bracketing conventions are a product of an actor's or organizational component's holistic framework of understanding, the resulting constraints placed on data might or might not serve to produce useful data for a work system. In this regard, data are treated as a measure of effectiveness by which situational reports appropriately contribute to awareness and understanding within a work system.

The Concept of Information

In the classical/positivist tradition, information is seen as a second-tier component of knowledge that is more interpreted than data, but not yet knowledge itself. As summarized in Figure 3, information is defined as a collection of interpreted facts or assertions from which functional conclusions and relationships can be drawn to

[3] Note that the signal processing based definition of data uses a static referent (*a priori* established pattern). The dynamic reference frame and its situational scope are key elements that distinguish a sensemaking/constructivist definition of data from that of a classical/positivist definition.

produce knowledge. Information is developed from data by applying universal meaning from an established or fixed ontology. The classical/positivist tradition holds that information is reflected in the content of messages that can be created, stored, and exchanged over various media (*e.g.*, verbal, electronic) within a work system. In this regard, information is treated as a universal resource or commodity that can flow into, be stored within, and potentially be used by a work system to develop a functional understanding of its problem space. In a practical sense, the classical framework emphasizes the electronic management of information flow and availability within an organization. Hence, the field of information science tends to be organized around methods and technologies for transmitting, storing, and displaying information.

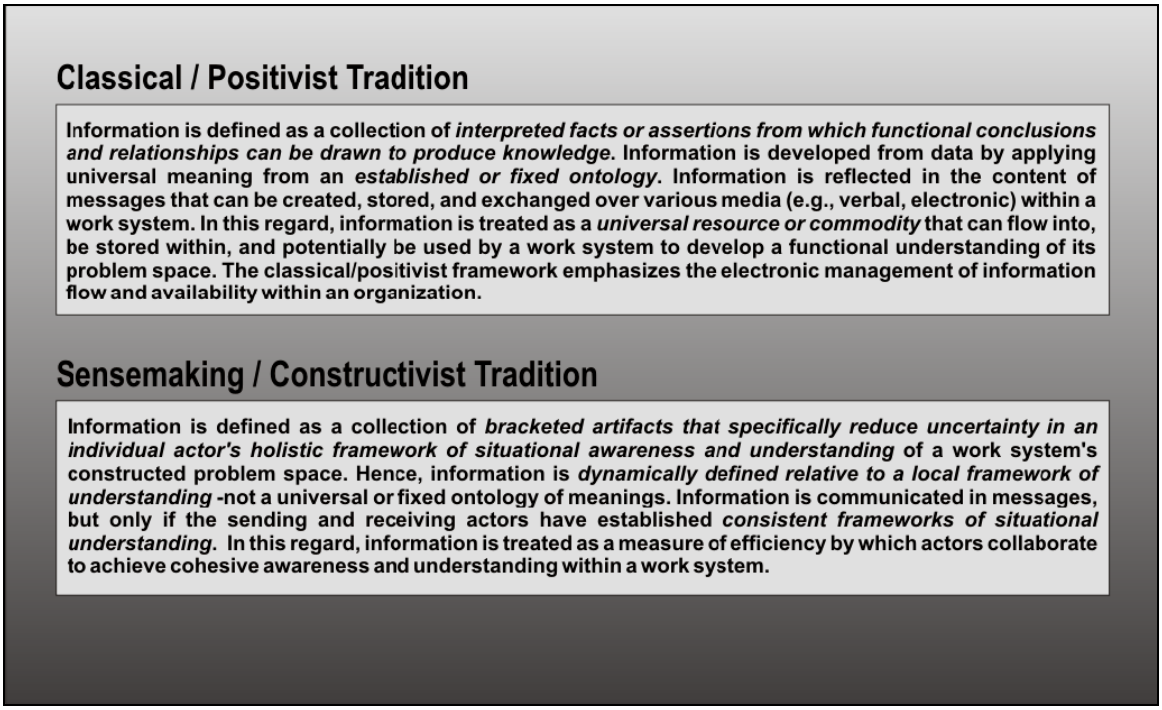

Figure 3 The Concept of Information

By contrast, the sensemaking/constructivist tradition views information as a property of the communication process between two individuals. Here, information is defined as a collection of bracketed artifacts that specifically reduce uncertainty in an individual actor's holistic framework of situational awareness and understanding of a work system's constructed problem space. Hence, information is dynamically defined relative to a local framework of understanding –not a universal or fixed ontology of meanings. Information is communicated in messages, but only if the sending and receiving actors have established consistent frameworks of situational understanding. In this regard, information is treated as a measure of efficiency by which actors collaborate to achieve cohesive awareness and understanding within a work system.

More specifically, the sensemaking/constructivist tradition sees information as being a property of the communication process between two individuals –the degree to which a message transaction correctly conveys meaning between the sender and the receiver. Such a view is related to the development of information theory, a branch of applied mathematics that deals with the reliability of storing data on a specific medium or communicating it in an efficient manner over a specific channel. Associated with this issue of reliability is the concept of information entropy, a formal description of how much information is said to be contained in a specific message or signal. Developed originally by Claude Shannon, it is a statistical property of the signal that describes the amount of uncertainty associated with reproducing the original event being described by the message or signal. (Shannon, 1948) While this mathematical definition of information is relevant in designing data compression techniques, it is not particularly suited to the study of human cognition. Nevertheless, the work of Shannon offers us insight into how we must look at information as it exists relative to a work system.

Shannon's definition of information entropy highlights the fact that the information content of a specific message is always defined relative to the total context within which it is considered. The concept of entropy, as it is

used in both thermodynamics and information theory, can be interpreted as the amount of additional data that is required to fully define a state but that remains uncommunicated by a particular message. For example, independent flips of a normal coin have an entropy value of 1 bit per flip. By contrast, if a coin has either two heads or two tails, then it is said to have an entropy value of 0 since we know with certainty what the next outcome will be. This simple example illustrates the fact that information content of a message is defined not by what is communicated, but by the overall properties of the system or environment being referred to by the message.

Extending this idea to a work system, if a particular message (*e.g.*, an e-mail message, web page content, or database entry) completely and unambiguously defines a specific object, event, or condition within the environment, then we might say that its entropy value is 0. However, from practical experience we know that this is never the case since our interpretation of an object, event, or condition within an environment depends upon our perspective and set of interests. From the point of view of information theory, we would say that our message is likely to have a high entropy value since a great deal of ambiguity remains to be resolved before the intent of the information content is correctly understood.

