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OUR EVOLVING DEFINITION OF KNOWLEDGE: IMPLICATIONS FOR C2ISR SYSTEM PERFORMANCE ASSESSMENT

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ABSTRACT

This paper argues for the need of a paradigm shift regarding the definition, measurement, and assessment of command, control, intelligence, surveillance, and reconnaissance (C2ISR) system performance. The need for a paradigm shift is brought about by the increasing complexity of the military's future operational problem space that is characterized by advent fourth generation warfare and network-centric command and control operations. At the core of this issue is the need to more appropriately address the cognitive and social aspects of C2ISR performance that highlight the role of various types of knowledge (explicit, tacit, and cultural) as well as the underlying elements of knowledge creation within a collaborative work environment. The paper summarizes several schools of philosophy regarding the nature of knowledge and its creation within real-world settings. This discussion is followed by a brief overview of several recent models of cognition that shed light on (1) the nature of how individuals match available information with their held beliefs and subjective expertise, (2) the nature of knowledge and its relationship to both work setting and social context, and (3) the process by which individuals coming from different perspectives and interests develop a shared understanding of a situation. The paper concludes by sketching the beginning key elements of a new framework for measuring and assessing C2ISR system performance in a dynamic and undefined operational environment.

INTRODUCTION

In his 1962 *The Structure of Scientific Revolutions*, Kuhn argued that a scientific community cannot practice its trade without some set of received beliefs.[1] These beliefs provide the framework for conducting acceptable research within the community –they establish the boundaries for what may be studied; what types of variables, assumptions, and methods may be used; and what conceptual paradigms and theories are accepted as relevant. To gain acceptance and publication rights, a researcher must conform to these boundaries. The principal methods of empiricism and analytic philosophy—*e.g*., analysis, observation, and induction—are iteratively applied within this framework to further decompose phenomena and develop refined understandings. As this process continues, the growth of knowledge and understanding within a given conceptual framework eventually reaches the point of diminished returns over time. As this point is reached, some researchers will begin to question the boundaries of the established scientific framework by considering new variables, new assumptions, new methods, and new conceptual paradigms. A period of struggle ensues as these new ideas compete against the scientific establishment for recognition and acceptance. Gradually, the new ideas take hold and the community once again engages in period of refinement. This refocusing of science to examine an area of investigation from a new perspective was defined by Kuhn as a *paradigm shift* –a point of discontinuity where the scientific community brings in a new set of foundational beliefs to frame the search for new knowledge. Thus, the evolution of scientific knowledge over time was seen by Kuhn to involve periods of "normal science" (reflecting the methods of empiricism and analytic philosophy) demarked by occasional paradigm shifts.

It would appear that the field of research on military command, control, intelligence, surveillance, and reconnaissance (C2ISR) systems has arrived at the need for a paradigm shift. No longer are the US military and its coalition partners facing a traditional Cold War scenario that is defined by large nation states engaged in attrition-type warfare. Rather, we now face an evolving operational environment in which military operations must be orchestrated with other diplomatic, information, and economic actions to achieve national security objectives in a particular region. We also face a new generation of adversaries marked by transnational terrorist groups and other social or cultural networks. Even the rapid, decisive military operations of Gulf War I of just a decade ago have given way to a new spectrum of actions that seek to restore stability and security to a region through peacekeeping, humanitarian assistance, and the reconstruction of social and governmental infrastructure. As a result, military command structures and their supporting C2ISR systems are now called upon to respond to an entirely new set of planning and execution challenges. Such challenges demand that we begin to approach the design and assessment of C2ISR systems in a new and more relevant manner.

But what are the paradigms that have marked the past several decades of C2ISR research? Why are these paradigms no longer adequate for providing a framework for C2ISR research? And finally, what new paradigms offer a more productive and relevant framework for identifying critical elements of C2ISR performance? In this paper, I will address two currently influential paradigms and argue that they are —at least in their popular interpretation—no longer adequate reflections of what actually transpires within a C2ISR organization and no longer useful characterizations of the socio-cognitive processes that define a military decision making process. The first influential paradigm is that of John Boyd's Observe-Orient-Decide-Act (OODA) loop, a model that has been misinterpreted and misused to imply that the primary objective of a C2ISR system is to supply the commander with increasing amounts of information.[2] Misapplications of Boyd's OODA loop model have contributed to the design and fielding of information technology that often flood a commander and his staff with overwhelming amounts of irrelevant information –a condition known as *information overload*. The second influential paradigm is the school of philosophy known as *analytic philosophy*, with its corollaries of *empiricism* and *atomism*. Analytic philosophy presumes that all knowledge and understanding in the world is built in a bottom-up fashion from elemental observations of the world through a process of logical induction and algorithmic fusion. It further presumes that knowledge, once created, possesses a universal quality that allows it to be shared and applied across all situations. Reflections of analytic philosophy are seen in the Joint Directors of Laboratories' definitions of information fusion that drive C2ISR system design[3] and in the use of information post-pull strategies within some network-centric designs.[4]

In the following paper, I will argue that both of these traditional paradigms yield a misleading conception of what military command and control is all about. Such paradigms consequently lead to the development of inappropriate metrics for assessing system productivity and efficiency. In lieu of these concepts, the paper explores several dichotomies including (1) bottom-up versus top-down models of creating knowledge and understanding and (2) individual versus collaborative models of sensemaking in a dynamic operational environment. From this discussion then emerge several ideas for developing a new framework for measuring and assessing C2ISR system performance.

THE NEED FOR A PARADIGM SHIFT: INCREASING COMPLEXITY OF THE OPERATIONAL PROBLEM SPACE

Before addressing these various models, it is useful to briefly summarize the why a broader set of concepts might be needed for assessing C2ISR system performance. Here, the pressure for change results from the increasing complexity of the operational problem space. This complexity has arisen in two ways: (1) the evolution of what T.X. Hammes calls fourth generation warfare and (2) the evolution of military C2ISR in the Information Age as now embodied in the concept of network-centric.

Fourth Generation Warfare

With the conclusion of major combat operations in both Afghanistan and Iraq, coalition forces face a much more complex challenge in the furtherance of its national security objectives –the emergence of what Colonel T.X. Hammes has termed fourth-generation warfare.[5] This form of warfare can be historically traced, beginning with the strategies of Mao Tse-Tung in China, and further developed conceptually by Ho Chi Minh in Vietnam, the FSLN and Sandinista movement in Nicaragua, and the Intifada movement in the Palestinian Occupied Territories. The concept of fourth-generation warfare differs significantly from the type of operation national military forces have been organized to conduct in recent years –rapid decisive defeat of a conventional military adversary, involving precision firepower and maneuver against a mechanized force that is controlled by a single, centralized command and control system. By contrast, fourth-generation warfare involves several unique elements that must be understood and disrupted if a coalition force is to prevail. At the strategic level, the goal of the conflict by the adversary is expressed primarily in political terms: the defeat of our political will to engage in a specific region of the world. The strategic tactic used is not conventional military defeat, but the convincing of the public and key coalition decision makers that the struggle is too costly on moral, human, economic, and social grounds. In terms of time scale, the adversary is prepared to wage this strategy over a period of years and bring it to successful completion only after achieving a convergence of political, economic, and social forces. At an operational and tactical level, a fourth-generation warfare adversary pursues operations primarily along the political, economic, and social dimensions of a region, conducting military operations typically in limited fashion and only where it furthers strategic interests. In fact, when engaged militarily, such an adversary will often resort to negotiating, pulling back, or even dissolving into the civilian populace since the strategic goal is not to win militarily, but to create the impression that the struggle is intractable.

To disrupt the operations of a fourth-generation adversary at the strategic, operational, and tactical levels, one must understand something about the unique nature of the adversary's command and influence system. It reflects a "system of systems" organizational structure and process unlike the traditional command and control system employed by conventional military forces.

