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The Socio-Cognitive Dynamics of Knowledge Creation in Scientific Knowledge Environments

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THE SOCIO-COGNITIVE DYNAMICS OF KNOWLEDGE CREATION IN SCIENTIFIC KNOWLEDGE ENVIRONMENTS

ABSTRACT

Despite increasing emphasis on knowledge work and knowledge workers, the dynamics of knowledge creation in a knowledge intensive domain such as Research and Development is an elusive topic. Drawing upon some early and contemporary writings in the cognitive philosophy of science and the sociology of knowledge domains, a preliminary framework of the dynamics of knowledge creation in the discovery/invention process is extended. Knowledge development is characterized as a cognitively based evolutionary learning process that is embedded in, and influenced by the social context. Scientific deductive and inductive action are located as the key drivers of knowledge development, where scientists construct and reconstruct cognitive models of the problem domain to be explored, invented, or discovered. Potential cognitive pitfalls that can adversely impact the quality of these knowledge development processes are discussed. The relationship between social context and cognition is explored. Some features of the scientific contextual environment that can influence the efficacy of scientific deductive and inductive action are identified.

'Theories do not simply develop; they are developed through the cognitive activities of particular scientists"

(Giere, 1992; p. xviii)

I. INTRODUCTION

As we move towards the 21st century we are experiencing many radical changes in the world of organizations and the nature of work. Two observable shifts in this changing landscape are the gradual replacement of capital and labor intensive firms by 'knowledge intensive firms' (Starbuck, 1992), and routine work by 'knowledge or non-routine work' (Pava, 1983). It has been observed that these changes are in response to intensified global competition and a resultant turbulent market environment where survival and success depend on producing newer, better, and more innovative products and services faster than ever before (Lawler, 1992; Galbraith and Lawler, 1993; Von Glinow and Mohrman, 1989).

Knowledge intensive firms denote a new species of organization where knowledge has relatively more importance than the inputs of labor and capital (Starbuck, 1992). The key input in such firms is expertise, both strategic and technical, which enables the firm to outperform rivals who possess only commonplace market knowledge. Examples of knowledge intensive firms are high technology companies such as in the computer and communication industries and the pharmaceutical and bio-technology industries.

These firms are primarily characterized by knowledge work as opposed to routine types of work. Routine work such as in traditional manufacturing can be well defined, is repetitive, and embedded in clear, shared goals. In contrast, knowledge work as in research and development is an inherently complex process requiring multi-disciplinary expertise in order to achieve a complex synthesis of highly specialized state-of-the-art technologies and knowledge domains (Purser, Pasmore and Tenkasi, 1992). More importantly , while routine work involves the production or manufacture of some product or process, knowledge work involves the **creation of knowledge** and it's application for the firm in new or improved technologies, products, services, or processes . It is therefore natural that competitive advantage in this evolving global economy of high technology, knowledge intensive firms is dependent on the quality of research and development activities that create the requisite knowledge necessary for continually spawning new products, services and capabilities. Given this importance of research and development for knowledge intensive firms it is hardly surprising that they have a ratio of R&D expenditure to sales which is twice the average for all industries (Von Glinow and Mohrman, 1989).

However, in spite of the increasing emphasis on knowledge work, knowledge workers, and knowledge intensive firms (Starbuck, 1992; Blackler, Reed and Whitaker, 1993), the dynamics of knowledge creation/development in a knowledge intensive domain such as research and development is still an elusive topic. Purser and Pasmore (1992) have noted that there is almost nothing in the management literature that relates directly to the actual processes of creation and application of knowledge in R&D. "The research and development organization functions like a black box component of an electronic system, inputs and outputs are identifiable, but the process of transformation remains mysterious and hidden from view (Purser and Pasmore, 1992; p. 2). Similar observations have been made in the philosophy of science domain (Whitley, 1972; Chubin and Restivo, 1983) . For example, Whitley (1972) has stated that, "The production of scientific facts [knowledge] is still a black box to the social studies of science".

In this paper, I draw upon contemporary writings in the sociology of knowledge and the cognitive philosophy of science domains, as well as take recourse in some early philosophical writings such as Plato's theory of knowledge, to offer a preliminary framework of the dynamics of knowledge creation in the discovery/invention process. I characterize the dynamics of knowledge production as principally a cognitively based evolutionary learning process that is embedded in, and influenced by the social context. The primary cognitive activity is one where scientists construct and reconstruct cognitive models of the problem domain to be explored, invented, or discovered. The cognitive modeling act is an attempt to understand the workings of nature; a process of constructing knowledge about the underlying laws of the natural universe.

The rest of the paper proceeds in the following manner. I briefly review the traditional context based approaches towards understanding R&D, point out their limitations in illumining the processes of knowledge production, and emphasize the centrality of cognitive processes in knowledge creation; propose a preliminary framework of knowledge development as a cognitively based evolutionary learning process; point out several cognitive pitfalls that can potentially impact the quality of knowledge development processes; explore the relationship between context and cognition and more specifically examine how the social context can influence the efficacy of cognitive processes in knowledge development; and conclude by discussing some avenues that scientific knowledge work teams can employ to enhance the effectiveness of knowledge development processes.

II. TRADITIONAL APPROACHES TO R&D- CONTEXT VS. PROCESS

Currently, our closest notions of knowledge work can be found in the literature on R&D and product innovation. However, these extant writings offer limited insights into the actual dynamics of knowledge creation in the R&D process. A brief review of the traditional approaches will clarify the point.

At one level we have studies which deal with structural aspects of innovation and knowledge development (Burns and Stalker, 1961; Galbraith, 1982). An early research effort examining the impact of structural conditions on innovation was carried out by Burns and Stalker (1961). In their study of electronic firms, they found that firms which were more successful at responding to the demand for innovation displayed a more "organic" form of organization. In contrast, the innovation laggards were encumbered by their highly bureaucratic or "mechanistic" organization structure.

Another set of studies emphasize the overall cultural conditions required for innovation (Pelz and Andrews, 1976; Kanter, 1983; Kanter, 1988). A good example of this tradition is Pelz and Andrews's (1976) pioneering research which examined the conditions under which scientists and engineers did effective work. Achievement was high under conditions that appeared inconsistent. On the one hand, effective research environments were characterized by sources of stability and confidence, and on the other sources of disruption or intellectual conflict. They concluded that if both conditions were present, the creative tension between them promoted achievement.

A third set of studies conceptualize R & D as an information processing system. Most research under this framework has an "information input" focus, that is, the way information enters an organization, and an "information exchange" focus which investigates the channels of communication through which information then flows. Representative areas of inquiry include: 1) the technical information acquisition patterns of engineers and scientists (Allen, 1977; Chakrabarti, Feinman and Fuentevilla, 1983); 2) the sources of information used in different stages of the innovation process and their relationship to R&D performance (Utterback, 1971; Rothwell, et al., 1974); 3) original stimulus to innovation and its relationship to technical and commercial success (Myers and Marquis, 1969; Goldhar et al., 1976); and 4) communication patterns and networks and information processing internal to the R&D laboratory (Allen and Cohen, 1969; Allen, Tushman and Lee, 1980).

While these different streams of research have extended a general framework in getting our hands around an elusive phenomenon such as research and development, we still do not have a direct handle on the actual processes of creation and application of knowledge in non-routine environments. The aforementioned traditions, structural, cultural, and information processing, restrict themselves to providing the social context for innovation and knowledge development, or as Chubin and Restivo (1983) suggest, they extend a 'black-box' notion of science as an institutionalized activity. Findings such as organic structures facilitate more innovation (Burns and Stalker, 1961), or innovation flourishes under climates that stimulate contradictory conditions of challenge and security (Pelz and Andrews, 1976), or access to internal and external sources of information are both critical for idea generation (Allen, 1977) all indicate context and not process- a legacy that can be traced back to early philosophers of science such as Reichenbach (1938) and Popper (1968) who argued that knowledge creation (discovery) is such an inexplicable process that inquiry into the nature of science should be confined to the context (of discovery) and not discovery itself.