A discussion of information entropy might seem academic; however, it raises a fundamental point that must be understood by the systems engineer. The semantic complexity of human-technological work systems is such that the "information as a commodity" paradigm is simply inadequate as an analytical framework. Rather, we must approach the definition and representation of information as an achieved quality of the process by which meaning is constructed, communicated, and interpreted within a work system. Thus, information is treated as a measure of efficiency by which actors collaborate to achieve cohesive awareness and understanding within a work system.

The Concept of Tacit Knowledge

From a survey of the broad literature, we conclude that the classical/positivist tradition speaks only indirectly of tacit knowledge. As summarized in Figure 4, tacit knowledge is one of two forms of knowledge said to exist within an organization –tacit (knowledge that is stored internally within an actor) and explicit (knowledge that is externally codified). As in the case of information versus data, the classical/positivist tradition fails to provide a precise distinction between knowledge and information. However, knowledge is generally considered to reflect the organization of information and experience for problem solving. More specifically, tacit knowledge exists internally in the mind of an actor and is considered to be structured similarly to explicit knowledge (*i.e.*, propositionally). At the same time, tacit knowledge—at least in part—can be externalized or separated from the actor in a codified form and shared with other actors. Following classical economic theory, the classical/positivist tradition treats knowledge as an economic asset that enables a work system to function. Accordingly, numerous management strategies have been proposed within this tradition that emphasizes the controlled management of knowledge (in both its tacit and explicit form) as a resource or commodity within a work system (*cf.* Brown & Duguid, 1998; Davenport & Prusak, 1998).

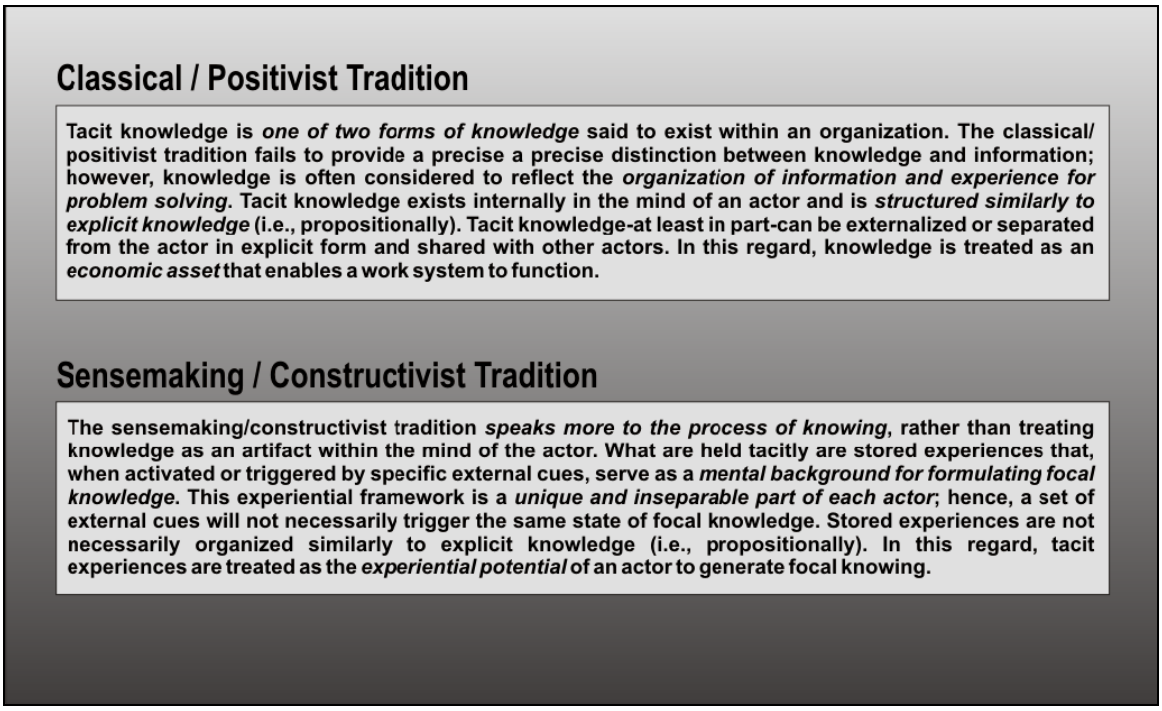

Figure 4 The Concept of Tacit Knowledge (Tacit Knowing)

By contrast, the sensemaking/constructivist framework speaks more to the process of knowing, rather than treating knowledge as an artifact within the mind of the actor. The term tacit knowledge comes from Michael Polanyi—a Hungarian medical scientist whose main interest was physical chemistry prior to turning to philosophy. In the late 1940s and early 1950s, Polanyi developed a series of lectures on personal knowledge at Manchester University. Collected in 1958 as part of his major work, *Personal Knowledge: Towards a Post Critical Epistemology*, his writings introduced the concept of *tacit knowledge* –knowledge that is intuitive and cannot be fully expressed in verbal form (Polanyi, 1958). Polanyi's concept of tacit knowledge was defined by three main theses: (1) true discovery cannot be accounted for by a set of articulated rules or algorithms; (2) while knowledge is public, it is also to a very great extent personal or constructed by humans; and (3) the knowledge that underlies explicit knowledge is more fundamental. Polanyi saw new experiences as always being assimilated through an existing body of held concepts that the individual has inherited from other users of the language. Those concepts are tacitly based and form the background for all thinking. In each activity of thinking, there are two different levels or dimensions of knowledge involved that are complementary and mutually exclusive: *focal knowledge* (knowledge about the object, problem, or phenomenon that is in focus) and tacit knowledge (background knowledge that serves as a tool for improving what is in focus).

As an illustration of how these two forms of knowledge are complementary, when a person reads a text (such as a book, e-mail message, or technical document), the words, jargon, and linguistic rules of their language serve as tacit subsidiary knowledge while their attention is focused on forming the meaning of the text (focal knowledge). To illustrate the fact that tacit and focal knowledge are mutually exclusive, consider another example of a proficient pianist playing a complex piece of music. The pianist's tacit expertise is reflected in his ability to translate abstract notations on a music score into physical motions that depress the piano keys in a certain order and rhythm. If the pianist suddenly shift attention from the piece of music he is playing to the physical movement of his fingers, he is likely to become disoriented and lost with regard to where he is at in the musical composition. Similar examples of tacit expertise can be seen from other areas of problem solving—*e.g*., chess playing, air-to-air combat, the planning of complex relief operations—where asking experts to explicitly decompose their thought process in the form of rules or algorithms can lead to disorientation and mask the very intuitive process which enables their expertise.