- First, the adversary will typically reflect a coalition of convergent interests rather than a single nation state or regime. Lacking a single "head" against which to develop a *coup d'oeil*, disrupting such a loose confederation will be based (1) identifying the critical linkages that bind these interests together and (2) developing strategies that can isolate or disrupt the cohesion of these interests.
- Second, the supporting elements of such an adversarial coalition exist at several tiers. At the top tier are found those insurgency leaders directly in charge of setting strategy and tactics. The second tier consists of those political, social, economic, religious, and even humanitarian organizations that lend indirect or covert support to the insurgency, but that otherwise fulfill a legitimate role within the region. The third tier consists of local population groups whose support and allegiance will change according to perceived needs of security and prosperity. Each of these tiers makes important contributions to the adversary's overall strategy. Yet, each will require a different approach to disruption or manipulation.
- Third, there will exist multiple and overlapping networks of command and influence across each of the political, social, economic, religious, humanitarian, and military dimensions of the region. Since each of these dimensions contribute to a different facet of the adversary's overall strategy, it will be important to understand the role, structure, and processes of each of these networks. Knowing where and how these networks intersect will also be an important step in their disruption.
- Fourth, given the diffuse and often informal nature of these various elements, a fourth-generation adversary accomplishes his strategic objectives through a combination of direct command and control, economic and social disruption, intimidation of specific individuals and groups, and the ability to exploit emergent crises for situational gain. Control of operations will be accomplished less through direct orders and more through establishing the local and global fitness conditions by which a complex, adaptive system evolves. Accordingly, disruption of these mechanisms will depend less on identifying and severing specific communication links and more on identifying and influencing the fitness conditions that shape behavior and outcome over the long run.

The implications of such warfare for C2ISR system design are obvious. First and foremost, the military commander must plan and prepare for a wide variety of effects-based operations that address the various political, military, economic, social, information, and infrastructure (PMESII) dimensions of the battlespace. Effects-based operations, in turn, require effective collaboration among the different stakeholders and experts participating in such operations in order to properly frame the decision space for military commanders and diplomats. As noted by Nancy Roberts, collaborative framing of the operational problem constitutes a critical first step of decisionmaking in what has become labeled a *wicked problem environment*.[6] The term *wicked problem* environment was originally defined by Horst Rittel and Melvin Webber.[7] Characteristics of wicked problem environments include (1) the problem is ill-structured so you don't understand it until you've developed a solution; (2) there is no "right" solution so problem-solving ends only when you run out of resources; (3) solutions are not right or wrong, simply "good enough" or "not good enough"; (4) each wicked problem involves a unique or novel set of factors and conditions; (5) every solution to a wicked problem is a "one shot solution" because you never get the opportunity to do it over; and (6) wicked problems have no obvious alternative solutions. Collaborative framing of the operational problem environment or decision space is also a critical element of coalition operations, as noted by former Supreme Allied Commander, General Wesley Clark.[8] If coalition partners do not share a common vision of the overall operation, it is likely that their various actions might be uncoordinated –and even counterproductive.

Network-Centric Operations

In the recent book, *Power to the Edge*, the point is argued that "*as bandwidth becomes ever less costly and more widely available, we will be able to not only allow people to process information as they see fit but also allow multiple individuals and organizations to have direct and simultaneous access to information and to each other. We will also be able to support richer interactions between and among individuals*."[9] However, in designing future C2ISR systems and information support technologies, it becomes important to establish exactly why such interactions are necessary. In the introduction of his book on effects-based operations, Ed Smith cites the following frustration of former Chief of Naval Operations, Admiral Mike Boorda, *"…it would sure be nice if we had some clear idea what it was we were trying to do first*."[10] Simply pushing or pulling information more efficiently around a network does not, by itself, improve the effectiveness of military operations in an effects-based coalition environment. Rather, it is that the network allows more effective interaction and reconciliation of differing perspectives so that the available information can be transformed by a cohesive understanding of command intent into relevant and actionable decisions by each of the involved participants. And, since military decisionmaking remains largely the responsibility of human beings, the design of information support technologies within such networks should be based on a sound understanding of how humans—both individually and collectively—frame and interpret available information to develop both shared understanding and coherent plans for action. Put another way, we need to turn our attention from information management to knowledge management.

Corresponding to the emergence of information technology (IT) in the latter half of the 20th century, interest began to grow in the question of how organizations—*e.g.*, large corporations, research institutes, military headquarters—create useful knowledge. Underlying this interest was the naïve belief that technology could provide information superiority which, in turn, would automatically translate into knowledge superiority and competitive advantage. However, results within both private industry and government have brought the realization that, in real world, the issue is a bit more complicated. In large part, this realization came about when it was discovered by some technology experts and management scientists that there is often no direct correlation between IT investment and organizational performance. Based on research from over a thousand large companies within the United States, Erik Brynjolfsson has shown that, while there is a slight positive correlation between IT investment and organizational productivity, a large variance exists in performance among these companies.[11] Examining the factors that contribute to this variance, Brynjolfsson found that "in advanced economies, IT is a promising source of productivity growth, but it makes little direct contribution to the overall performance of a company or the economy until it's combined with complementary investments in work practices, human capital, and organizational restructuring."

Karl Erik Sveiby, author of The *New Organizational Wealth: Managing and Measuring Knowledge-Based Assets*, recognized this same IT-productivity gap and adds that the confusion of "information" with "knowledge" has led organizations to invest billions of dollars in IT ventures that have often yielded marginal returns.[12] The emerging focus of the IT community on knowledge is seen further in the writings of Yogesh Malhotra who noted that this issue reflects a transition of the economy from an era of competitive advantage based on information to one based on knowledge creation.[13] And, while computers still offer organizations a great information-processing capability, the wicked problem environment of the new world of business imposes the need to variety and complexity of interpretations of information outputs generated by computer systems. Such variety is necessary for deciphering—making sense of—the multiple world views of the uncertain and unpredictable future. In such an environment, the objective of an organization is not to indulge in long-term planning of the future. Rather, the emphasis is on understanding the various world views that might impact the strategic direction of the organization.

Building a New Paradigm for C2ISR System Research and Analysis

Taken together, the transformation issues of fourth generation warfare and network-centric operations call for the development of a new paradigm for C2ISR research and analysis. Accordingly, the next section of this paper summarizes several schools of philosophy regarding the nature of knowledge and its creation within real-world settings. This discussion is followed by a brief overview of several recent models of cognition that shed light on (1) the nature of how individuals match available information with their held beliefs and subjective expertise, (2) the nature of knowledge and its relationship to both work setting and social context, and (3) the process by which individuals coming from different perspectives and interests develop a shared understanding of a situation. The paper concludes by sketching the beginning key elements of a new framework for measuring and assessing C2ISR system performance in a dynamic and undefined operational environment.

COMPETING SCHOOLS OF PHILOSOPHY REGARDING THE NATURE OF KNOWLEDGE AND ITS CREATION

The Rationalism of the Early Greeks

Early Greek philosophers such as Euclid and Socrates thought of knowledge as the development of understanding that proceeds out of logical questioning. Plato added to this system by positing that true knowledge must be referenced to an ideal world, as opposed to the world that one could apperceive through their senses. This school of thought—known as rationalism—posits that knowledge is derived primarily through logical reasoning without reference to empirical observation. Rationalism is reflected in the language and methods of mathematics and is seen to strongly influence the fields of engineering and artificial intelligence.

The Empiricism of Bacon, Hobbes, Locke, Berkeley, and Hume

Although Aristotle incorporated observation into his rational methods, it was Francis Bacon—in his *Novum Organum* of 1620—that made the powerful argument that knowledge should be based on empirical observation. According to Bacon, knowledge is created primarily through empirical observation and induction, wherein one accumulates observation upon observation until general facts emerged from specific facts. Others of this period such as Thomas Hobbes would modify Bacon's extreme position—known as empiricism—by adding that a certain degree of human rationalism was necessary to organize general facts into theories and laws. Other philosophers of the British empiricist school would refine Bacon's method even further. John Locke was concerned about the validity of knowledge and concluded in his *Essay Concerning Human Understanding* (1690) that knowledge comes from experience, either through the senses or through reflection on sensory data. Locke later introduced in the fourth edition of his *Essay* the notion of association –that ideas are combined in experience according to such principles as similarity and contiguity. Thus, knowledge was seen as the association of basic facts or more primitive level ideas on the basis of "natural" connections that exist in the world.

Locke also introduced a distinction between the so-called "primary" and "secondary" properties of objects in the world. Primary properties were considered to be those inherent characteristics of an object that existed independent of the perceiver –e.g., solidity, figure, motion, and number. In contrast, secondary properties of objects were considered functions of the mind and thus varied according to the perceiver –e.g., color, sound, taste. As a successor to Locke, George Berkeley took the position in his *Principles of Human Knowledge* (1710) that the mind was the ultimate reality (*esse est percipi*, or "to be is to be perceived"). This extreme position argues that the world only exists in one's mind. Berkeley, also being a theologian, attempted to explain the stability, independence, and order of external objects by brining in the all-perceiving mind of God. Continuing this same tradition of empiricism and the primacy of the mind, David Hume—in his 1886 Treatise on Human Nature—added the concept of "cause and effect" as a powerful mechanism for associating experience. True to Locke's position, however, Hume argued that cause and effect were not to be found existing in things observed, but only in the mind of the observer.