The core process in knowledge systems such as product development is one of creating knowledge about products or processes. Thus, while the context can play a role in influencing scientific reasoning processes (Knorr-Cetina, 1981), cognitive processes are the 'engine of innovation'; they are the transformative core that constitute the fundamental basis of knowledge production in scientific settings. "Theories [knowledge] do not simply develop; they are developed through the cognitive activities of particular scientists" (Giere, 1992: xviii).

The essence of knowledge work is a cognitive activity; a learning, thinking, reasoning, reflexive, evolutionary process, involving the transformation of equivocal and chaotic information inputs (e.g., requests for new products, market need data, technical ideas) into a codified and valued set of concrete outputs (e.g., product designs, prototypes, or strategic decisions). The emphasis is on on-going sense making and learning. Further, one can surmise that the quality of outputs generated by knowledge work systems will be dependent on the quality of learning and thinking processes evidenced in these environments.

However, stressing the centrality of cognitive processes in knowledge development is not intended to downplay the role of context. As social animals we are contextual beings, influenced by and in turn influencing our social context (Berger and Luckman, 1967; Giddens, 1979). Our interpretation of the world is grounded in context (Gadamer, 1976).

The power of context has not gone unnoticed in research on scientific environments either. The sociology of (scientific) knowledge has been broadly defined as the theory and study of the social or existential conditioning of thought (Manneheim, 1954). For example, Knorr-Cetina (1981) in her comprehensive participant-observer study extending over a year and covering 330 scientists in a California research center, has powerfully illustrated that scientists are contextual reasoners, and scientific knowledge is essentially socially conditioned. The social context influences how they think, what they think, and what they choose to work on. In her study Knorr-Cetina (1981) found that many scientific ideas were triggered by the resources and facilities available in the laboratories as well as the dynamics of interaction between the researchers. Some ideas were the contingent result of other factors such as leadership influences.

The primacy of situational contingencies in influencing scientific practices is an all pervading theme in the philosophy of science literature. Even the purists among the cognitive philosophers of science acknowledge the role of social context in scientific processes. As succinctly stated by Giere, 1992:

> "A cognitive theory of science could not be a complete theory of science. The cognitive activities of scientists are embedded in a social fabric whose contribution to the course of scientific development may be as great as that of the cognitive interactions between scientists and the natural world. Thus cognitive models of science have to be supplemented with social models."(p. xxv-xxvi)

However, while an understanding of the context is indeed necessary, the other side of the coin is that, for a complete understanding of science or research and development, one cannot ignore the cognitive components of science - the scientific reasoning processes that are the practices of knowledge production in scientific contexts.

Knorr-Cetina (1981) also makes a similar observation:

> "To look simply at the social aspects of scientific organization and communication has been considered insufficient. Scientific practice is marked by cognitive concerns and we cannot hope to understand it without giving them due consideration." (p. 22)

In sum, these logics dictate that social models of science should be supplemented with cognitive models. Alternately the role of social context in influencing scientific reasoning processes has to be recognized.

III. KNOWLEDGE CREATION AS A COGNITIVELY BASED EVOLUTIONARY LEARNING PROCESS

"Knowledge cannot be a commodity that is found ready-made but must be the result of cognizing subjects' on-going constructions." ...It is the outcome of **" perceptual and conceptual structures which we manage to establish, use, maintain, and develop in the flow of our actual experience"**

(Von Glasersfeld, 1984; p. 4)

Science as a cognitive process is a relatively recent conception. Though exciting and potentially significant, the literature is exploratory in nature. For example, Rubinstein et al. (1984), who have incorporated elements from a number of disciplines such as Piagetian, Buddhist, and developmental psychology, social and cultural anthropology, evolutionary biology, and information processing theory, view their framework as a "first and preliminary view of science as a cognitive process" (p. xxiv). Their intention is to open this area as a legitimate area of discourse and not to offer a final account of sciencing.

We will be relying principally on the expositions of contemporary cognitive philosophers of science such as Rubinstein et al. (1984), Giere (1992) and Nersessian (1992) as well as some relevant work from Plato's theory of knowledge to illuminate the processes of 'sciencing' (White, 1938), or those specific activities of the human cognitive system that underlie the invention/discovery of the products and processes of science. Below, I will present the major ideas from the above scholars to extend a preliminary framework of the cognitive dynamics of knowledge creation in scientific environments.

The Creative Heart of Scientific Reasoning

Though the nature of specific representations (pictorial vs. linguistic vs. symbolic) are still undergoing formulation, most cognitive theorists agree that the creative heart of scientific reasoning is a cognitive modeling process of **the new problem domain** to be explained, discovered or invented (Nersessian, 1992; Darden, 1992; Rubinstein et al., 1984; Fleck, 1979; Kuhn, 1970; Wimsatt, 1981; Simon, 1966; 1973a; 1973b).

While scientific concepts may be represented propositionally (language-like) or imagistically (pictorially), in reasoning and understanding, people construct mental models of real and imaginary phenomena, events, situations, problems, processes etc. Thinking about and in terms of a theory necessitates the construction of mental models and the entities or processes they represent.

Herbert Simon's (1966; 1973a; 1973b) model of scientific discovery (invention) entails the construction of a problem-solving model of a wider problem space. To illustrate, confronted with an anomalous problem such as the behavior of liquids in nature, or a specific phenomenon to be realized such as making possible 'human flight', scientists' engage in a *mental search* for images, hypotheses and data, and finally laws to explain the data or the phenomenon to be realized (such as human flight).

For example, in the case of behavior of liquids the goal state might be an image of a law that describes the final temperature of liquids as a function of initial temperatures, quantities, and types of liquid. The initial model to realize this goal state may incorporate everything the scientists' know about the phenomena of interest such as the fact that liquids of different temperatures when mixed together have a resulting temperature between the two initial temperatures. The scientists' then undertake a process of confirming (or disconfirming) the model by activities such as making new instruments, heating liquids, conducting experiments and so on (Bradshaw, 1992). In this process they also frequently revise their images and hypotheses

This cognitive modeling process is not only unique to scientific discovery, but forms the fundamental basis of how we know, what we know (Rubinstein et al., 1984). This idea resonates well with the comprehensive literature on the 'schematic' bases of social information processing, or those memorial structures on the basis of which individuals give meaning to and navigate the social world (Bartlett, 1932; Taylor and Crocker, 1981; Neisser, 1976; Schank and Abelson, 1977; Weick, 1979).

However, there is a critical distinction between conditions of the social environment and conditions of the scientific environment. The schematic bases of social information processing hold that the social world may not carry any innate causal laws. Thus social and organizational environments are ultimately malleable, enacted realities, and often times acts of invention rather than discovery - impositions that subsequently impose (Weick, 1979; Daft and Weick, 1984). On the contrary scientific environments appear to represent certain causal laws (Woolgar, 1983; Charlesworth et al., 1989) which have to be at least approximately understood (or discovered) for scientific success. For example, it would be foolish to argue that stellar findings of science such as Boyle's law or Crick and Watson's theory of DNA do not have transcultural validity (Charlesworth et al., 1989).

Operational Environment and the Cognized Environment

To understand more completely the cognitive modeling process of the new problem domain, we have to distinguish between the 'objective world' or the world outside and the 'cognized world' or the cognitive construal of reality. Rubinstein et al. (1984) classify this as the 'operational environment' (which can be equated to Simon's problem space), and the 'cognized environment' (which would be the problem model).