In writing about knowledge and its creation, Polanyi employed both "knowledge as a commodity" and "knowledge as a transactional process" terminology. In a commodity sense, articulated knowledge was defined by Polanyi as that portion of tacit knowledge that could be explicitly expressed in words. When tacit knowledge is

made explicit through language, it can be shared with others and focused for reflection. Indeed, it is this ability to articulate some portion of our knowledge that separates mankind from lower animals. Lower animals might possess a greater store of tacit knowledge (*e.g.*, some animals seem to be able to sense the oncoming of earthquakes); however, they cannot systematically organize their memory for sharing and reflection. By contrast, the development of language (followed by the development of printing, books, the internet, *etc.*) provided mankind the ability to systematically organize a portion of individual thinking in terms of articulated concepts. Because we know more than we can tell, however, what has been articulated in explicit and formalized form is to some degree underdetermined by that of which we know tacitly.

In a transactional sense, Polanyi also spoke to how individuals acquire and use knowledge. Knowledge is not simply a static repository of facts. Rather, knowledge can also be defined as a mental activity –the process of knowing. In fact, Polanyi often used the terms "knowledge" and "knowing" synonymously. As humans, we are engaged in the process of "knowing" all of the time, unconsciously switching back and forth between tacit knowing and focal knowing as the situation demands, and as our attention shifts from one aspect to another. Knowledge also relates to action-taking: knowledge is a tool by which an individual either acts or gathers additional knowledge to perform work. Thus, a person's skill level in some area of work is a function of the meta-cognitive strategies the person uses to access and employ their tacit knowledge in order to construct and shape their focal knowledge.

Thus, the sensemaking/constructivist framework speaks more to the process of knowing, rather than treating knowledge as an artifact within the mind of the actor. What are held tacitly are stored experiences that, when activated or triggered by specific external cues, serve as a mental background for formulating focal knowledge. This experiential framework is considered a unique and inseparable part of each actor. Hence, a set of external cues will not necessarily trigger the same state of focal knowledge. Stored experiences are not necessarily organized similarly to explicit knowledge (*i.e.*, propositionally). In this regard, tacit experiences are treated as the experiential potential of an actor to generate focal knowing.

The Concept of Focal Knowledge

The classical/positivist tradition does not explicitly highlight focal knowledge as a specific class of knowledge, stating that it merely is the knowledge relevant to a set of logical propositions of interest in some situation. As noted in Figure 5, knowledge is said to establish universal truth through the propositional organization of empirical evidence. Knowledge is treated as the means by which actors can establish an interconnected framework of truth values in order to predictively solve a specific problem. In this regard, the classical framework often presumes that organizations and work systems operate with a "single mind" that is capable of logically constructing and comprehending this entire network of truth values. Hence, the concept of knowledge being "focal" or confined in some attentional sense is not really addressed within the classical/positivist tradition.

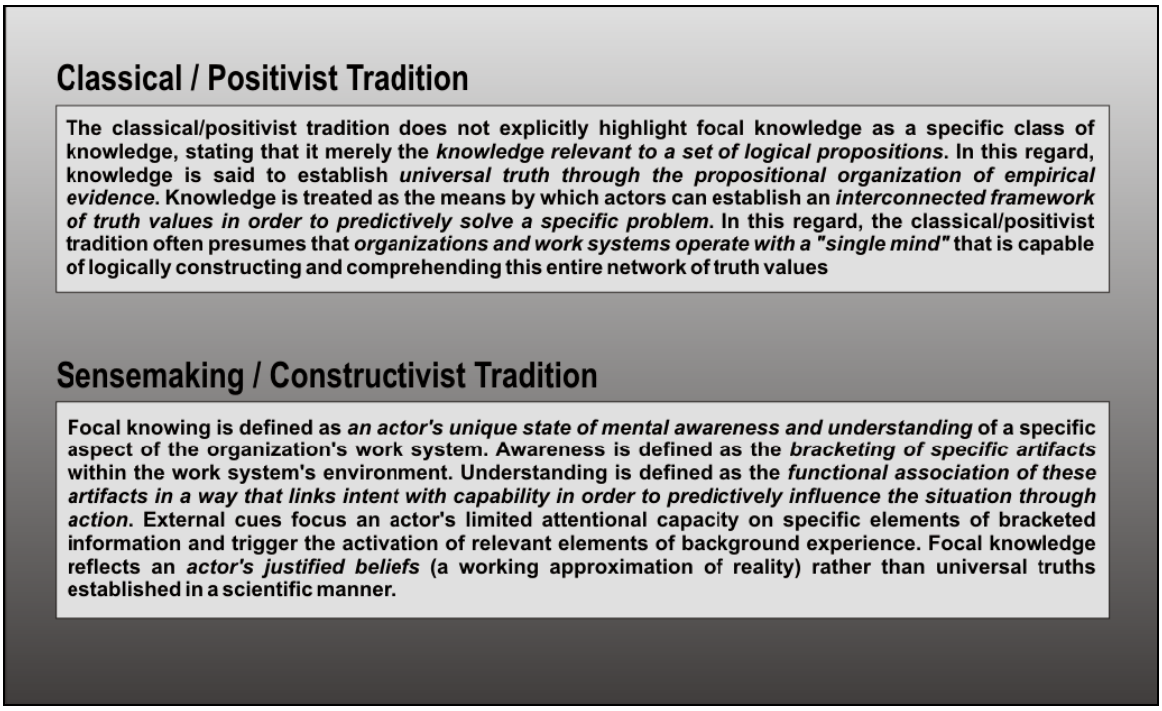

Figure 5 The Concept of Focal Knowledge

Within the sensemaking/constructivist tradition, focal knowing is defined as an actor's unique state of mental awareness and understanding of a specific aspect of the organization's work system. To better understand this position, we examine the recent work of Haridimos Tsoukas. Further expanding upon the ideas of Polanyi, Tsoukas describes the process of knowing in terms of two levels of awareness: focal and subsidiary (Tsoukas, 2003). Focal knowledge consists of a person's mental awareness of a set of specific targets –*i.e.*, objects, events, conditions, relationships, etc. of current interest. However, what gives meaning and significance to these target objects, events, and so forth is a person's subsidiary awareness of sensory experiences that are related to focal targets. Most importantly, these two forms of awareness are mutually exclusive. That is, if a person attempts to shift their attention to one of the subsidiary knowledge elements, then they lose awareness of the original target. For example, consider an accomplished pianist. At this level of expertise, the focus of the pianist's attention is on the symbology reflected in the music score –that is, they are thinking strictly in terms of the blend of sounds that correspond to the notations on each page of music. At a subsidiary level, their tacit expertise allows them to subconsciously relate each music note or other notation to a set of finger movements on the keyboard. If they suddenly are required to shift their attention to the actual finger movements, their ability to comprehend the overall piece of music is destroyed. In a more complex example, consider a skilled emergency operations dispatcher. What constitutes a good portion of their expertise is their subsidiary understanding of the functional capabilities of the various response units. Hence, when an emergency call is received, they can immediately respond with an appropriate mix of units. However, if they are required to focus on the specific mechanics of one particular unit, they are likely to lose their ability to maintain an understanding of the overall situation. The irreversibility of this mental shift is unlike that found in explicit analytical analysis where attention can be focused on supporting details and then back to the main problem without any loss of knowledge. For a person's internal mental process, however, such a shift changes the very nature of the mental activity and causes the dynamic structure between focal and subsidiary elements to be lost.