Analytic Philosophy and Predicate Calculus

In parallel with a growing emphasis on empiricism as the basis of knowledge, other schools of philosophy began to form around the notion that knowledge was more fully developed—and, hence, more available to the individual—through logical analysis. A major contributor to this position was Bertrand Russell, a British mathematician and philosopher of the early 20th century. Like Moore, Russell rejected the idealism of Plato (universal truths) and Immanuel Kant (time and space are defined by the mind) that was also reflected in the religions of the world (life is governed by a higher Being or force). Instead, Russell believed that knowledge could be attained through two principal means: acquisition and description. Acquisition of knowledge through one's senses accounted for only a small portion of what a person knows at a specific time. By contrast, the bulk of one's knowledge and understanding of the world comes through description. Since descriptions are enabled by language, knowledge then becomes a function language and grammar. This dichotomy of knowledge then led to the formal development of logical positivism, the notion that statements are meaningful only if they can be verified through either empirical evidence (observation and experiment) or analysis (logic). Although not accepted by all adherents of this movement, logical positivism in its extreme form argued that any concepts that could not be logically demonstrated to be either true or false were not worthy of study –hence, concepts such as societal values, God, beauty, were considered to be outside the realm of science and philosophy. Years later, another British philosopher would challenge the notion of verifiability in logical positivism by arguing that falsifiability is a more correct approach to science (and knowledge) in real life –*i.e.*, statements cannot be "proved" since the possibility always exists for discovering contradictory evidence.

Since most of our knowledge was believed to come through description, Bertrand Russell argued that a principal challenge of analysis was the breaking down of concepts into formal elements of language that could be logically combined to produce truths or contradictions. This emphasis led to yet another position on knowledge called analytic philosophy. The term analytic philosophy is somewhat ambiguous, but generally refers to the following ideas. As a broad method of philosophy, analytic philosophy emphasized the need for argumentation and evidence, avoidance of ambiguity, and attention to detail. As a specific doctrine of knowledge, analytic philosophy argued that knowledge should be built upon logical positivism and an outgrowth of this approach called logical atomism. Logical atomism—the notion that language can be broken down into primitive elements—gave rise through the work of George Edward Moore to the development and use of predicate calculus that has dominated much of artificial intelligence research. Interestingly, a student of Russell and Moore at Cambridge, Ludwig Wittgenstein, earned his doctoral degree through his publication of *Tracticus Logico-Philosophicus* that endorsed the position of analytic philosophy. Later in life, however, Wittgenstein would recant this position and expose a weakness of the analytic doctrine –that the meaning of words often depends upon context and usage. Such criticism not only distanced Wittgenstein from his fellow philosophers, but also opened the door for others to later examine knowledge from a more subjective point of view.

Needless to say, analytic philosophy has come to dominate much of science, particularly within English-speaking countries. Inherent in this school of thinking are several ideas that many researchers—particularly in the physical sciences—have come to accept without question the idea that knowledge is based on (1) the accumulation of empirical "facts" and analytic "descriptions," (2) that these facts and descriptions somehow possess universal properties that are independent of situation or individual viewpoint, and (3) that knowledge can be logically built or unfolded through the processes of induction and decomposition, respectively.

Outgrowths of Empiricism and Analytic Philosophy

Before moving on to more recent theories of knowledge, it is instructive to review two immediate outgrowths of both empiricism and analytic philosophy –*associationism* and *structuralism*. Associationism is practically synonymous with a traditional view of science: it is the belief that the primary task of science is to identify relationships between phenomena –to look for functional relationships. As a school of psychology, associationism gave rise to a focus on stimulus-response (S-R) pairs, conditioning, and reinforcement by such researchers as Ivan Pavlov, E.L. Thorndike, and R.I. Watson. Later forms of associationism developed by B.F. Skinner and William Estes focused on the development of learning theories –including specific mathematical models of learning based on cognitive association. From the viewpoint of epistemology, adoption of this view begins to move one closer to the notion that knowledge—at least in a practical sense—deals with relating concepts (*e.g.*, goals, constraints, options and conditions) to action. Years later, Gary Klein would incorporate the basic ideas of associationism in his theoretical development of naturalistic decision making wherein experts are seen to depend upon the recognition of specific situational cues (stimuli) that give rise to learned action responses.[14] While a stimulus-response model of creating actionable knowledge seems to be relevant for guiding expert behavior in familiar situations, the S-R model is seen to be less effective (if not completely irrelevant) when individuals face novel or unfamiliar situations.

A second immediate outgrowth of associationism was structuralism, as seen in the work of Wilhelm Wundt in Germany and E.B. Titchener in the United States. In terms of science, structuralism holds that the primary task of psychology is the discovery and classification of elementary conscious experiences that, when related and combined, give rise to more complex thoughts. In a certain respect, structuralism was motivated by Mendeleev's development of the periodic table of physical elements in chemistry around 1870. Desiring to transform psychology into a more "respectable" science, Wundt sought to identify and characterize thinking as being made up of complex combinations of elemental thoughts and sensations that could somehow be arranged in systematic fashion –much like physical compounds were chemically comprised of combinations of different elements. Wundt's research methods focused on introspection performed by trained test subjects under carefully controlled laboratory conditions. Subsequently, Titchener would bring the same theories and methods to the United States around the beginning of the 20th century –attempting to unify all sciences, but distinguishing the physical science type of observation (looking at) from that of psychology (looking within). Another of Titchener's contributions was his concept of stimulus error, the error of paying attention to only the properties of the stimulus, rather than cognitive experience produced by the stimulus on the individual. Similarly, Wundt would argue that physics deals with understanding experience as independent of the individual whereas psychology deals with understanding experience as dependent on the individual. Other researchers, such as Franz Brentano and Carl Stumpf, would extend and modify the focus and methods of structuralism. However, despite the dedicated work of these researchers over a period of several decades, structuralism failed to produce a promised "periodic table" of mental elements. Instead, Titchener's program of study gradually narrowed its focus to simply sensations instead than addressing the broader issue of how knowledge was organized within the mind. As a result, the field of psychology chose to largely ignore the inner workings of the mind in favor of what would become behavioralism (limited to the study of overt behavior). Unfortunately, lost also were some of the more useful ideas and methods of controlled introspection. Years later, many of these ideas and methods would be “rediscovered” in the fields of artificial intelligence and cognitive systems engineering.

From the standpoint of epistemology, structuralism has had significant influence on how modern science approaches the study of knowledge. First, structuralism holds that the primary data of interest to research is reported experiences, as obtained through carefully controlled introspection. Years later, many of the so-called knowledge elicitation techniques developed by artificial intelligence researchers would incorporate techniques and ideas originally introduced by Wundt and Titchener. Second, structuralism posits that it is possible to produce higher forms of knowledge through the combination of more primitive thought elements. Thus, the focus of inquiry was generally placed on the elements of thought, rather than the mental process by which they are combined to produce more complex thinking. A reflection of this aspect of structuralism can be seen in the development of information technology where the focus has often been limited to identifying the elements of information to be collected, stored, shared, and displayed. Like the early structuralists, latter day designers of information systems often focus their energies on the seemingly easier part of the problem (identifying and classifying information elements) – rather than on understanding and representing the epistemological processes by which elements of information can be combined to produce actionable knowledge. Finally, structuralism reinforces the notion that basic elements of cognition are somehow universal in nature and that they can be combined by a set of universal laws to produce higher levels of knowledge.