The operational environment is the world that is objectively real and moldable while the cognized environment consists of all the information modeled in an individual's cognitive structures through the operation of which the individual recognizes, processes information about, and responds to the operational environment or the objective scientific reality.

The cognitive modeling act is an attempt to understand the workings of nature; a process of constructing knowledge about the underlying laws of the scientific operational environment. For example, in the case of 'human flight' it would be attempts at modeling and understanding the workings of the aerodynamic laws of flight. The construction of knowledge about the scientific operational environment is the key aspect of the cognitive modeling process in scientific inventions.

Scientific Success as 'Adaptive Isomorphism'

The construction of knowledge about the operational environment in the form of the cognized environment model is complex and open to selection. And individuals may construct models that have little or no correspondence to the operational environment. They may have different hypotheses or cause and effect relations that are not really predictive of the 'truth state' of a particular operational environment.. While some cognized models may combine veridicality and/or delusion in their adaptation to the operational environment (Laughlin and Stephens, 1980) however, "The central goal of [effective] science is to bring the cognized models of the [scientific] operational environment into the most adaptive possible alignments with the actual entities and relations within the operational environment" (Rubinstein et al., p. 37). "For any [operational] domain there is [presumably] only one operational logic [truth state], but potentially many cognized logics" (Rubinstein et al., 1984; p. 33).

In other words, for successful scientific innovations, the cognized model should progressively become 'adaptively isomorphic' with the operational environment. Isomorphism refers to the correspondence between the elements and relations constituting a particular system, and the elements and relations constituting another system of a different form. The relationship may be expressed as follows; a relationship between two systems S and S' is isomorphic when there is the same number of elements in the two systems and there is a one-to-one correspondence of the relations among these elements in the two systems.

Complete isomorphism means that the cognitive organization of one system completely maps the organization of another. But complete isomorphism rarely exists; our knowledge of the operational environment is inherently fallible (Hume, 1739; 1748; d'Aquili, 1972). Hence the cognized environment is 'adaptively isomorphic' with the operational environment when there is a degree of optimal 'fit' between the cognized environment model and the operational environment. That is over a period of time the scientist should be able to progressively complexify his or her model of the new problem domain so that it **mirrors the natural laws** governing the operational universe or the wider problem space.

Complexification

Complexification is a term borrowed from the literature on self-organizing systems (von Foerster, 1960; Ashby, 1962). Essentially, it is the ability of the [cognitive] system to, over a period of time, construct and reconstruct itself in new and complex ways (Knorr-Cetina, 1981) in order to attain a level of optimal fit with the operational environment.

Drawing from developmental cognitive psychologists such as Piaget (1977) and Flavell (1963), Rubinstein et al. (1984) posit that complexification of the cognitive model is a pre-requisite for 'adaptive isomorphism' and thus scientific success. They term this process of complexification, ontogenetic development. The notion of complexification is also reflected by Kanter (1983) who suggests that; "...to produce innovation more complexity is essential; more relationships, more sources of information, more angles on the problem.." (p. 148).

The cognitive models should go through a process of ontogenetic development, where they become adaptively intelligent (Feldman et al., 1974) as they move from one level of complexity to another. Development is distinguishable from related concepts such as growth or change, because within a range it has a fixed direction and connotes reorganization, rather than a simple addition or replacement of elements (Waddington, 1957). Development proceeds from states that are relatively undifferentiated, global and rigid to states that are relatively more differentiated, integrated, abstract and flexible (Werner, 1957). Successful cognitive models demonstrate stage characteristics (Flavell, 1963). In other words, over a period of time cognitive models form complete coherent structures which are more complex than the preceding structures and which incorporate these preceding structures within its own organization, thus becoming progressively isomorphic with the operational environment.

Plato's theory of knowledge concurs on the nature of this evolutionary complexification process and the necessity for attaining adaptive isomorphism with the truth state of the operational environment . Viewed by many as his most creative and influential philosophical contribution (Levine, 1984) the central question posed by Plato in Book VI of the ***Republic*** is; what is true knowledge? , and how can true knowledge be reached?

In response to this question Plato proposes a ladder of knowledge that has four levels. Each higher level of knowledge enables one to make the level below more intelligible and true knowledge requires that the individual is able to ascend from one level of knowledge to another.

The first level of knowledge is what he terms as *conjecture* or *imagination*. This stage is symbolized by more of a global, undifferentiated awareness, where the individual has some vague mental picture of what has to be discovered, invented or to be explained. It is a world of images and reflection that are only shadows of the world of actual objects.

The next stage is the level of *belief* or *perception*. This is the level of knowledge on which there occurs the recognition of things, of three-dimensional visible objects that makes the images, shadows and reflections more intelligible and more concrete. At this level the classification and organization of the perceived objects that make the images more concrete, begin. However, as Plato warns us the stage of *belief* is not based on abstract truths or principles that are unchanging and hence it is not *true knowledge*. It is still not the kind of knowledge on the basis of which the individual could rationally classify, predict, explain and systematize what he or she knows. It is, however, *true opinion,* since it does recognize actual objects and provide rough classifications and predictions.

The third level in the ladder of knowledge is the level of *rational understanding* or *intellect*. The change is from shifting, and changing particular objects of perception to the rational understanding or comprehension of abstract, unchanging, universal concepts of the world. This is the stage of *forms as essences,* meaning that they constitute the essential qualities of particular things. Plato is here describing the kind of knowledge that characterizes mathematics and natural sciences, forms of knowledge that are objective and immutable, and reflect the natural laws of the world.

The fourth and final stage is *reason*, the highest level of knowledge. At this stage the mind uses the method of *dialectic*. Dialectic is the crowning knowledge of all knowledge where according to Plato the true knowledge seeker has come to his or her own realm. Dialectics is the stage where the contradictions and opposites of any law or concept is recognized and fragmentary aspects are synthesized and coordinated.

Herbert Simon's model of scientific discovery also shows close parallels with Plato's ladder of knowledge. Simon (1966) suggests that when confronted with a problem to be explained or a phenomenon to be realized scientists engage in a mental search for images/models (which parallels Plato's conjecture), then hypotheses and data (which can be likened to Plato's second stage) with the desired final outcome being laws to explain the problem or the phenomenon to be realized (which would be subsumed by Plato's latter stages of understanding and reason).

Notwithstanding the naming of the specific stages of the knowledge development process, the key point is that knowledge production in scientific enterprise involve evolutionary cognitive learning processes.

Thinking in science as Deductive-Inductive alternation

The day-to-day, fundamental, knowledge creation processes through which scientists attempt to progressively **complexify** their cognized models into a state of adaptive isomorphism with the 'operational environment' are deduction and induction. Science is a process of inquiry that progressively explores the operational environment via a systematic alternation of deduction and induction for purposes of cognitive adaptation (Rubinstein et al., 1984; Merton, 1973; Eysenck and Keane, 1990). However, while the deductive-inductive differentiation is often used to organize and draw distinctions between reasoning tasks, they are not steadfast categories. Many tasks involve a mixture of both (Eysenck and Keane, 1990). Neither is the process linear or straightforward; "scientific truth as actually created is not a point-by-point elegant creation" (Star, 1993; p. 97).

Deduction is that phase of the cycle of inquiry during which cognitive models are initially formulated (or the problem conceptualized) and subsequently reformulated to give rational coherence to, and attempt to explain the phenomena of interest. Once formulated scientific models are tested for accuracy of fit with reference to the operational environment through inductive processes of information evaluation and reformulated if necessary. Thus deduction can be labeled as 'cognitive model formulation and reformulation' or problem conceptualization and reconceptualization.