Tsoukas argues that the transformation of tacit expertise into focal knowledge involves three components: the subsidiary particulars, the focal target, and the knower who links the two (Tsoukas, 2003). This same argument is reflected in Polanyi's statement that all knowing is personal knowing (Polanyi & Prosch, 1975). Furthermore, the process is dynamic in the sense that the linking of subsidiary particulars with the focal target is done in an unconscious trial-and-error manner –that is, a person continues to refine his understanding of some situation without knowing how he does it. (Polanyi, 1967)

Summarizing the work of Tsoukas, we see that focal knowledge can be represented as a dynamic state of understanding that is continuously created—and improved—by the individual actor. Something within the

environment draws the attention of the actor to a specific set of objects, events, conditions, or relationships. These artifacts are held within focal attention in symbolic form. Simultaneously, these artifacts trigger activation of subsidiary knowledge elements representing the particulars of experience. Awareness of these particulars remains at a subconscious level; yet, their activation gives rise to the mental awareness of meaning for the person. Together, this mental framework of focal target elements and subconsciously linked subsidiary elements constitutes an actor's understanding of a given situation. The mental process of linking subsidiary knowledge elements to a focal target is continuously refined or adjusted until the actor senses a stable fit. Because the particulars of tacit expertise are unique to each individual, a set of objects, events, conditions, or relationships can produce different states of understanding in different actors.

Such a paradigm is consistent with the more recently developed *data/frame theory of sensemaking* introduced by Gary Klein *et al*. (2007) This theory asserts that (1) sensemaking is the process of fitting data into a frame and fitting a frame around the data, (2) data (information from the environment) are inferred using the currently adopted frame, rather than being perceptual primitives, (3) frames inferred from a few key anchors (mental clues that give rise to the activation of a specific framework), and (4) sensemaking usually ceases when the data and frame are brought into mental congruence. Klein's theory further states that experts and novices employ the same reasoning processes. However, experts employ a richer repertoire of frames and, thus, typically exhibit a deeper level of understanding in a given situation. Finally, the theory underscores the dynamic nature of this process –that people primarily rely upon "just in time" mental models of a specific situation to guide their decision making and action taking. Here, Klein distinguishes between his "just in time" mental models and the more popular notion of comprehensive mental models that describe a complete system or function. Just in time mental models, by contrast, are thought to be more often only partial or incomplete understandings of some phenomena that have been mentally cobbled together to provide a good enough explanation –akin to Nonaka and Takeuchi's concept of justified true belief. (Nonaka & Takeuchi, 1995) By substituting "subsidiary particulars" for "just in time mental model," we see that Klein's data/frame theory of sensemaking fits well with the paradigm that knowledge is a dynamically achieved state of understanding.

Thus, within the sensemaking/constructivist tradition, focal knowing is defined as an actor's unique state of mental awareness and understanding arising out of the activation of specific portions of the actor's tacit experience. Applying the ideas of Polanyi, Tsoukas, and Klein *et al* to an organization's work system, we see that awareness can be defined as the bracketing of specific artifacts within the work system's environment. Understanding is then defined as the functional association of these artifacts in a data/frame-like manner that links intent with capability in order to predictively influence the situation through action. Hence, focal knowledge (or all knowledge, as defined by the sensemaking/constructivist tradition) is pragmatically shaped by the need to take action. External cues focus an actor's attention on specific elements of bracketed information and trigger the activation of relevant elements of background experience. Because an actor's attentional capacity is limited, and because this process is heavily shaped by prior experience, we see that focal knowledge reflects an actor's justified beliefs—a working approximation of reality—rather than universal truths established in a scientific manner.

The Concept of Explicit Knowledge

Within the classical/positivist tradition, knowledge is said to exist in either of two forms: tacit or explicit. However, rarely do writings within this tradition draw any important distinctions between these two forms, except to state that tacit knowledge exists in the mind of the actor and explicit knowledge is codified in a variety of external forms –*e.g*., physical and electronic documents, work procedures and theories of action, organizational culture, and stories. To see this point more clearly, we examine the writings of several researchers in this field. Within the past decade, the popular conception of knowledge has been significantly shaped by the seminal work of Ikujiro Nonaka and Hirotaka Takeuchi. In this work, they view explicit knowledge as being merely an expressed form of tacit knowledge (Nonaka & Takeuchi, 1995). Conversely, tacit knowledge is defined by these authors as knowledge awaiting translation or conversion. While their work addresses the broader question of how knowledge is created and shared at a social or organizational level of analysis, it is nevertheless instructive to examine its implications for the individual actor. In this model, the conversion of tacit knowledge into explicit knowledge—and then back into tacit knowledge—is accomplished through a cyclical process involving four phases: socialization, externalization, combination, and internalization. Treating knowledge as a transformable commodity, the SECI model of Nonaka and Takeuchi defines these phases in the following manner:

- *Socialization* is the direct sharing and creation of tacit knowledge through face-to-face communication and shared experience (such as an apprenticeship),

- *Externalization* is the articulation of tacit knowledge into explicit knowledge through dialog and reflection,
- *Combination* is the systematic integration and application of explicit knowledge and information in a specific work area, and
- *Internalization* is the learning or acquisition of new tacit knowledge through action and practice.