Reactions against Empiricism and Analytic Philosophy in Science

The traditions of empiricism and analytic philosophy eventually came to dominate science, both in terms of how knowledge is seen to be defined and in terms of methodology. Here, the scientific method reflects an iterative and recursive application of four activities: characterization, hypothesis, prediction, and experiment. Underlying the scientific method is the need for (1) precise, operational definition and measurement, (2) empirical observation and repeatable demonstration, (3) the creation of knowledge through the process of induction, and (4) the systematic accumulation of scientific knowledge within a stable framework of theories and definitions. From an epistemological point of view, the scientific method presumes that science is built exclusively upon objective knowledge that can be empirically validated, inductively created, and universally shared –i.e., knowledge is assumed to exist separately from the knower. Hand in hand with these presumptions is the notion that data (observed facts) begets information (data organized and invested with meaning) and that information begets knowledge (truths that can be universally employed to guide action). Within the military, evidence of this type of thinking is seen clearly in the definition of the multiple levels of intelligence fusion developed by the Joint Directors of Laboratories.[15] This definition, in its most naïve form, defines knowledge as being built in a bottom-up fashion from empirical observations, to the identification of battlespace entities and tracks (Level 1), to the fusing of spatial and temporal patterns into an adversary’s order of battle (Level 2), to the inference of adversary intentions and potential threats (Level 3). Such a definition, however, is somewhat vague and has led to numerous attempts to produce a more workable definition of knowledge creation.[16] Nevertheless, the underlying assumptions about knowledge creation reflected this type of bottom-up, analytical philosophy paradigm has permeated much of the thinking within C2ISR system research and analysis. Such an approach presumes that knowledge creation can be reduced to algorithmic computations and automated by machine technology –thus placing little or no emphasis on the role of human experience and expertise in the knowledge creation process. Moreover, the universality of knowledge implied by the analytic philosophy leaves little opportunity for examining the factors that influence knowledge creation within a wicked problem context where each stakeholder or expert might view the operational situation from a different perspective.

However, beginning in the early 1900s, a number of scientists began to challenge several of these epistemological assumptions. Prominently, the role of induction—the inference of a generalized conclusion from a set of specific instances—was challenged by Karl Popper, a British philosopher of the early and middle 20th century. Specifically, Popper argued that objective observation is not always feasible or desirable when presented with a large number of "facts" –a condition that is likely to lead to data or information overload. In addition, objective "facts" about a situation are not always as they seem since data inputs are likely to be subject to the interpretations and filtering of those providing them. Such obstacles can make empirical justification and the inductive development of laws or theories for prediction somewhat problematic. Finally, Popper agreed with the indeterminacy views of Willard Quine and Pierre Maurice Marie Duhem who stated that any theory can be made compatible with any empirical observation by the addition of suitable *ad hoc* hypotheses. This is analogous to the way in which an infinite number of curves can be drawn through any set of data points on a graph. This led Popper to develop his famous principle of falsifiability that reflects the apparently paradoxical idea that a proposition or theory cannot be scientific if it does not admit consideration of the possibility of its being false. In his 1951 paper, *Two Dogmas of Empiricism*, Willard Quine would go on to develop his concept of confirmation holism that states scientific theories are confirmed or disconfirmed as a whole.[17] Thus, the framework of a theory (formal conceptual scheme) is just as open to revision as the "content" of the theory. The idea that entire theoretical frameworks are subject to revision in science was further elaborated by Thomas Kuhn in his definition of a paradigm shift mentioned in the introduction of this paper. For example, in physics, research was once framed exclusively by the Newtonian laws of force and motion, only to be replaced by Einstein's framework of relativity. Within the past few years, the framework of relativity has given way to the notion that elemental components called "strings" provide a more unifying understanding of matter, time, energy, and gravity.

These various reactions against (or modifications of) empiricism and analytic philosophy within the scientific community suggest that the nature of knowledge and knowledge creation cannot be explained completely in terms of a "bottom-up" process that begins with empirical observation, objective definition and collection of "data," inductive hypothesis formation, and experimental validation. Rather, as first suggested by Quine, Duhem, and Popper, and then later formally theorized by Kuhn, the creation and definition of knowledge is often framed by an existing set of beliefs that are socially developed and evolved over time.

The Social Formation of Understanding: Linguistic Determinism, Personal Constructs, and Tacit Knowledge

In a broader sense, the debate over objectivity versus subjectivity reflected in Kuhn's concept of paradigm shifts was also appearing in other communities of practice. Collectively, these movements would begin to further distinguish knowledge that was implicit or internal to the individual versus knowledge that was somehow made explicit and shareable. Four such bodies of work are illustrative of this point and add clarity to the notion that knowledge was socially defined.

One body of work is found in the field of psycholinguistics, the study of language and how it relates to the formation of meaning and understanding within a community or society. Of specific note in this area 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.[18] 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, each 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 conceptual 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. Finally, there is a dynamic aspect to linguistic relativity. In a classic 1932 experiment by Carmichael, Hogan, and Walter, subjects were shown a drawing of a crescent shape and then told that it either represented a crescent moon or the letter "C".[19] When asked to later reproduce the shape from memory, subjects tended to distort their recalled version of the shape to more resemble the verbal definition they had been provided. Thus, language can have an influence on spatial or visual memory.

At about this same time, George Kelly—an engineer who later became a clinical psychologist—began to similarly notice that different people can often hold quite different and unique conceptions of the world around them. As part of his theory of personality, Kelly posited that each individual acts as a scientist – that from the dawn of consciousness, we each try to make sense of the world as we experience it, and we do this by constantly forming, testing, and refining hypotheses about the world.[20] By the time an individual reaches adulthood, the person has developed a very complex model of the world and their place in it. Kelly defined this phenomenon in terms of personal constructs, an individual's organization of unique mental models of the world that are both shaped by prior experience and are used to interpret new experiences. Core constructs were further defined by Kelly as those deeply-held values and principles that are unlikely to change when the individual is faced with contradictory information. Retaining an engineer's desire for precision, Kelly also developed an objective method for eliciting the personal constructs of an individual. Though Kelly adamantly denied being part of the "cognitive psychology" movement, his *Repertory Grid* method would become a useful tool in the field of cognitive systems engineering.

In a similar way, Michael Polanyi—a Hungarian medical scientist whose main work was in the field of physical chemistry prior to turning to philosophy, developed a series of lectures on personal knowledge at Manchester University in the late 1940s and early 1950s. 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.[21] Polanyi's concept of tacit knowledge was reflected in 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 the concepts that the individual disposes and which 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 or an operations order), 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. To illustrate the fact that tacit and focal knowledge are mutually exclusive, consider the example of a proficient pianist playing a complex piece of music. If they suddenly shift their attention from the piece of music they are playing to the movement of their fingers, they are likely to become disoriented and lost with regard to where they are at in the musical composition. Similar examples can be seen from other areas of expertise—*e.g.*, chess playing, air-to-air combat—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.

Polanyi wrote about knowledge in both static and dynamic terms. In static terms, articulated knowledge was defined by Polanyi as that portion of tacit knowledge that could be explicitly articulated 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 dynamic terms, Polanyi's theory also speaks 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. Also in a dynamic sense, knowledge relates to action-taking: knowledge is a tool by which an individual either acts or gathers additional knowledge. The skill with which an individual acts or gathers additional knowledge is a function of the meta-cognitive strategies the person uses to access and employ their tacit knowledge in order to shape and guide their focal knowledge.

Returning to the work of Karl Popper, Popper sought to reconcile Russell's notion of "universal elements of thought" with the idea developed by Berkeley and Hume that each individual holds a unique view of the world. The resulting theory, published in a 1972, employs a three-world model that embraces both objective and subjective classes of knowledge.[22] According to Popper, *World One* is defined as the world of physics –the world of physical objects and forces that can be objectively measured and defined. *World Two* refers to the psychological world of the individual –the personal world of feelings, dispositions to act, and all kinds of subjective experiences. Finally, *World Three* refers to the conceptual products of the human minds that can be collectively shared within society –the world of books, databases, and other explicit writings that provide descriptions of problems, theories, values, and so forth. A physical object such as a book (or even a military operations order) belongs to World One. It contains information that belongs to World Three since it was created by a specific individual (or set of individuals) and then made available for others to read. When read by two different people, it gives rise to two distinct sets of World Two interpretations, based on their World One brain functions. Importantly, the World Three information contained in the book or military order, being limited by the constructs of language and symbology, reflects only a small part of the World Two knowledge of the original author. Likewise, the manner in which this information is interpreted by the recipients will be influenced by their own World Two knowledge. This being said, however, Popper acknowledges that there will likely be some degree of objective correspondence between (1) the author's World Two thoughts and the World Three contents of the communicated information and (2) between the World Three contents of the communicated information and the recipient's World Two interpretation. This degree of objective correspondence is what makes human communication possible within a society. Popper thus concluded that it is possible to accept the reality (and autonomy) of World Three information while, at the same time, admitting that it is the product of the human mind. In terms of knowledge classes, the conceptual content of World Three information reflects both objective and subjective classes of knowledge.