The primary process by which new scientific representations are constructed or problem models formulated in the deductive phase involve reasoning based on metaphors, images, past models etc. It is widely recognized that analogy is the primary means through which we transfer knowledge from one domain to another. For example, Koestler (1964) in his famous work on the act of creation has suggested that deep analogies form the basis of solutions to unfamiliar problems. In essence the cognitive modeling process is one where relational structures from existing modes of representation are abstracted from a source domain and fitted to the constraints of the new problem domain (Nersessian, 1992). For example, Rutherford in understanding the structure of the atom is reputed to have used a pictorial representation of the solar system. It was through this analogue that he recognized that electrons revolve around the nucleus in the same way that planets revolve around the sun (Gentner, 1983).

Induction is the counterpart to deduction. It is that phase of the cycle of inquiry during which information pertaining to the operational environment is collected and evaluated as either being redundant (i.e. anticipated by and therefore a verification of an explicit or implicit model), or anomalous (i.e. novel in relation to the model of reference). It is frequently the outcome of an operative action of testing the cognitive model on the operational environment through experimentation by devising new instruments, developing new compounds etc.. It is a processual notion, the manner in which information and alternatives are interpreted, evaluated, and used by individuals (Price-Williams, 1969). Induction should be able to facilitate the incorporation of potential material from the environment enabling cognitive model confirmation or reformulation.

Thus, through a lengthy series of alternations between deduction (model formulation and reformulation) and induction (processing information from the operational environment) a body of confirmation is gathered to support or reject the model.

In summary, scientific success is dependent upon the quality of thinking and learning processes as resident in deductive and inductive action. The quality of problem or model formulation and reformulation (deduction) and the quality of information/alternatives evaluation (induction) ultimately drive the success of scientific innovations. That is, the scientist should be able to 'assimilate' sensory input from the inductive act of testing the cognitive model into the existing cognitive model, and 'accommodate' the model to the characteristics of the input, or in other words reorganize the internal structure of the cognized model so that progressively it creates a better 'fit' between the individual's cognitive structure and the 'operational environment' (Rubinstein et al., 1984).

Deductive and Inductive processes as drivers of scientific innovation - Invention of the Airplane

Let us draw upon an example to illustrate the point. Bradshaw (1992) focuses on the much discussed historical question as to why the Wright brothers were so successful at solving the 'problem of human flight' (the operational environment) while so many others failed. He locates the crucial difference as resting in the quality of deductive and inductive activities demonstrated by the Wright brothers vis-à-vis their competitors.

A primary reason was that there were two different cognitive models of flight in operation; 'airmen' models of flight and 'chauffeurs of the air' models of flight. The problem of flight was conceptualized in very opposite ways. Chauffeurs of the air tradition believed that an airplane would resemble a car, and could be "driven" into the sky. Members of this group including Maxim, the inventor of the machine gun, usually built complete airplanes. Maxim's machine had a wing span of one hundred feet, was powered by a steam engine, and had cast-iron wheels. The Airmen, however, recognized that flying was **quite different from driving a car**, and needed to be understood on its own terms. For example, the Wright brothers built several kites to explore the natural laws of flight.

Bradshaw feels that the differences in the cognitive models of flight though apt, is not sufficient to distinguish the Wright brothers from other unsuccessful inventors of the airmen tradition. One critical reason for their success was that they were open and paid detailed attention to information obtained (induction) from the operational environment. Their cognitive model of flight became increasingly sophisticated. They constantly reformulated their initial cognitive model based on the information obtained from extensive testing.

The unsuccessful inventors of the 'airmen' tradition had a propensity to construct complete aircrafts and then to test the craft by measuring distance and time in flight. To these designers the airplane consisted of a set of structures, such as wings, fuselage, propulsion plant etc. and developing an aircraft meant exploring the set of possible designs. Thus if a particular design failed the emphasis was on constructing a different design and hoping that this one would fly. They did not pay attention to diagnostic information from these test flights. And "without more diagnostic information concerning factors that contributed to various aspects of the craft's performance, investigators could only guess about better alternatives" (Bradshaw, 1992; p. 292).

On the contrary, the Wright brothers explored solutions to problems using directed experiments. They built a kite to explore lateral control, and lift and thrust were solved through the use of wind tunnel experiments. Another characteristic of the brothers' research was the extensive testing performed on each model and continually revising their understanding of aerodynamic laws; "By testing early gliders as kites, the Wright brothers were able to measure lift and drag, and discovered an important error in aerodynamics overlooked by other investigators" (Bradshaw, 1992; pp. 246-247).

In sum, it was the quality of problem conceptualization and reconceptualization (deduction) and quality of information and alternatives evaluation (induction) that distinguished the Wright brothers' from the other unsuccessful inventors. In their example we can see elements of complexification and adaptive isomorphism. Their cognitive model of flight became increasingly sophisticated. They understood and solved one problem after another such as lift, thrust, and lateral control. They were good analogical reasoners (deduction) using kites as early gliders and wind tunnels to simulate wind velocity and air turbulence. Further, they changed their models based on information obtained (induction) from extensive testing.

IV. COGNITIVE PITFALLS THAT CAN AFFECT THE QUALITY OF DEDUCTIVE AND INDUCTIVE ACTION

In the previous section I related the factors the drive scientific innovations. I suggested that the quality and complexity of deductive (problem model conceptualization) and inductive (information evaluation) processes ultimately dictate scientific innovations since they drive complexification and adaptive isomorphism. In this section I will attend to cognitive barriers that can impact the quality of deductive and inductive action.

The principle barrier arises from what I will term as the 'paradox of complexity' in scientific environments. Sciencing entails the construction of complex models of a complex world (Wimsatt, 1981); scientific work involves the representation of chaos in an orderly fashion (Star, 1983). Adaptive isomorphism demands complexification of the cognitive model. For example, Pasmore (1993) in his study of scientific processes at Polaroid cites the scientists as saying that the process of instant photography is so complex that it is akin to 'creating life for an instant'. In that one minute between the time the picture is taken and the developed photograph is delivered there are more than 60,000 simultaneous chemical reactions that take place and that have to be contended with.

Faust (1984) quotes Einstein who recognized that the scientist is faced with the problem of identifying facts "from the immense abundance of the most complex experience....The stimuli are nearly infinite; variations in possible observations and observational procedures are infinite. To achieve constancies or reliable scientific facts, one must thus eliminate entire worlds of possibilities, in the process making numerous judgments and decisions that substantially influence outcome" (Einstein cited in Faust, 1984; p. 9). In essence, complexity of science demands complexity on the part of the scientist.

However, in this requirement of complexity is the paradox. While at one level successful sciencing demands complexity at another level the imposition of complexification results in a tendency towards simplification.

The tendency towards simplification is driven by the innate human cognitive limitations in dealing with complexity. When exposed to high environmental uncertainty, complexity, and ambiguity, decision makers can repress awareness of the uncertainty, modify their perceptions of the environment so that it appears more certain, and act on a simplified model of reality which they construct (Schwenk, 1984; Janis, 1989). These simplification processes are essentially a defense to counteract the dissonance experienced when exposed to a state of psychological uncertainty (Michael, 1973). They frequently operate outside the bounds of day-to-day consciousness, and can be open to but not manifest total awareness (Count, 1974).

As Rubinstein, et al (1984) concur, when a strong influence is exerted on the cognitive system by large amounts of environmental complexity, it closes down and ceases to deal with complex and contradictory input. It restricts itself to a nonadaptive and simplified cognized environmental model. That is the cognized environmental model constructs itself in terms of simplified cause and effect relations of the operational environment and use of this model constrains the functioning of the system to those simplified elements and relations.