A similar view is expressed in the work of Chun Wei Choo in his writings on the "knowing organization" (Choo, 1998). Specifically, Choo focuses on the use of information to support three principal processes within any organization: sensemaking, knowledge creation, and decision making. According to Choo, sensemaking is triggered by ecological change and leads to the construction of enacted environments and shared interpretations that serve as meaningful frameworks for future actions. Following the work of Nonaka, Choo defines knowledge creation as the transformation of tacit knowledge into expressed knowledge –specifically in response to problems and opportunities. Choo further expands the commodity view of knowledge by emphasizing the need to manage three forms of knowledge within an organization: (1) tacit knowledge embedded in the experience and expertise of individuals; (2) explicit knowledge codified as rules, principles, and other expressed artifacts; and (3) cultural knowledge expressed as assumptions, beliefs, and values. Decision making then selects the course of action that are anticipated to achieve the goals of the organization and cope with the conditions of uncertainty (Choo & Johnston, 2004). While Choo employs some of the language and terms used by the sensemaking/constructivist tradition, his concept of tacit and explicit knowledge as equivalent economic commodities within an organization suggests more of a classical/positivist view in its fundamental definition of knowledge.

Interest in knowledge management and the development of information technology support tools for supporting knowledge management has increased significantly over the past decade. However, embedded in the term "knowledge management" is the assumption that knowledge is a "thing" that can be managed –something that exists independently from the individual actor. Taking this notion one step further, it is naively assumed by many developers of information technology that this "thing" called knowledge can be managed in a manner similar to that for information and data –*i.e.*, each construct is treated as if it is a fixed (but transformable) commodity that can be created, stored, transmitted, shared, and utilized within in organization. As a result, what passes for "knowledge management" software in many cases is nothing more than a repackaging of older "information management" and "data management" ideas. Despite the popularity of approaching knowledge management as simply an information management or data management problem, the failure to recognize important distinctions between data, information, and knowledge has led to more hype than real progress in this area (*cf.* McDermott, 1999; Wilson, 2002).

Like tacit and focal knowledge, the classical/positivist tradition treats explicit knowledge as a unified set of universal truths that can be applied to any work situation. In this regard, explicit knowledge can be exchanged among actors and logically combined to form new knowledge that adds to the body of unified truths available to an organization's work system. As summarized in Figure 6, the classical/positivist tradition treats explicit knowledge as an economic asset that enables a work system to function. As noted earlier with the concept of tacit knowledge, the classical/positivist view provides little distinction between information and knowledge, except to say that knowledge is generally reflects the organization of information and experience for problem solving. Consequently, corporate strategies for managing explicit knowledge differ little from earlier strategies proposed for information management.

By contrast, the sensemaking/constructivist tradition does not address the concept of explicit knowledge, per se. Rather, what becomes externalized and shared are bracketed artifacts (observed facts or abstracted assertions) that draw attention to specific aspects of a situation and/or specific intentions, capabilities, and actions. These artifacts correspond to, but do not equate with, an actor's internal state of awareness and understanding. The artifacts can be codified in a variety of forms –*e.g.*, physical and electronic documents, work procedures and theories of action, organizational culture, and stories. To better appreciate this view, we again review some of the relevant literature.

Classical / Positivist Tradition

Explicit knowledge is *one of two forms of knowledge* said to exist within an organization. Explicit knowledge is *codified in a variety of forms* -e.g., physical and electronic documents, work procedures and theories of action, organizational culture, and stories. Like tacit and focal knowledge, explicit knowledge *reflects universal truths that can be applied to any work situation*. In this regard, explicit knowledge can be *exchanged among actors and logically combined to form new knowledge* relevant to an organization's work system. Accordingly, the classical/positivist tradition treats explicit knowledge as an existing or acquirable *economic asset* that enables a work system to function.

Sensemaking / Constructivist Tradition

Since knowledge is defined as an actor's internal state of awareness and understanding, the sensemaking/ constructivist tradition *does not address the concept of explicit knowledge*. Rather, *what becomes externalized and shared are bracketed artifacts (observed facts or abstracted assertions) that draw attention to specific aspects of a situation and/or specific intentions, capabilities, and actions*. These artifacts *correspond to, but do not equate with, an actor's internal state of awareness and understanding*. The artifacts can be *codified in a variety of forms* -e.g., physical and electronic documents, work procedures and theories of action, organizational culture, and stories. The sensemaking/constructivist tradition does not consider knowledge to be an existing or acquirable asset. Rather, it argues that knowledge is created on demand as dictated by the specific details and needs of each situation. Further,this creation of explicit knowledge occurs through a process of redesciption wherein the interpretation and application of individual experience is continuously shaped through social interaction and action taking.

Figure 6 The Concept of Explicit Knowledge (Externalized Artifacts)

From a systems engineering perspective, it is tempting to represent knowledge as a transformable commodity within a complex human-technological work system. Problems arise, however, when one attempts to address the dynamic nature of how actors adapt and adjust the application of their expertise to different situations. If, as claimed by Nonaka and Takeuchi, explicit knowledge and tacit knowledge are merely different forms of the same thing, then it would seem reasonable to structurally represent the internal mental state of an actor (*e.g.*, situation awareness and understanding) in forms similar to those used in external expressions.

A key to understanding Nonaka and Takeuchi's SECI model is its assumption that tacit knowledge can be directly transformed into an equivalent expressed form. That is, it is assumed that tacit knowledge—including the meaning of concepts embedded within this knowledge—is somehow organized, linked, and stored internally in the mind of the actor as it would be in some externalized expression. To illustrate, consider a work system in which an actor must perform some complex, yet subtle problem solving task. Suppose further that the experience level of the individual is such that their expertise cannot be expressed in simple rule-based form. That is, their ability to notice, account for, and reconcile subtle patterns and features of the problem reflects a more holistic form of perception and reasoning. The question becomes, "How do we represent this type of tacit knowledge?" However appealing it might be, one cannot reduce this holistic expertise to a universal set of predicate logic statements –an approach that has been often attempted with little success in constructing artificial intelligence or expert system software. As experienced by researchers within the field of artificial intelligence, such an approach can lead to enormous propositional structures that collapse under their own weight as they attempt to account for disposition and context.