While neither Kelly nor Polanyi was considered "true" philosophers by their contemporaries, their writings would significantly influence other researchers who were searching for a more practical definition of knowledge. Likewise, the work of Sapir and Whorf is influential, but does not come strictly out of the field of philosophy. Finally, the work of Popper is not widely recognized among scholars within the United States. The reason for this is that Popper's work ran counter to several dominant orthodoxies, specifically the ideas of Plato and Aristotle. Yet, Popper's work—like that of Polanyi—would lay the foundation for the later conceptualization and modeling of knowledge in several fields of study. One field in particular that has been significantly influenced by these writing is the area of knowledge management. It is to this area that the discussion now turns.

RECENT MODELS OF KNOWLEDGE CREATION

Tacit Knowledge: How Should We Characterize It?

As noted earlier, the works of Polanyi, Keller, Popper, Sapir and Whorf each historically identified two broad forms of knowledge: (1) knowledge that is tacit, personal, hidden, and which forms a background framework for an individual's interpretation of the world and (2) knowledge that is explicitly codified in symbolic form, universally sharable with others, and available for public reflection. More recently, other researchers have expanded upon this distinction to define various typologies. In fact, as pointed out by Haridimos Tsoukas, "*The significance of 'tacit knowledge' for the functioning of organizations has not escaped the attention of management theorists. Ever since Nonaka and Takeuchi have published their influential* The Knowledge-Creating Company*, it is nearly impossible to find a publication on organizational knowledge and knowledge management that does not make a reference to, or use the term 'tacit knowledge'*."[23] In this work, Ikujiro Nonaka and Hirotaka Takeuchi define knowledge as justified true *belief*.[24] In contrast with the positivist approach traditionally held within Western society, these authors place emphasis on the adjective *justified* rather than *true*. Hence, they see individuals and organizations in everyday life as treating knowledge in terms of a workable level of certainty and understanding, rather than seeking knowledge in an absolute truth sense.

Likewise, Thomas Davenport and Lawrence Prusack pragmatically define tacit knowledge as "*a fluid mix of framed experiences, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices, and norms*."[25] Closely relating knowledge with action, Davenport and Prusack emphasize the following components of tacit knowledge within an organization: staff *experience* gained over time from training and informal learning, *ground truth* experienced from personally significant real-life situations, *complexity* reflecting a myriad of situation elements that might or might not fit a simple or elegant model of understanding, *judgment* reflecting the significance or importance of new situational elements, *rules-of-thumb* that reflects intuitive solutions developed through trial and error over time, and *values and beliefs* that reflect held preferences for interpreting observations.

In his articulation of organizational sensemaking, Karl Weick extends this view to the organizational level by noting that individuals within organizations make sense of their present situation by relating their current observations via some relevant pattern or connection to past moments of experience.[26] This relationship can be expressed in the following manner:

[past experience] + [connection] + [current experience] = meaningful definition of current situation

Collectively, these patterns or connections to past experience are eventually shared in common among organizational members in one or more of the following forms of tacit knowledge that are intuitively held in common to some degree across the organization: ideology (shared, relatively coherently interrelated set of emotionally charged beliefs about cause-effect relationships, value-driven preferences for certain outcomes, and normative expectations), *third-order controls* (unconscious or taken for granted set of premises or assumptions that primarily operate early in the problem framing and problem solving process), *paradigms* (shared set of inductive assumptions describing what elements make up a specific aspect of the world, how they act, how they relate to one another, and how they may be known), *theories* *of action* (simplified, abstract stimulus-response propositions that guide organizational actions to make them more manageable and consistent, and to maintain the participants' sense of personal responsibility), *tradition* (guiding images and beliefs in symbolic form regarding the past history of the organization) and *stories* (narrative guides to future expectations and action that reflect a vivid, sequenced account of events, conditions, and outcomes for situations).

Extending the study of knowledge to a societal level, Chun Wei Choo acknowledges a distinction between explicit and tacit forms of knowledge, but adds yet a third classification: *cultural knowledge*.[27] Here, Choo defines cultural knowledge as the beliefs an organization holds to be true based on experience, observation, reflection about itself and its environment. Over time, an organization develops shared beliefs about the nature of its main business, core capabilities, markets, competitors, and so on. These beliefs then form the criteria for judging and selecting alternatives and new ideas, and for evaluating projects and proposals. In this way an organization uses its cultural knowledge to answer questions such as "What kind of an organization are we?" "What knowledge would be valuable to the organization?" and "What knowledge would be worth pursuing? In a more recent work[28], Choo considers the national cultural dimensions originally developed by Geert Hofstede[29] and argues that these dimensions are useful for explaining how knowledge is defined and managed within different national cultures. These dimensions include power distance, individualism versus collectivism, masculinity versus femininity, uncertainty avoidance, and long-term versus short-term orientation. Cultural differences along each of these dimensions can be found among numerous nations that have participated in military coalitions in recent years. Hence, their potential for influencing the functioning of coalition C2ISR systems is significant.

Creating Actionable Knowledge: Pragmatic Models of Individual Sensemaking

Attention is turned next to the issue of creating actionable knowledge. Polanyi refers to this issue in his distinction of between *focal knowledge* and *tacit knowledge*. Focal knowledge refers to knowledge about the issue, problem, object, or phenomenon that is the current focus of attention. Tacit knowledge, by contrast, is the breadth of background knowledge that serves to identify, filter, sharpen, and bring meaning to that which is in focus. Hence, the term actionable knowledge equates to Polanyi's focal knowledge –knowledge that provides understanding of the current situation, frames the situation in terms of recognizable problems, and provides a plausible cause-effect pathway for taking action. Several recent bodies of work have focused on the pragmatic issue of creating actionable knowledge – at both the individual and organizational level. As compared with the theoretical writings of earlier philosophers and researchers, each of these works adopts a more pragmatic pint of view in characterizing the nature of knowledge and how it is used in the real operational world.

Considered first is recent work by Winston Sieck and a team of researchers from Klein Associates.[30] Extending the earlier work of Gary Klein on recognition-primed decision making, their work proposes a data/frame model of focal knowledge creation that consists of various mental functions performed in a recursive manner. The data/frame model—as the name might imply—hypothesizes that creating focal knowledge involves fitting available data (environmental cues) into an explanatory frame (a constructed mental model of the situation built from fragmentary mental models). According to Sieck *et al*, "*The purpose of the frame is to a) define the elements of the situation, b) describe the significance of these elements, c) describe their relationship to each other, d) filter out irrelevant messages while highlighting relevant messages, and e) reflect the context of the situation, not just the data*." Further, they note that, *"…data elements are not perfect representations of the world, but are constructed. They are sampled from the available information in the environment and defined in terms of available frames*." Sieck *et al* refer to the creation of focal knowledge as *sensemaking* –making sense of an on-going situation. As seen in terms of the data/frame model, sensemaking is an iterative process in which the individual's information gathering activities and mental construction activities are continually played off against one another in order to maintain the "best" interpretation of the current situation. Sieck *et al* characterizes this interplay in terms of six specific cognitive activities that can elaborate, question, preserve, compare, seek, or reinterpret essential elements of an explanatory frame. These six functions of sensemaking serve to construct, maintain, and continually adapt the frame so as to provide the best interpretation of the current situation. The "just-in-time" nature of the frame hypothesized in Sieck's model stands in contrast to the belief previously held by some researchers of naturalistic decision making that experts somehow maintained complete mental models of familiar situations in long-term memory. As such, the more recent model of sensemaking provided by Sieck *et al* characterizes focal knowledge creation as a flexible process that is continuously adapted to the needs of the current situation.

Alison Kidd extends our understanding of these processes in her discussion of a *knowledge worker*.[31] As distinguished from other classes of information workers, a knowledge worker is an individual whose work focus and content are continually changed by the information they process. Hence, her work recognizes the potential for dynamic interplay between an individual's focal knowledge content and their perceived flow of work tasks. In describing the manner in which individuals store tacit knowledge, Kidd rejects the popular notion that humans somehow maintain a store of information in their minds like a computerized information system. Rather, an individual maintains a constantly updated view or model of the world as an integrated whole and relies upon this immediately available model to interpret their current situation. As new externalized information is received and combined, its internalization by the individual serves to reform or modify their model of the world. Once internalized, this new information becomes difficult to retrieve as separable "facts". Thus, Kidd argues for a more ecological theory of knowledge in which individuals are continually interacting with their environment to update and maintain a "current" model of the world. Cognitively speaking, the human mind can be said to be designed such that it primarily operates around this "current" model of the world, rather than maintaining an ability (like a computer) to regurgitate specific facts or individual elements of information.