Under further anomalous input the cognized environment model closes down and ceases to deal with such input. It functions for as long as possible in ways that maintain its integrity. It does this in a variety of modes including actively seeking (sometimes creating) information that would support the cognitive model (Janis, 1989; Schank and Abelson, 1977), distorting information for assimilation into the system (Wallace, 1957; Turiel, 1966), rejecting the information (Hastorf and Cantril, 1954; Festinger, 1956), and holding the information within memory without assimilating it into the cognized environment (Rubinstein et al., 1984).

Actively seeking information that confirms the conceptual model in the face of anomalous input has been one of the primary tenets of schematic information processing theories (Schank and Abelson, 1977; Neisser, 1976; Weick, 1979). It is achieved by selectively bracketing an anomalous environment and choosing information that confirms. "[People] tend to make the data fit the schema, rather than vice versa" (Fiske and Taylor, 1984; p. 177), a tendency that has been called schema perseverance (Ross, 1977). Scientists can interpret the operational environment in terms that are constrained by their own level of intellectual-affective functioning and can drastically change the meaning of the information from the operational environment to suit their cognitive organization (Rubinstein et al., 1984).

Given the fact that deduction has to do with cognitive model construction and modification, while induction is information evaluation, we can distinguish between two broad classes of simplification activity. One class has to do with problem/model conceptualization and the other with information and alternatives evaluation. Janis (1989) has observed a similar distinction in that cognitive simplification processes are reliance on 'simple rules of the thumb' to deal with complex and fuzzy problems, which can manifest themselves in faulty framing of the problem, inadequate information search and evaluation of alternatives, and biased appraisal of consequences. Cognitive simplification processes have also been alternately called 'process biases', 'heuristics' and 'simple decision rules' (Kahneman, Slovic and Tversky, 1982; Nisbet and Ross, 1980; Schwenk, 1984).

Polarizing deduction and induction

As we have noted before, deduction and induction are mutually interdependent activities and strict delineations are impossible. Both are needed for complexification and adaptive isomorphism. In fact, polarizing deduction and induction, or in other words, paying undue attention to one at the expense of another, has been termed 'monophasis' (as opposed to 'diaphasis' which results in complexification) by Rubinstein et al. (1984). Enduring schema perseverance which rejects all sorts of information from the operational environment is an overemphasis on deduction. On the other hand, stressing data generation as the primary mode of scientific problem solving with minimal levels of problem conceptualization is one pattern which tilts the balance towards induction.

Data-driven inquiry without adequate problem conceptualization has been frequently observed in scientific environments. A recent study (Groemminger et al., 1993) conducted by a group of research scientists is illustrative. These scientists were employed by the Personal Products division of Bausch and Lomb, an international pharmaceutical company focusing mainly on eye-care products. The team of scientists analyzed their own work patterns to understand why they had a very high rate of laboratory rework. Rework was defined as "any task or experiment within the major activities of R&D that has to be repeated to answer the same question" (Groemminger et al., 1993; p. 35).

One of the main reasons for a high incidence of rework was traced to lack of adequate problem conceptualization including not paying enough attention to principles of experimental design and control. The tendency was to plunge into randomly designed experiments and generate data. Not having a well though out conceptual model, which is a basic requirement for designing well controlled experiments, pushed them back to the drawing board over and over again. One measure which drastically reduced the amount of rework was the scientists taking a refresher course on hypotheses formulation and principles of experimental design with a local university.

Purser (1990) in his study of R&D practices in a high technology organization found the same obsession with generating data without adequately thinking through the issues involved. This pattern contributed to repeated delays and rework. A similar bent is noticeable in the Wright brothers' example. The unsuccessful inventors did not appear to have thought through the underlying workings of the laws of flight. Their tendency was to build as many models as possible and test if they would fly.

While we have discussed some broad levels of deductive and inductive simplification, in the next two sections we will concentrate on some specific simplifications which can occur in problem conceptualization and information evaluation activities.

Deduction as Analogical Reasoning and Analogic Simplifications

As detailed before, the primary basis for the construction of scientific models is analogical reasoning. It is widely recognized that analogical reasoning is the primary means through which we transfer knowledge from one domain to another. Whether it is imagistic reasoning, metaphorical reasoning, or propositional reasoning, they are all part of similarity classifications in general.

However, *analogical recognition* should be differentiated from *'primary recognition'*. In the case of primary recognition we can no longer distinguish between the two conceptual systems. Thus instead of an association such as A is like B, it is an assertion that A is B. Analogical classification is not primary recognition. Rather it implies a degree of distance or independence between the two conceptual systems brought together by the similarity classification (Knorr-Cetina, 1981).

In a sense, when we determine that a given situation fits a particular interpretation we are concluding that the current situation is analogous to those from which the interpretations were originally derived. In other words, the original situation serves as a kind of paradigm against which the new situation is matched. However, this distinction can be overlooked and analogical recognition can become a case of primary recognition; "Even more important is the fact that we are apt to make inferences about unobserved aspects of the new situation from the paradigm case" (p. 51). The classification involved can be used in a *literal* way, and a metaphor or analogue can become a literal interpretation over a period of time.

One could infer from Knorr-Cetina's statement that considerable care has to be exercised with analogical transfers. Confusing analogical recognition, which presumes a certain level of independence among concepts, with primary recognition (where one becomes the other) can not only be problematic in terms of making inferences about unobserved aspects of the target domain (new situation) from the base domain, but it can also lead to a framing of the situation in a way that future information is sought to confirm this initial framing of the problem situation.

Nersessian's (1992) extends a similar view; "..in investigations of analogies used as mental models of a domain, it has been demonstrated that inferences made in problem solving depend significantly upon the specific analogy in terms of which the domain has been represented" (p. 20). For example, Gentner and Gentner (1983) did a study where subjects constructed a mental model of electricity in terms of either an analogy with flowing water or with swarming objects. Specific inferences, sometimes erroneous could be traced directly to the analogy. These findings give support to the view that analogies are not 'merely' guides to thinking with logical inferencing solving the problem. But, ***"analogies themselves do the inferential work and generate the problem solution"*** (Nersessian, 1992; p. 20).

Inappropriate analogical transfer in problem conceptualization- A case example

A particularly germane example of inappropriate analogical transfer in R&D is evident in a pharmaceutical new product development project that is documented in Tenkasi (1994). The project was an attempt to develop a drug to treat an affliction which occurs in the human colon. The idea was to come up with a target release drug, or in other words, a drug which will not start to act until it reached the human colon. The drug, if developed successfully, could potentially command a very large market.

Early in the project it was decided to use a ***rat model*** to understand the workings of the human colon. The project was pushed through pre-clinicals (animal trials) and was considered fairly successful. However, once the project reached clinical (human) trials it failed. The main reason was that the drug could not get through the wall of the human colon. The formulation dissipated beforehand. The original hypothesis and the subsequent choice of the rat model did not take into consideration the thickness of the wall of the human colon. Hindsight implied that it would have been more appropriate to use a primate model (such as a monkey or chimpanzee) which more closely resembled the human system.

We can deduce that the major reason for failure of the project was the use of an inappropriate analogy in cognitive model formulation, where a simpler non-human analogue was employed to understand the workings of a complex human system. Further, based on the analogy several inferences were made, potentially leading to a situation where the rat metaphor became a literal interpretation over a period of time. This can be categorized as an instance of overlooking the fact that analogical reasoning implies a degree of distance or independence between the two conceptual systems brought together by the similarity classification (Knorr-Cetina, 1981).

Interestingly, the basic hypothesis and the choice of the model was never questioned seriously once it was proposed, even though there was a certain amount of uncertainty about the basic approach. There was not a lot of discussion or efforts at revisiting the basic hypothesis, and the reservations which several members who subsequently joined the team had about the issues at hand were not given adequate hearing. The emphasis was on *advancing* the project. It appeared that subsequent information that only confirmed the initial framing of the problem situation was listened to.