The problem of context is at the heart of this issue. That is, knowledge as it is applied in a given situation seems to be different from the universal knowledge implied by the classical/positivist tradition. The question here leads to our two possible views of knowledge. Adopting the classical/positivist tradition, we would say that knowledge is universal and what is added by an actor in a specific situation are "contextual qualifiers." Adopting the sensemaking/constructivist tradition, we would say that knowledge within an individual is a dynamically achieved state of personal awareness and understanding, whereas what can be brought forth externally is merely a codified set of cues that can potentially trigger a state of focal knowledge in each individual. To further illuminate how each philosophical tradition handles this question, we look at some additional research. Within the classical/positivist tradition, the later writings of Nonaka (in partnership with Noboru Konno) introduce the Japanese concept of *Ba* to handle context (Nonaka & Konno, 1998). *Ba* is generally defined as a shared space for emerging relationships. More

specifically, Nonaka and Konno argue that different forms of *Ba* can exist to support each of the four stages of their SECI model. For example, shared feelings, emotions, and mental models are said to facilitate the face-to-face transfer of tacit knowledge in the socialization phase. Organization culture, on the other hand, is said to facilitate the exchange and combination of explicit knowledge in the combination phase. Indeed, other researchers within this tradition have adopted the concept of *Ba* as a new paradigm for studying the management of knowledge within an organization (Creplet, 2001). A similar approach is taken by John Seely Brown and Paul Duguid in their study of knowledge management within an organization (Brown & Duguid, 1998). On the one hand, Brown and Duguid adopt the classical/positivist tradition by noting that the "know-what" (reflecting information) and "know-how" (reflecting tacit knowledge) are both critical to organizational performance and, thus, should be managed like any other economic asset. However, Brown and Duguid also adopt Polanyi's explicit knowledge / tacit knowledge dichotomy when distinguishing between the know-what and know-how that constitute the core competencies of a work system. In comparing these two artifacts, Brown and Duguid stress the importance of managing know-how in order to achieve organizational competence. Implied in their discussions of knowledge management is the notion that actionable knowledge (what is termed focal knowledge in the sensemaking/constructivist tradition) is created by skilled managers through their ability to appropriately transform know-how (what is termed experiential potential in the sensemaking/constructivist tradition) in a specific work situation. In fact, they introduce yet another term—dispositional knowledge—to describe the manager's ability to recognize situational context.

Several problems exist with contextual qualifiers such as Nonaka and Konno's concept of *Ba* and Brown and Duguid's concept of dispositional knowledge. The first problem deals with the lack of a rigorous description for either term. Thus, while concepts such as *Ba* and dispositional knowledge sound plausible as an explanation for how universal knowledge gets adapted and applied in a specific situation, they offer the system engineer little in the way of a workable analytical definition. That the classical/positivist tradition has struggled with this issue is seen in current attempts by the computer science community to develop generalized methods for machine-automated information mining. An example of this approach is seen in an attempt by Oleksiy Khiriyenko and Vagan Terziyan to develop a standardized approach for handling semantic context in the search for information on the World Wide Web (Khiriyenko & Terziyan, 2006). Their strategy, however, merely calls for the appending of additional information (called context-sensitive metadata) onto the existing store of knowledge –an approach that would likely collapse under the total weight of information required to contextualize even a small portion of the World Wide Web.

A second, and perhaps more fundamental, problem with this approach is that concepts such as *Ba*, dispositional knowledge, and metadata merely represent additional forms of universal knowledge (as it is defined in a universal manner by the classical/positivist tradition). Such a representational strategy leaves the systems engineer with no recourse except to construct ever larger data structures and rules sets for handling every possible context or situation. It would seem then that the classical/positivist position regarding knowledge has painted the systems engineer into a corner with no way to escape.

As an alternative approach to defining explicit knowledge, we recall our earlier discussion of the ideas introduced by Tsoukas –namely, that focal knowledge is best represented as a dynamic state of understanding that is continuously created—and improved—by the individual actor. Such a definition avoids the "contextual qualifier" trap created within the classical/positivist tradition by declaring that the terms "tacit knowledge" and "explicit knowledge" are oxymoronic. Thus, within the sensemaking/constructivist tradition, one can speak of knowledge only in a focal, individual sense, and not in an explicit, community sense. Such a statement has significant implications for systems engineers interested in modeling and studying the performance of complex human-technological work systems. As noted by Tsoukas, an organization can be said to neither possess existing propositional knowledge nor discover such knowledge through such strategies as acquisition or knowledge mapping. Rather, it is more proper to speak of organizations as creating knowledge on an "as needed basis" through the services of its human actors (Tsoukas, 2005). The idea that knowledge is created on demand runs counter to the classical economic metaphor underlying the vast body of knowledge management literature. Yet, on reflection, the idea of creating knowledge on demand seems to align itself with how human actors and organizations actually behave –especially when faced with complex or wicked problem environments.

This idea was given empirical support through a recent study by Juani Swart and Annie Pye that examined how various actors within a large retail bank collaborated to make sense of novel work situations (Swart & Pye, 2002). From their findings, these authors concluded that organizational knowledge is best conceptualized as being grounded in tacit experience and collective by nature. A key element of sensemaking was defined as *redescription* – a process by which tacit experience is enacted through social dialog and interaction. Thus, in contrast to the claim by

Nonaka and Takeuchi that tacit knowledge can be directly explicated or made explicit, Swart and Pye found evidence that such experience is redescribed through action. Thus, while descriptions of organizational experience are held individually within each actor, the interpretation and application of this experience to a present situation is shaped by the collective actions of these actors. Such a finding challenges the traditional view within the classical/positivist tradition that situation understanding comes first and then is followed by action. Rather, the evidence seems to suggest that both understanding and action evolve simultaneously and are mutually influenced by one another.

Thus, sensemaking/constructivist tradition does not consider knowledge to be an existing or acquirable asset. Rather, it argues that knowledge is created on demand as dictated by the specific details and needs of each situation. Further, this creation of explicit knowledge occurs through a process of redescription wherein the interpretation and application of individual experience is continuously shaped through social interaction and action taking.

The Concept of Shared Knowledge

The construct of shared knowledge is a popular concept within the classical/positivist literature on corporate knowledge management (cf. Crémer, 1993; Thompson, Levine & Messick, 1999; Saint-Onge & Armstrong, 2004) and collaborative work technology (cf. Patil et al, 1992; deValk & Martin, 2006; MacEachren & Cai, 2006). As summarized in Figure 7, the classical/positivist tradition defines shared knowledge as two or more actors possessing identical frameworks of truth values that can be used to predictively solve a specific problem. Embedded within this idea is the notion that knowledge consists of an interrelated set of universal truths or propositions –hence, it is communal rather than personal in nature. As illustrated by Nonaka and Takeuchi's SECI model discussed earlier, knowledge can be shared in either of two forms: explicit or tacit. Shared explicit knowledge comes about through the exchange of codified knowledge documents, work procedures, and so forth. Shared tacit knowledge is developed through the internalization of these codified artifacts and—in some cases—through common work experience.