Consistent with the data/frame model of focal knowledge creation is the US Army's current research on critical thinking skills, as directed by Sharon Reidel.[32] A general finding of this research has been the notion that individuals display two specific patterns of focal knowledge creation that are labeled *System 1* and *System 2* thinking, respectively.[33] System 1 thinking is characterized as "*intuition, fast, parallel, associative, effortless, automatic, influenced by accessibility, limited awareness of process*," whereas System 2 thinking is seen as "*reasoning, slow, effortful, flexible, controlled, conscious.*" Obviously, System 1 thinking provides competitive advantage in situations that are familiar and known to the individual. However, System 1 thinking—being constructive in nature—can lead to any number of interpretive and decisionmaking errors when the individual faces situations that are novel or uncertain. Thus, an appropriate counterbalance to such error is System 2 thinking that is more analytical—and more deliberate—in nature. At the heart of this issue is the need to develop a meta-cognitive strategy that moves back and forth between these two patterns of knowledge creation as the situation demands. In response, the Army has developed a normative model for developing and maintaining an effective interpretation of the current situation in a military context. From a review of the cognitive literature on decision making, coupled with the findings of a workshop, the US Army identified a set of eight meta-cognitive skills that were considered (1) important to the success of battle command operations and (2) difficult to execute –*i.e.*, required formal training in order to achieve skill proficiency.[34] In many ways, these skills—suggesting the need for commanders to continually test and adjust the framing of their situation interpretation—reflect the sensemaking functions identified by Sieck *et al*. These skills include (1) framing the problem, (2) recognizing the main point in a message, (3) visualizing the plan, (4) constructing plausible stories to link incidents, (5) recognizing personal bias and fallibility, (6) generalizing from specific instances, (7) adopting multiple perspectives, and (8) determining when to seek more information.

Creating Shared Knowledge: Pragmatic Models of Collaborative Sensemaking

In terms of individual sensemaking, the various bodies of research cited earlier have provided us with broad understanding of how available cues and information from the environment are combined with tacit knowledge to produce focal knowledge –a just-in-time understanding of the current situation that serves to (1) identify and define problems requiring attention and (2) guide the development of appropriate action responses. However, sensemaking is rarely an individual activity. Rather, it generally involves multiple participants and usually occurs in the context of an organizational structure of some kind. Moving to the level of the organization, Karl Weick emphasizes sensemaking as a collaborative, socio-cognitive process of creating actionable knowledge within an environment where each expert and stakeholder holds a different perspective.[35] Taking a pragmatic view of focal knowledge creation, Weick's research adds to our understanding of both process and content by characterizing organizational sensemaking as (1) grounded in personal identity construction, (2) retrospective of past experience, (3) actively enacting the environment rather than merely passively interpreting it, (4) socially influenced in terms of shared meanings, (5) on-going without beginning or end, (6) guided by specific extracted cues, and (7) driven by plausibility rather than accuracy. Overall, Weick emphasizes the close relationship between knowledge and action by characterizing organizational sensemaking in terms of four basic processes –two of which are belief-driven and two of which are action-driven. Belief-driven processes include *arguing* (the notion that different perspectives often compete for recognition and acceptance within organizations) and *expectation* (the notion that focal knowledge continually seeks to anticipate future outcomes for specific situations). Here, Weick argues that expectations are more directive and filtered than arguments because of the need for plausibility and responsiveness of action. Action-driven process include *commitment* (the notion that command decisions within organizations can have—like beliefs, cultures, and traditions—an anchoring effect on subsequent sensemaking activities) and *manipulation* (the notion that individuals and organizations not only frame their worlds to conform to a given perspective, but also act in ways to consciously shape their worlds to conform to these views).

While Weick provides an overview of the major themes involved in collaborative sensemaking, his work does not address the specific cognitive mechanisms involved in this process. To develop this part of our understanding, we must turn to several other bodies of current research. In his book, *InfoSense: Turning Information into Knowledge*, Keith Devlin introduces the notion of a *common ground* of understanding as a necessary component of conversation between two or more individuals.[36] As summarized by Devlin, "*The naïve conception of a conversation as a series of alternating, individual utterances is not what generally happens in practice. For one thing, there are usually false starts, overlaps, and interruptions. Moreover, a conversation comprises, not a series of individual utterances, but a sequence of cooperative events called contributions. These contributions are mini-negotiations that serve to establish the meaning of the words spoken and hence the information they convey. …The participants base their contributions on the common ground and design their contributions to add new information to the common ground. Thus, the entire conversation can be regarded as a process of negotiating the identification and the growth of the common ground.*" The notion of a common ground provides an interesting metaphor for describing the overhead cost of collaboration. Here, Devlin notes that as more participants are added to a conversation, the number of negotiating exchanges required for establishing a common ground of understanding can rise significantly.

As interesting as Devlin's metaphor might be, it leaves open the question of exactly what is being represented. To address this issue, we consider the work of Nonaka and Takeuchi.[37] In their discussion of justified true beliefs, they see such beliefs as existing in two complementary forms within an organization—explicit and tacit—that can be transformed back and forth from one form to another through the processes of *socialization* (directly acquiring tacit knowledge through shared experiences), *externalization* (converting one's tacit knowledge into explicit concepts through the use of abstractions, metaphors, analogies, or models), *combination* (acquiring and integrating abstractions, metaphors, analogies, and models from different sources to produce new explicit knowledge), and *internalization* (incorporating new explicit knowledge into one's existing tacit knowledge –thus potentially modifying the structure and focus of that tacit knowledge). Occurring together in a spiraling pattern, these processes serve to *organizationally amplify* the knowledge of individuals such that new and more productive knowledge is generated. The definition of these four processes has given rise to the popular notion by some knowledge management researchers that the phenomena of shared understanding and collaborative knowledge creation somehow involve a three-step process that is roughly characterized as follows:

- Step 1: Individual A externalizes a portion of their tacit knowledge in the symbolic form of information that can be shared with others. Individuals B and C do likewise.
- Step 2: Individuals A, B, and C engage in the exchange of their externalized information elements, or combine it to form new elements (theories, models, or reflected understandings).
- Step 3: Each individual then internalizes the new information elements, thereby modifying or adding to their own existing tacit knowledge structure.

While such a characterization follows the work of Nonaka and Takeuchi and has a certain intuitive appeal, other researchers have taken issue with specific aspects of this paradigm. Specifically, Haridimos Tsoukas rejects Nonaka & Takeuchi's original interpretation of tacit knowledge as knowledge not-yet-articulated –knowledge awaiting translation or conversion into explicit knowledge.[38] Here, Tsoukas emphasizes the ineffable nature of tacit knowledge and argues that Nonaka and Takeuchi's definition is meaningless –reducing tacit knowledge to merely that which can be articulated. In contrast, Tsoukas sees tacit and explicit knowledge not as two ends of a continuum but as merely two aspects of the same thing. As he describes, "*Tacit knowledge consists of a set of particulars of which we are subsidiarily aware as we focus on something else. Tacit knowing is vectorial: we know the particulars by relying on our awareness of them for attending to something else. Since subsidiaries exist as such by bearing on the focus* to *which we are attending* from *them, they cannot be separated from the focus and examined independently, for if this is done, their meaning will be lost. While we can certainly focus on particulars, we cannot do so in the context of action in which we are subsidiarily aware of them. Moreover, by focusing on particulars after a particular action has been performed, we are* not *focusing on them as they bear on the original focus of action, for their meaning is necessarily derived from their connection to that focus. When we focus on particulars we do so in a new context of action which itself is underlain by a new set of subsidiary particulars. Thus the idea that somehow one can focus on a set of particulars and convert them into explicit knowledge is unsustainable.*" Tsoukas concludes from his analysis that, essentially, nothing in the form of identifiable knowledge elements is being converted, exchanged, and re-assimilated. Rather, what is taking place among individuals is a recursive process in which the individuals are drawing each other's attention to different things that are deemed relevant to the central focus of their attention. That is, the exchange of information serves to shift or expand the individual's vectors of attention to a new set of subsidiary or peripheral relevant knowledge elements that can be used to interpret the object (or problem) of their primary attention.