Other Types of Simplifications in Problem Conceptualization

In the above section we engaged in a detailed discussion on simplification in analogical reasoning since it is a primary process in deductive action. Comprehensive lists of other types of simplifications of problem conceptualization and information and alternatives evaluation have been documented (Hogarth, 1987; Kahneman et al., 1982; Nisbet and Ross, 1980; Schwenk, 1984)

Some more simplifications which can affect problem conceptualization are:

Prior (single) hypothesis bias is a simplification process which can affect problem conceptualization. Laboratory studies (Levine, 1971; Pruitt, 1961; Wasson, 1960) suggest that individuals who formed erroneous beliefs or hypotheses about the relationship between variables, consistently used them as guides for decision making despite abundant evidence over numerous trials that the hypothesis or belief is wrong.

Miller (1993) provides some interesting field examples of prior hypotheses bias in action. He cites the examples of companies such as Control Data, Wang Labs, and Polaroid which had initially achieved major success by out-innovating their competitors and consequently turned this policy into an obsession. They began to concentrate solely on technological innovation, not paying any attention to the costs or needs of the customers. Marketing, production and financial activities were neglected while R&D was the only function being paid attention to. "Subsidiary goals of service and market penetration were driven out by an increasing obsession with scientific progress" (Miller, 1993; p. 117). Consequently they suffered in the market.

Problem set: Similar to the notion of single (prior) hypothesis bias, problem set is demonstrated when there is a repeated use of one or few problem solving strategies. Examinations of this simplification have been dealt with in laboratory studies by Anderson and Johnson (1966) and Newell and Simon (1972).

Single outcome calculation: This is a tendency originally noticed by Cyert and March (1963) and later elaborated by Steinbruner (1974). Under this condition, individuals, rather than attempting to specify all relevant variables in constructing the problem domain such as different values and goals, and suggesting a number of alternative courses of action, tend to **oversimplify** the problem. They tend to focus on a single or few of the variables, values, or goals and a single alternative course of action for achieving it.

Related to the strategy of choosing a single alternative course of action and lack of alternative contingency plans is a phenomenon labeled as the Illusion of control (Lefcourt, 1973; Langer, 1975; Langer and Roth, 1975; Larwood and Whittaker, 1977). Subject to this constraint decision makers may overestimate the extent to which the outcomes of a strategy are under their (or somebody else's) personal control. Further, they may assume that through additional efforts they can make their strategy succeed should problems arise. .

Tversky and Kahneman (1974) have pointed to a cognitive process called representativeness bias which causes a decision-maker to overestimate the extent to which a situation or sample is representative of the situation or population to which the decision maker wishes to generalize. This process has been attributed at least partial responsibility for decision-makers viewing strategic decisions in terms of simple analogies. It also results in overestimating the extent to which the past is representative of the present and the extent to which framing of problems in the past will be *predictive* of outcomes in the present problem. Thus, representativeness bias involves insensitivity to predictability. In making predictions of the various courses of action, decision-makers do not take into account the extent to which the evidence for predictions is reliable, or the extent to which the criterion is related to the cues which they use to predict it (Tversky and Kahneman, 1974).

Another dynamic which influences the representativeness bias is insensitivity to sample size considerations. Though information from a number of trials or a large number of past strategies would be necessary to make verifications of, or generalizations about a successful strategy, decision makers are often unable (or unwilling) to collect data on a number of trials or a number of past strategies. They often overgeneralize patterns, models, and findings from a small database. They tend to develop confidence in their predictions from small amounts of data, feeling that these data are representative of the population as a whole. Tversky and Kahneman (1974) call this as a belief in 'law of small numbers'. Nisbet and Ross (1980) feel that decision makers are especially susceptible to the law of small numbers when considering one or few vividly described cases.

Induction as Information Evaluation and Evaluation Simplifications

In this section we have tried to group together the simplifications around information and alternatives evaluation, or in brief *inductive action*. However, a lot of the simplifications pertaining to problem conceptualization also have to do with processes of information and alternatives evaluation. Deduction and induction are interdependent, iterative, and cyclical, and clean distinctions are not possible.

Adjustment and anchoring is a simplification proposed by Tversky and Kahneman (1974) that has to do with information evaluation. Individuals often construct initial models and understandings about a phenomenon and are expected to revise these judgments as new data comes in. However, when this simplification is in operation, the adjustments are insufficient and individuals are biased towards their initial understandings. That is, decision makers, while they may attend to negative information about the robustness of their initial models they may not make full use of it or may actually disregard this negative information. Further, they may seek and use only that information which is consistent with their initial understandings and for that purpose rely on certain particular sources. In sum, it is a tendency of leaning towards favored information and favored information sources. Kozielecki (1981) in a series of laboratory experiments showed that decision makers overestimated the value of information which confirmed their hypotheses and undervalued disconfirming information.

Bolstering or magnifying the attractiveness of preferred alternatives (Festinger, 1956; Steinbruner, 1974) is a tendency that goes with adjustment and anchoring. In a series of laboratory experiments, Festinger (1956) demonstrated that one way of promoting a preferred alternative or information is to bolster or develop arguments to magnify its attractiveness. This is done in order to increase the 'spread' of desirability between the preferred alternatives and the non-preferred alternatives.

Another simplification which can come in to play in dealing with non-preferred alternatives are inferences of impossibility . This is a tactic where decision makers may devote a great deal of effort to identifying the *negative aspects of* non-preferred alternatives and further attempt to convince themselves that they are not possible to implement (Steinbruner, 1974).

Denying value trade-offs is in operation when decision makers attempt to interpret facts in such a way that the favored alternative appears to serve several values/ends simultaneously with no costs associated with the option (Steinbruner, 1974; Jervis, 1976). They typically deny that there are cost-benefit trade-offs and that there may be some values/ends not served by the favored alternative.

Devaluation of partially described alternatives: Yates, Jagacinski and Faber (1978) demonstrated that under conditions of uncertainty, decision makers showed a preference for complete information, that is, they valued alternatives that were more completely described than others. In a group of strategic alternatives, it is likely that the probable consequences of some of the alternatives will be more completely described/available than others. Yates et al. found that individuals tended to devalue the alternative that was partially described. An explanation provided for this phenomenon was that since partially described alternatives involve further uncertainty for decision makers, they tend to negatively evaluate such alternatives. Alternatives which are better described appear to resolve more uncertainties and therefore have more value.

Selectively evaluating information and alternatives- A case example

A relevant example of selectively evaluating information and alternatives in Research and Development is illustrated in Tenkasi (1994). As in the previous example this was also a drug development project. The objective of the project was to develop a pain killer. The initial intent was to go for a regional application either in an injectable or topical (for example ointment) form. This decision was partly influenced by the fact that the drug compound showed some toxic side effects. Toxicity was established as a concern very early on in the project.

There was a change in leadership and a new project leader took over. The new leader arbitrarily decided to change the focus of the drug from a regional form (injectable or topical) to an oral form. This change in focus seemed to be driven purely by economic motives. Oral delivery drugs commanded a larger market and were economically attractive. Management also approved this change;

Several members of the project team were angry at this shift in focus; they felt it was a 'lay on' since they did not have any input into the decision. And, the issue of toxicity was still looming large, taking more acute proportions now, because the delivery form was oral.

However, the project leader did not pay much heed to these objections and proceeded to push ahead for the oral delivery form. It appeared that it was a clear case of denying the cost-benefit trade-offs *of this* preferred alternative, by the project leader. The driving focus was the market potential (benefits) of an oral drug without consideration of the (costs of) toxicity issues.