The classical/positivist tradition emphasizes the issue of knowledge isolation across an organization, rather than considering the possibility that actors might hold different or conflicting knowledge. Underlying this issue is the assumption that organizations operate as a "single mind," an idea based on neo-classical economics and the theory of the firm. In its original form, the theory of the firm emerged from the work of Ronald Coase who discounted the effects of market transactions and emphasized the role of an overall entrepreneur or single decision maker who coordinates work production within a company (Coase, 1937). The neo-classical theory of the firm has been seriously challenged by more recent managerial and behavior theories of the firm that emphasize knowledge or information disparities across a company (cf. Cyert & March, 1964; Williamson & Winter (eds), 1991; Simon, 1997; Neuert, 2005;). Nevertheless, the idea that organizational decision making is concentrated in the single mind of a leader (or in a networked collection of actors that operate as a single mind) has persisted over the years within the management science and computer science communities (cf. Hiltz & Turoff, 1993; Alberts et al, 2001). In turn, classical-based knowledge management strategies emphasize the development of universal languages and ontologies of meaning, organizational knowledge maps, information mining technologies, and knowledge networks as ways of maximizing the sharing of a universal knowledge base.

The idea that organizations can develop and share a unified framework of explicit knowledge is an attractive one. However, as just mentioned, implementation of this idea in practice has proved challenging. In reviewing one such attempt within the Defense Advanced Research Project Agency (DARPA), Ramesh Patil and his colleagues noted the difficulties associated with constructing a universal ontology (Patil *et al*, 1992). Specifically, these authors admitted that computer scientists are only beginning to understand the epistemological challenges associated with creating a common ontological framework that could map across different domains of expertise. More recently, a plethora of Web Ontology Language initiatives have emerged from the field of computer science. A web ontology language is defined as a markup language or tag language for publishing and sharing information using defined ontologies on the World Wide Web. It is also considered the major technology needed to implement the concept of a Semantic Web, an extension of the current World Wide Web that enables granular access to the underlying data is said to comprise the knowledge available on the Web.

Classical / Positivist Tradition

The classical/positivist tradition defines shared knowledge as *two or more actors possessing identical frameworks of truth values* that can be used to predictively solve a specific problem. *Shared explicit knowledge comes about through the exchange of codified knowledge documents, work procedures, and so forth. Shared tacit knowledge is developed through the internalization of these codified artifacts and (in some case) through common work experience.* The classical/positivist tradition *emphasizes the issue of knowledge isolation across an organization*, rather than considering the possibility that actors might hold different or conflicting knowledge. In this regard, classical-based knowledge management strategies *emphasize knowledge maps and knowledge networks* as ways of maximizing shared knowledge and achieving a *"single mind"* within an organization.

Sensemaking / Constructivist Tradition

Since actors within an organization each possess a *unique internal state of awareness and understanding*, the sensemaking/constructivist tradition speaks of collective knowledge rather than shared knowledge. *Collective knowledge is defined as the sum of individual knowledge across a set of actors*. In terms of work systems, the sensemaking tradition acknowledges that this *knowledge is distributed across the actors* within an organization. In order for the work system to function as a coherent whole, the actors must (1) organize and partition the work process according to this distribution of knowledge and (2) mentally and socially interact so as to achieve a workable degree of epistemological consistency across their respective knowledge states. The sensemaking/constructivist tradition emphasizes the processes of arguing and negotiation, expectation development, organizational *commitment, and environmental manipulation* as mechanisms for achieving consistency and coherency. The resulting state of knowledge produced within an organization is distributed (1) in a computational sense across actors, (2) in an indeterminate sense in that what this knowledge is or needs to be cannot be known in advance, and (3) in an ecological sense wherein this knowledge is shaped by the specifics of the environmental context. This creates a tension and inevitable gap between canonical practice and innovation, between universal practice and the particulars of the situation, between the ideal and the practical, and between the formal model and the workable solution. Shared understanding between two actors, to the extent it occurs, is momentary and the result of interpreting and enacting information in a specific, temporary arrangement.

Figure 7 The Concept of Shared Knowledge (Collective Knowledge)

Conceptually, the idea of Web Ontology Languages and the creation of a Semantic Web embody the very essence of the classical/positivist view of knowledge –*i.e*., knowledge can be universally classified and semantically organized into a "unified theory of everything." However, after witnessing eight years of research, the concept is not without its doubters and even some acrimonious debate (Joyce, 2001). Some of this criticism has been formalized in academic papers that address the technical challenges of implementing unified ontologies in a practical manner – *e.g*., issues of ontology scalability (Sheth & Ramakrishnan, 2003) and the difficulty of accommodating multicultural differences (Veltman, 2004). Other criticism has arisen in the form of weblog entries, a unique product of the Web, itself. Here, criticisms have dealt more with inconsistencies between what the Semantic Web project is attempting to accomplish and the manner in which humans actually think and work. For example, one popular pundit within the field of electronic media has noted that the creation and publication of information in the real world is often a messy process (semantically speaking) and does not follow the pristine rules established by the academic developers of formal ontologies (Doctorow, 2003). Some of this messiness is due to the inexactitude of human thinking while some of it results from the fact that information in the real world always reflects embedded intentions and perspectives (what might be called context). Hence, the notion that contextual application can ultimately being handled through the specification of metadata structures is considered idealistic and naïve. Yet another issue deals with the practicalities of human problem solving (Shirky, 2003). The Semantic Web concept (and other projects that focus on the development of unified ontologies and propositional frameworks) presumes a model of problem solving based on formal syllogisms –*e.g*., "*A: a ball is red. B: red objects are found in this room. Therefore, C: the ball is in this room.*" As seen in this example, syllogisms often deal in absurd absolutes. People, on the other hand, approach problem solving in a much more generalized manner. In real world problem solving, planning, and decision making, people more often employ nuance, metaphor, and interpreted meaning, not formal mathematics, to construct what Nonaka and Takeuchi define as justified true belief (Nonaka & Takeuchi, 1995). In light of these criticisms, some computer scientists have concluded that the way in which people might respond to metadata and the way they use it in creating new web pages remains a mystery. Accordingly, they note that future research should take human reasoning into account when studying the creation of metadata (Zhang & Jastram, 2006).