So what is meant by the notion of *shared understanding*? Or, what is involved cognitively in the collaborative creation of new knowledge, as argued by Nonaka and Takeuchi? Clearly, since tacit knowledge is personal and largely ineffable, it is not possible to speak of one individual directly transferring their tacit knowledge to another individual. Indeed, following the arguments of Kidd and Tsoukas, tacit knowledge does not exist in a form that can be isolated down to specific elements of information or understanding and shared with others. Rather, the concepts of shared understanding and collaborative knowledge creation involve the type of process postulated in Figure 1.

Initially, individuals hold different perspectives of a given issue, based on their respective experience and areas of functional expertise. As shown at the top diagram of Figure 1, each person frames the issue with a different set of activated subsidiary knowledge elements thought to be relevant. As these individuals collaborate, they communicate their perspectives by drawing attention to specific elements of activated knowledge and by articulating them to some degree in the form of information that can be exchanged (middle diagram in Figure 1). Given the difficulty of externalizing tacit knowledge, these articulations, by nature, reflect only an approximation of each individual's activated knowledge –ignoring some elements and only partially describing the remainder. Finally, the exchanged information is seen in the bottom diagram to modify the perspective of each individual, thus bring them closer into alignment with each other. This alignment is not perfect for two reasons. First, the information might fail to reflect all of the relevant subsidiary knowledge elements perceived by the other individual. Second, the information received goes through an additional interpretation process by the receiver as it is internalized into additional subsidiary knowledge elements. However, the process can be seen to result in a refocusing of each individual toward a more common awareness of the factors and elements relevant to the central issue in question –even if the individual understandings of those factors and elements remain intuitive and personal.

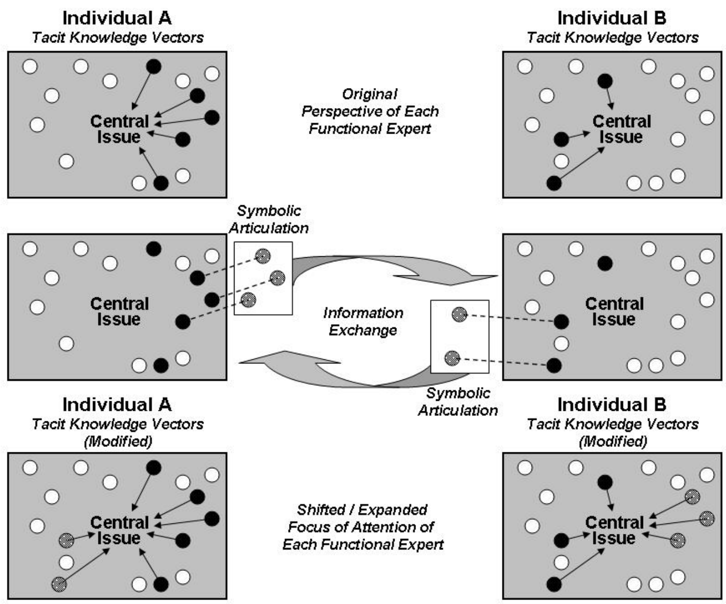

Figure 1 The Development of Shared Understanding

A final body of work relevant to collaborative knowledge creation is that of Paul Feltovitch, Kenneth Ford, and Robert Hoffman that addresses how expertise is employed in specific work contexts.[39] Reviewing the fields of cognitive and social research, these authors posit that "expertise" should not merely be viewed as a cognitive state of an individual –a set of cognitive skills and experience-based knowledge that enables effective problem-solving. Rather, they argue from a sociological point of view that expertise is actually better defined by the work role that certain individuals are placed in by a variety of contextual factors. Thus, it is the match between the demands of the operational environment and the individual's skills and knowledge that enable this individual to perform as an expert. Their resulting model is extended in this paper to suggest a possible framework for identifying and assessing C2ISR system performance issues. Figure 2 illustrates this model.

As shown in Figure 2, the model incorporates four system elements linked together in a tetrahedral structure: (1) *knowledge workers*, (2) *problem-task structure*, (3) *social-organizational context*, and (4) *knowledge creation*. Knowledge workers reflect that aspect of operational expertise that is associated with individual commanders, other key decision makers, and their supporting staffs. Listed in the box above are those combat development variables that influence the quality and characteristics of these knowledge workers that are made available to perform the sensemaking and decision making tasks within the C4ISR system. To the left are shown the variables that define the problem-task structure for the C4ISR system. The list of variables here is quite extensive and changes in any of these variables can significantly alter the requirements placed on the C4ISR system. From the viewpoint of expertise, these variables are seen to influence the relevance of specific types of cognitive skills and experience-based knowledge.

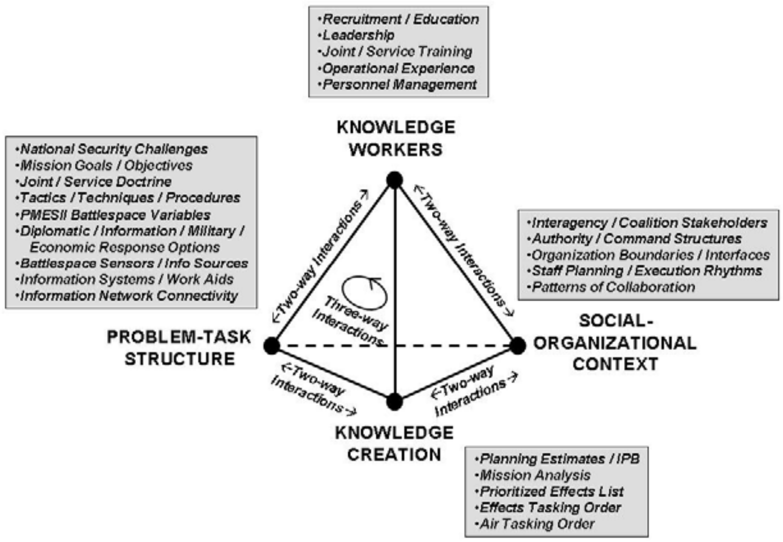

Figure 2 Tetrahedral Model of C2ISR System Performance

To the right are shown the variables that define the social-organizational context of the knowledge work performed within the C4ISR system. These variables shape and modify the process by which the knowledge work is performed. To a large extent, these variables socially determine the role played by different expert within the C4ISR system –hence, they contribute to the overall definition of expertise at the system level. Finally, at the bottom, knowledge creation is seen as the product generated by the C4ISR system –the translation of command intent into specific, directed actions that achieved a desired set of effects against an adversary or regional population. The value of arranging these system elements in a 3-dimensional tetrahedral structure is seen in the ability of the structure to illustrate the complexity and specific research and development challenges within the C4ISR system acquisition process. The lines connecting each point of the tetrahedron can be interpreted as the two-way interactions occurring among the various sets of variables. For example, human factor engineering research has traditionally concerned itself primarily with the interaction between knowledge workers at the top and information systems and work aids at the left. Training research and development often focuses on issues lying along the axis between knowledge workers and social-organizational context. Research and development on collaboration aids lies along the line between work aids (problem-task structure) and patterns of collaboration (social-organizational context). At the same time, there exist three-way interactions among these variable sets.

A NEW FRAMEWORK FOR MEASURING AND ASSESSING C2ISR SYSTEM PERFORMANCE

The preceding discussion suggests an outline for a new research paradigm or conceptual framework for measuring and assessing critical elements of C2ISR system performance. This new framework reflects the basic purpose of a military C2ISR: to support the commander's decisionmaking process through the development of actionable, effects-based knowledge that enables a joint or coalition to effectively engage a future adversary across multiple PMESII dimensions of a battlespace. To that end, the new framework acknowledges that an essential component of C2ISR system performance is the ability of a network-centric command and control organization to effectively manage the integration of several forms of knowledge (explicit, tacit, and cultural) within and across the various formal and *ad hoc* patterns of collaboration that exist within a joint or coalition staff process and battle rhythm.