In fact, the project leader coined the objections as an 'academic debate' and hired an outside consultant to convince the R&D director to go oral, and not waste time with regional applications. This could be viewed as a strategy to bolster the attractiveness of the preferred alternative and downplaying the attractiveness of the non-preferred alternative. Some comments regarding this action were;

> "project leader filtered information to suit [his] vested interest-consultant data got filtered";
>
> "[The] project leader filtered information to provide biased positive message to management."

Another similar strategy employed for amplifying the negative aspects of the non-preferred alternatives was the project leader's insistence that the current evidence on toxicity was uncertain. According to him there was a need to push the drug to clinical **human** trials to determine the real impact of toxicity.

And, when the issue of toxicity was raised in terms of whether it was possible to separate drug efficacy from toxicity, the project leader had great difficulty in hearing data that did not support his primary hypothesis;

He viewed himself as the product champion and was willing to listen to only selective information that confirmed his framing of the issues or otherwise what is known as an adjustment and anchoring bias.

Meanwhile, the team and especially one key scientist was convinced that the toxicity issue had to be resolved before the drug could be moved to clinicals and was working hard to understand the issues involved. His fear was that if the drug goes to clinicals, it may be rejected by FDA (Federal Drug Administration) due to the toxicity issues, and that this may jeopardize the whole class of compounds (potential drug candidates) which had been developed from similar base chemicals.

However, the project leader exerted a lot of pressure to move the drug candidate for clinical tests. Management also concurred with the project leader and were questioning as to why such detailed investigations were necessary.

The drug was submitted for permission for conducting clinical tests and as predicted by some of the scientists, the result was an FDA hold which was FDAs way of flagging toxicity problems.

Subsequently, the drug candidate was moved back to preclinicals and a backup team was formed to investigate the toxicity issues. The project leader still insisted on an oral delivery drug. Meanwhile, there was more evidence that the toxicity could not be separated from the drug's curative effect. New consultants brought in by the team also pointed out that the oral delivery form was infeasible.

A new section leader who came into the project finally convinced management (and the project leader) that a local/regional application (injectable or topical) was probably the best approach. Further, it was decided that before inquiry in humans, systematic study of the toxic effects should be undertaken with primate models. In other words, it took many years of development time, delays, and heavy investments to learn as one scientist framed it;

> "to listen to the data, don't {sic} try to force fit a compound into the endpoint you want".

In sum, based on the previous examples we can surmise that cognitive simplification processes in deductive and inductive action can significantly hamper the creation of successful scientific knowledge as well as contribute to delays in the product development process. This augurs well with our earlier theoretical conceptions of the requirement of complexification and adaptive isomorphism for scientific success and cognitive simplification activity as a principal barrier that can hinder the process.

V. RELATIONSHIP BETWEEN CONTEXT AND COGNITION - THE IMPACT OF SOCIAL CONTEXT ON THE EFFICACY OF COGNITIVE PROCESSES IN KNOWLEDGE DEVELOPMENT

Earlier, we had discussed the importance of social context in scientific innovations. The review of various pieces of management oriented literature on organizational innovation, principally the structural, cultural, and information processing approaches, suggested that the focus was rather exclusively on context. This lopsided emphasis on pure context indicated the need for the development of a cognitively based understanding of scientific innovations. And of equal importance was the necessity to develop deeper understandings of the relationship of context to cognitive activities. A review of the writings in the philosophy of science domain, particularly the cognitive philosophy of science reinforced these views.

Cognitive philosophers such as Giere (1992), emphasized that cognitive activities of scientists are embedded in a social fabric. An examination of the social context and its relationship to the cognitive activities of the scientists' is very critical to understand scientific development - "cognitive models of science have to be supplemented with social models" (Giere, 1992: p. xxvi).

In essence, this line of thought implies that the social context can play a role in influencing scientific reasoning processes, and varied features of the context can contribute towards the required complexity, or result in simplifications of the scientific reasoning processes of deduction and induction. In other words, we can view the contextual features as *antecedentory variables* influencing the quality of cognitive processes in scientific environments. An understanding of this relationship can also be advantageous from an interventional perspective in being able to make more *informed design choices* about the scientific contextual environment.

Complexity of conceptual system is related to quality of deductive and inductive action

The exposition of Rubinstein et al., (1984) is particularly illuminating in arriving at a preliminary understanding of the relationship between context and cognitive activities. Their principle argument is that the definition of and responses to the 'objective' reality are determined by the structure of the 'apperceiving' cognitive system. It follows that more complex cognitive systems can model (deduction) the operational environment in more complex terms than simple structures do, and they may adapt to the environment in more complex and flexible ways, which is a requirement for scientific success.

Likewise, conceptual structures of differing complexity have different modes of information interpretation (induction). Lower level structures tend to be concrete, use simplified categorical thinking, and try to avoid ambiguity and conflict, by quickly closing themselves to the uncertainty of the informational environment. Simple, cognized logics and models can define a particular inquiry as 'invalid' and 'inappropriate', thereby impeding inquiry into a particular domain (Welsch, 1983; Hufford, 1982). Higher level structures, on the contrary, are flexible and can generate multiple perspectives on, and solutions to problems. Complex cognized models inhibit premature closure of theory and thereby facilitate accommodation of previously anomalous data that otherwise might have been ignored or rejected within the theory (Rubinstein et al., 1984).

Schroeder (1971: 257) similarly proposes that conceptual systems at lower levels of structuring show a:

> "tendency to standardize [simplify] judgments in a novel situation; a greater inability to interrelate perspectives; a poorer delineation between means and ends; the availabilities of fewer pathways for achieving ends; a poorer capacity to act 'as if' and to understand the others' perspectives; and less potential to perceive the self as a causal agent in interaction with the environment".

We can then surmise that *conceptual systems with higher levels of structuring of complexity will tend to show a higher level of cognitive complexificaton processes or* *alternately a lower level of cognitive simplification processes* in their various work activities.

Capacity for complexity is resident in the differentiative and integrative capacity of conceptual system

The notion of a 'cognitive system' and the state of its [perceptual] complexity (or simplicity) is a characteristic that can be attributed to systems at different levels of social organization; individuals, groups, and whole social institutions. As Rubinstein et al. clarify; "Differences in structure [of complexity]..have consequences not only for the behavior of individuals but also for any combination of individuals including social institutions" (p. 39).

This capacity for complexity which enables 'optimal complexity in scientific model building' is termed *cognitive organizational complexity* (Rubinstein et al., 1984). Cognitive organizational complexity is constituted by two variables; dimensions and rules. Dimensions refer to the number of units or parts of information considered by a system (individual) when addressing information. Thus, it denotes the way in which a set of stimuli can be ordered. Dimensions then are essentially the ordering principles or categories used by a system to interpret informational input. Each conceptual system is in part made up of dimensions representing independent attributes along which stimuli can be ordered. Yet the number of dimensions in itself will not suffice for attaining an optimal level of cognitive organizational complexity. It also need rules for connecting (or integrating) these differentiated and diverse categories or dimensions. Rules can be of two types posit Rubinstein et al. Mixed rules, which are relatively permanent guides for information interpretation, and emergent rules, that are highly flexible guides capable of generating many and new perspectives. In summary, cognitive organizational complexity is reflected in a system's *differentiative and integrative capacity*.