Thus, it would seem that the concept of shared knowledge presents significant challenges for the classical/positivist tradition. Reflected in these challenges is the need for what Thomas Kuhn originally defined as a paradigm shift, a point in the development of a science where our basic assumptions must change in order to provide new perspective and understanding (Kuhn, 1975). This brings our discussion to consider the sensemaking/constructivist view of shared knowledge –or, more appropriately, the concept of collective knowledge. Since actors within an organization each possess a unique internal state of awareness and understanding that cannot be directed shared with others, the sensemaking/constructivist tradition speaks to the concept of collective knowledge. As summarized in Figure 7, collective knowledge is defined as the sum of individual knowledge across a set of actors. In terms of work systems, the sensemaking/constructivist framework argues that various components of the knowledge relevant to the functioning of the work system are typically distributed across the actors within an organization. In order for the work system to function as a coherent whole, the actors must organize and partition the work process according to this distribution of knowledge. In addition, they must mentally and socially interact in such a way as to achieve a workable degree of epistemological consistency across their respective internal knowledge states. Given these two needs, a principal question becomes whether or not these individual states of knowledge are organized in a sufficiently consistent and coherent manner to enable the work system to function in a productive manner. Here, the sensemaking/constructivist framework emphasizes the processes of arguing and negotiation, expectation development, organizational commitment, and environmental manipulation as mechanisms for achieving consistency and coherency. This tradition further sees resulting state of knowledge produced within an organization to be distributed (1) in a computational sense across actors, (2) in an indeterminate sense in that what this knowledge is or needs to be cannot be known in advance, and (3) in an ecological sense wherein this knowledge is shaped by the specifics of the environmental context. This creates a tension and inevitable gap between canonical practice and innovation, between universal practice and the particulars of the situation, between the ideal and the practical, and between the formal model and the workable solution. Shared understanding between two actors, to the extent it occurs, is momentary and the result of interpreting and enacting information in a specific, temporary arrangement.

To better understand this point of view, we turn to several writings that have recently emerged within the field of knowledge management. In an empirical study of how knowledge was created within a large software development company, Wanda Orlikowski echoes Swart and Pye's idea discussed earlier that knowledge emerges within an organization through social interaction and enactment. Specifically, she argues that knowing is not a static embedded capability or stable disposition of the actors within an organization, but rather is an ongoing social accomplishment of actors engaged in a world of practice (Olikowski, 2002). The implication of this finding for systems engineers is that organizational knowing is not best modeled in terms of fixed knowledge assets, technological artifacts, or infrastructure capital. Rather, what are important to represent are the everyday, situated practices and interactions of the human actors within the organization. In turn, these practices—if they are appropriately orchestrated—result in the representation of knowledge integration as performed achievement within an organization, and not a static framework of propositional truths.

Haridimos Tsoukas extends this argument by defining an organization as a distributed knowledge system (Tsoukas, 2005). Citing the earlier research of economist and political philosopher Friedrich Hayek on dispersed knowledge in market places (*cf.* Hayek, 1945, 1982, 1989), Tsoukas notes that the major organizational problem faced by companies is the creation and use of knowledge that is not, and cannot, be known in its totality by a single mind. Within an organization, knowledge is distributed in several ways. First, it is distributed in a computational sense among both work routines and the different actors who must collaborate to combine their individual knowledge within a work process. Thus, the knowledge that specifically emerges within a work system is heavily influenced by the social dynamics that impact this collaborative process. Second, knowledge is distributed in an indeterminate sense –*i.e.*, nobody knows in advance what that knowledge is or needs to be. The indeterminate nature of created knowledge is reflected in the simple sentence, "I don't know what I need to know until I need to know it." Third, knowledge is distributed in an ecological sense. The specifics of knowledge created within a work system are derived in part from the broader environmental context within which the organization operates. Given these three aspects of knowledge distribution within an organization, Tsoukas argues that normative expectations, dispositions, and interactive situations are inevitably in tension with one another. Thus, there will always be a gap between canonical practice and innovation, between universal practice and the particulars of the situation, between the ideal and the practical, and between the formal model and the workable solution. Such gaps are closed only through practitioners exercising their individual judgment as to what is relevant and workable in a given work situation.

More recently, Knut Rolland and his associates at the Norwegian University of Science and Technology studied the concept of common information spaces and how they are created within a large-scale organization that operates across heterogeneous work contexts (Rolland *et al*, 2006). Based on their empirical field work with a major international oil and gas company, these authors concluded that a key characteristic of common information spaces is their malleability and momentary nature. In contrast to previous models of organizational knowledge, they found that artifacts of knowledge and information are constantly changing in both content and in relation to one another. Thus, what might be termed as shared understanding between actors occurs at the spur of the moment when information is enacted and made sense of in a specific, temporary arrangement. Further, they challenged the prevailing view that collaboration always serves to achieve integration of knowledge. By contrast, they found in their empirical observations that social and technological mechanisms used for collaboration within a large scale organization tend instead to reproduce the initial fragmentation of knowledge and information. Thus, they see the idea of a fully integrated knowledge system as something that can never exist in a practical sense, a situation they metaphorically describe as hunting for treasure at the end of a rainbow.

A Way Forward

A comparison of these two opposing traditions leaves us in the position of asking, "Which philosophical framework offers a better way forward for studying complex human-technological work systems?" As might be guessed by the reader, we believe that the sensemaking/constructivist tradition provides a better starting point for developing a unified framework for analysis –albeit one that requires some effort to define with adequate rigor. Accordingly, we reject the notion that data, information, and knowledge should be analytically considered as linearly-structured, universally-defined, and shareable commodities within a neo-classical economic model of organization. Rather, we take on the much more difficult challenge of considering data, information, and knowledge as a dynamic network of individually-defined, contextually-situated, self-referent, and negotiated meanings and actions that is maintained through a complex mental and social process of collaboration operating within an underdetermined and evolving operational environment.

In making this choice, the authors acknowledge the pervasive reflection of the classical/positivist position in much of the systems engineering literature to date. Nevertheless, it is the sensemaking/ constructivist tradition that comes closer to describing human behavior and work systems within a performance-oriented ecology. Given the fact that we seek to develop better analytic tools that can be used to help a work system improve performance, the sensemaking/constructivist paradigm suggests itself as being useful. In other words, this paradigm treats as central those factors of a work system that seems to be essential to its definition as a phenomenon. It is a philosophical orientation that is at least starting with the 'right' phenomenon. The old way of thinking reflected in the classical/positivist view has failed to yield adequate understanding of how complex human-technological work systems function. It has great difficulty in providing analytic leverage for organizational analysis under complex, wick problem performance environments. It simply does not seem to scale well to these more complex analytic challenges. As we have tried to indicate here, this scaling problem may arise from factors that reest at the very core of this paradigm. Referring to Thomas Kuhn's concept of a paradigm shift in science, the old thinking has run its course. It is now time for a new paradigm that is better suited to a deeper understanding of the phenomenon of interest.

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