The basic elements of the framework are suggested by the diagrams illustrated in Figure 1 and 2. Beginning with the tetrahedral diagram in Figure 2, we see that the collaborative integration of explicit, tacit, and cultural knowledge within a network-centric command and control organization is affected by the confluence of three system elements: knowledge workers, problem-task structure, and social-organizational context that combine in various ways to produce a fourth element, the creation of relevant, actionable knowledge for the commander and other key decisionmakers. Each of these elements, as well as the two-way and three-way interactions of these elements provide the basis for developing meaningful performance metrics that are diagnostic for both the system developer and system user. Figure 3 illustrates one possible set of metrics that might be employed in the design and development of a C2ISR system. As seen in this example, the first three system elements provide the basis for developing process-related metrics relevant to C2ISR system performance, whereas the fourth system element provides the basis for developing product outcome metrics. Of course, the specific emphasis given to each metric would vary depending upon the nature of the research –*e.g.*, information technology development, training research, organizational design.

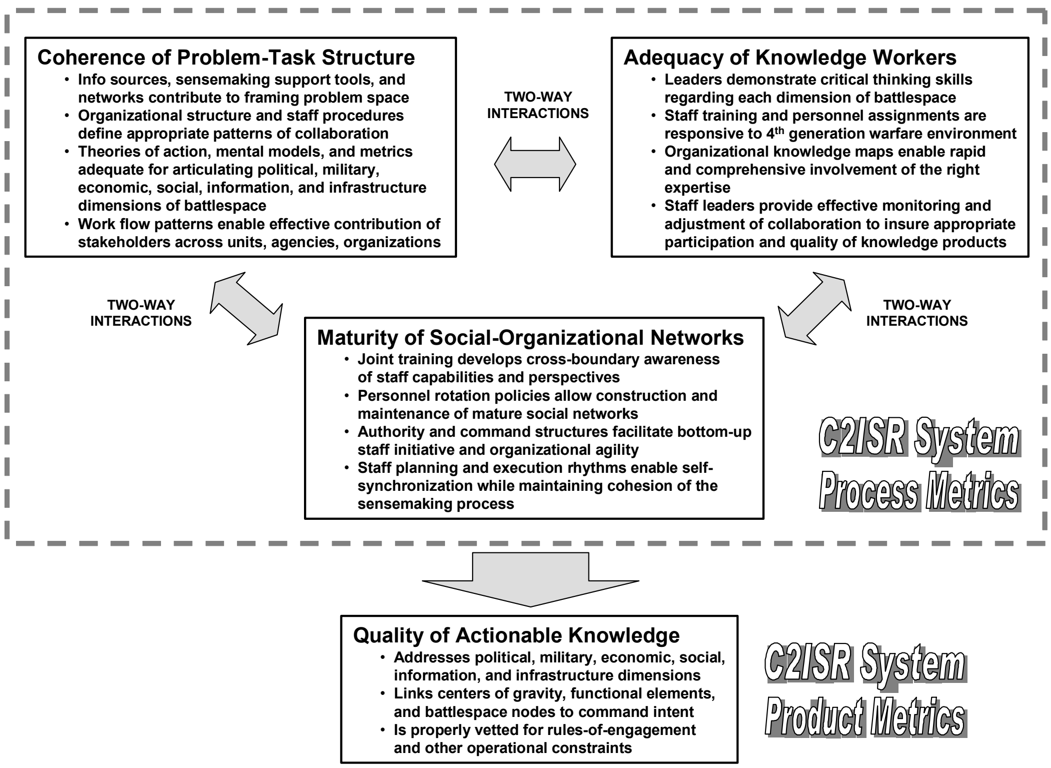

Figure 3 Example Areas of Metrics for Assessing Overall C2ISR System Performance

Moving to the diagram illustrated in Figure 1, we see that the basic process of collaborative knowledge creation within a network-centric command and control organization involves not just the exchange of information (long thought to be a primary dimension of C2ISR system performance), but the effective interaction of various stakeholders and experts who bring different operational perspectives to bear upon each work task within a joint or coalition battle rhythm. This process is seen to repeat itself within and across the various formal and *ad hoc* patterns of collaboration that exist within a joint or coalition staff process and battle rhythm. At the core of this interaction is the exchange of cognitive pointers that serve to bring the data/frame structures of each participant into closer alignment with each other. The effectiveness and efficiency of such interactions can be significantly diminished by any number of technological, cognitive, social, and organizational obstacles defined along the various edges of the tetrahedral model. Figure 4 illustrates three sets of metrics that focus specifically on the nature and quality of collaborative knowledge creation within a C2ISR system. Shown at the upper left of this figure are a set of example metrics that focus on the cognitive process of individual sensemaking within each step in an operational planning or execution process. Following next are a set of metrics that specifically deal with the collaboration process –*i.e.*, the process by which participants articulate their individual perspectives on a given task, exchange attentional cues with other participants, and reconcile their various understanding. Shown at the bottom of this illustration is a set of metrics that address the quality of the shared sensemaking or shared understanding produced by this process.

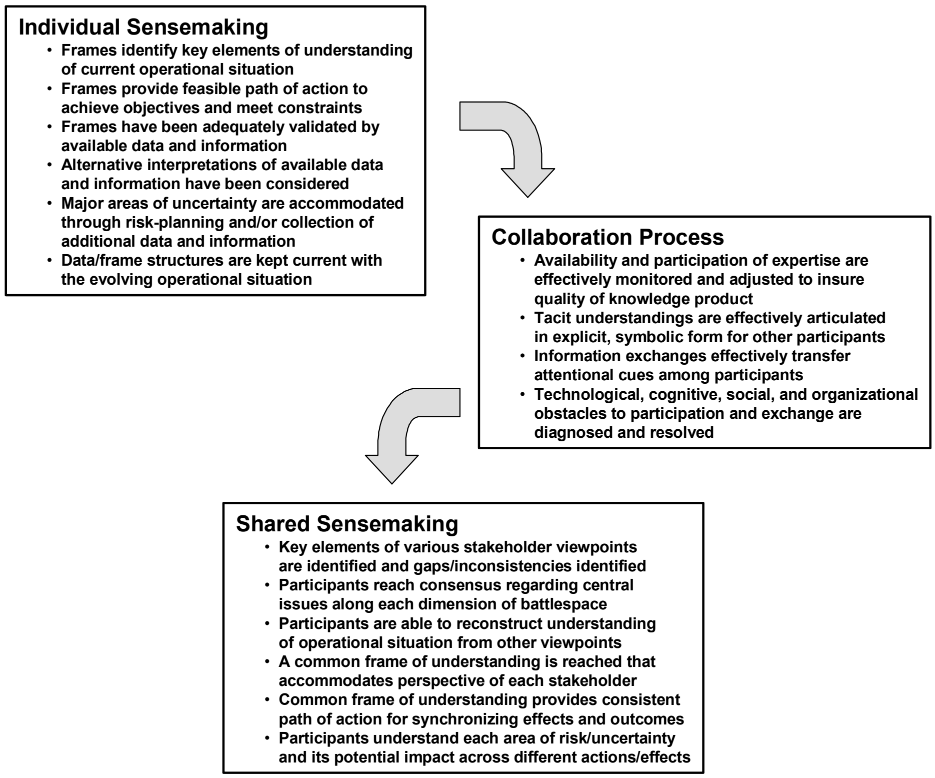

Figure 4 Example Metrics Assessing the Quality of Collaborative Knowledge Creation

The construction of specific metrics for guiding the development of a particular information support system, staff training program, personnel management policy, organizational design, or other aspect would be dependent upon the nature and focus of the individual program. Hence, it is beyond the scope of this paper to present such metrics. However, it is believed that the preceding discussion provides the theoretical foundation for just such an undertaking.

In summary, the present discussion has shown the importance of recognizing that different classes of knowledge—explicit, tacit, and cultural— ultimately contribute to C2ISR system performance and, hence, must be taken into consideration by researchers and system developers. Much of the philosophical and behavioral science literature that contributes to our understanding of these forms of knowledge have long been considered by those steeped in the analytic philosophy tradition to be beyond the purview of analysis. More recent theories and models of knowledge creation, however, have provided the basis for rigorously—if not completely quantitatively—considering such factors in an analytic fashion. Thus, it becomes possible to focus the attention of C2ISR system studies and analyses on what is truly important, and not merely on what can be easily measured and quantified. In this regard, it is hoped that the present paper will stimulate further elaboration of the various ideas presented and that, collectively, this work will move C2ISR research into a new—and more enlightened—period of normal science.

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