Bowers and Hilgard (1981), in a similar vein, suggest that the ability of individuals to make sense of and in turn acquire new knowledge is dependent upon the **breadth** of categories of existing knowledge, the **differentiation** of those categories, and the **linkages** across them; a theme also reflected in the work of psychologists such as Ellis (1965) and Lindsay and Norman (1977). Drawing from these and similar works, Cohen and Levinthal (1990) extend the notion of such individual 'cognitive organization complexity' to organizations. They argue that most critical to a firm's innovative capabilities is its ability to recognize the value of new external information, assimilate it, and apply it to commercial ends. They label this capability a firm's *Absorptive capacity* which is a function of the firm's existing (prior) related knowledge including the diversity of knowledge domains. However, absorptive capacity refers not only to the acquisition of information by an organization, but also to the organizations' ability to exploit it, which depends on transfers of knowledge across and within subunits, which is the process of integration. Cohen and Levinthal (1990), in their study have shown that organizations' with higher levels of absorptive capacity are also able to generate more innovations, thus making it essential for firms to "dedicate effort exclusively to creating absorptive capacity (i.e., absorptive capacity is not a by-product)" (p. 150).

The sources of 'cognitive organizational complexity' are social, argue Rubinstein et al. The structure [level] of complexity of any cognitive system is influenced by and is *manifest* in the attributes of the social environment. In a similar vein, writers such as Bowers and Hilgard (1981) and Cohen and Levinthal (1990) posit that the notion of absorptive capacity is abstract and has 'virtual' existence. It is essentially located and observable in the contextual features of the organization. It is a function of processes and practices such as prior related knowledge, diversity of background of members, and transfers of knowledge across sub-units that go into determining differentiation and integration abilities (absorptive capacity) of a conceptual system. Therefore, if cognitive organizational complexity or absorptive capacity is manifest in features of the context, one can view the contextual features as *antecedentory conditions or variables* influencing the quality of cognitive processes in scientific environments.

This explanation also provides further insights on the nature of the relationship between context and cognition. We can argue then that this relationship can be viewed in terms of whether the context facilitates a conceptual system in attaining the 'optimal level of complexity' required for scientific success. Thus, features of the social context can influence cognitive complexification or alternately cognitive simplification processes.

However, we realize that the notion of context and the potential range of its distinguishing features is expansive. It could take the form of the structural context, and features such as mechanistic and organic structures (Burns and Stalker, 1961) or the cultural context with distinguishing attributes of segmentalist or integrative cultures (Kanter, 1983). Moreover, several of these contextual dimensions can influence the level of cognitive organizational complexity of a conceptual system. For example, Kanter (1983) suggests that complexity is essential for innovation; "...to produce innovation, more complexity is essential; more relationships, more sources of information, more angles on the problem.." (p. 148). She goes on to add that integrative cultures and structures facilitate complexity by encouraging the treatment of problems as 'wholes' and help consider the wider implications of actions; "To see problems integratively is to see them as wholes, related to larger wholes,.." (p. 27) On the contrary, segmentalist cultures do not contribute to the required complexity. They hamper complexity by compartmentalizing actions, events, and problems and by keeping each piece isolated from the other. Such cultures direct people to see problems as narrowly as possible, independently of their context, and independently of their connections to other problems.

While many of these contextual dimensions and their relationship to the quality of cognitive activities in scientific enterprise are worth further investigation, as a starting point we can identify from the organizational literature some specific contextual variables which have been implicated as potentially impacting the quality of cognitive activities in various task domains. We can surmise some of these contextual variables as contributing to the differentiative capacity of the scientific conceptual system while others contribute to integrative processes. The proposed relationships have been summarized in the form of propositions.

From a differentiation perspective the following contextual variables can be identified;

Group Deliberative Norms

Janis (1989) in his study of policy making in uncertain task domains suggests that one observable condition that can result in the policy making process becoming dominated by defective cognitive procedures are organizational norms, traditions or doctrines. Norms that limit groups from undertaking comprehensive information search and short-circuit the essential steps of problem solving result in avoidable errors.

However, norms that allow members to be dubious about and question each others' key presumptions, "particularly those affecting the way the problem is formulated, the types of alternatives that are excluded at the onset, and the way cogent information about positive and negative consequences is interpreted" (p. 105), can go a long way in reducing the possibility of a group resorting to simplistic decision rules.

Similarly, Walsh et al. (1988) argue that norms that allow assumption surfacing (Mason and Mitroff, 1981), where each member's beliefs would likely surface in the group's deliberations, can be beneficial for groups. An awareness of different assumptions and beliefs held by all the members of a decision making group can contribute to more effective decision making. As each individual shares his or her perspective, the group as a whole would have come to terms with these differing beliefs thus allowing a more comprehensive treatment of the issues at hand.

Thus we can deduce that the higher the level of norms that allow for surfacing and discussion of conflicting interpretations, higher will be the quality of deductive and inductive action in scientific environments.

Requisite Expertise and Diversity in 'Mind Sets'

Ashby's (1956) law of requisite variety suggests that the internal diversity of a self-regulating system should match the diversity of the environment if it is to survive. This line of reasoning provides us with two key insights regarding the requirements of conceptual systems to achieve an optimal level of complexity, namely requisite expertise of knowledge domains and requisite diversity in mind-sets.

Requisite expertise of knowledge domains is best achieved by making sure that the required amount of knowledge is distributed among the members of a conceptual system, or all the right parties are represented in a group.

Given that most Research and Development situations involve learning in novel domains, Cohen and Levinthal posit that requisite knowledge plays a critical role in such learning. In a setting in which there is uncertainty about the knowledge domains from which potentially useful information may emerge, they suggest that required expertise provides a more robust basis for learning because it increases the prospect that the incoming information will relate to what is already known. In addition to strengthening assimilative powers, requisite expertise "facilitates the innovative process by enabling the individual to make novel associations and linkages" (p. 131).

Likewise, Purser (1990), and Pasmore and Gurley (1991), have noted that a major knowledge related variance in new product development settings is lack of requisite expertise, as manifest in missing parties or wrong parties in deliberations, and lack of consultation with relevant parties internal to the firm and external to the firm.

Also of particular relevance is a recent study by Ancona and Caldwell (1992) where they examined whether variations in functional diversity of membership in the composition of new product development teams had an impact on team performance. The implied rationale was that functional diversity would increase the requisite mix of knowledge domains represented in new product development teams and thus contribute to improved performance.

Requisite Diversity in Mind-Sets

While requisite expertise indicates adequate representation of different knowledge domains, Janis (1989) underscores the need for adequate variety in the cognitive styles of members of a group. His observations are especially relevant since he advances a direct linkage between diversity in 'mind sets' in member make up of a group, and the possibility of reduced use of simple cognitive rules in policy making.

His comments in this regard are worth reproducing:

> ".....The following hypothesis seems plausible: **Errors arising from misleading assumptions have the best chance of being corrected when there is moderate degree of heterogeneity in basic attitudes and beliefs among the members of a policy making group** (emphasis added) - .... [By] heterogeneity I mean that the divergences in "mind-set" among them are such that the members tend to be dubious about each others' key presumptions, particularly those affecting the way the problem is formulated, the types of alternatives that are excluded at the onset, and the way cogent information about positive and negative consequences is interpreted." (p. 99)

Walsh, Henderson, and Deighton (1988) offer similar observations on the benefits of requisite diversity in cognitive domains among a group of managers. When facing very complex informational environments, a group requires sufficient variety in their cognitive schemas to cover the potential range of the informational domain. Thus, when a group approaches a decision, each member may hold a schema of the information domain of the decision issue. Each individual's schema for the information domain will vary in the number of categories or dimensions represented in it. That is, each aspect of the information domain may not appear in the schema of someone in the group. However, with sufficient variety in members' schemas one can have potential coverage of the informational domain.

In summary, based on the above literature we can infer that variations in the levels of requisite expertise and requisite diversity in mind-sets *will show a relationship to the quality of deductive and inductive action in scientific work*.

Knowledge Interfaces

Cohen and Levinthal (1990) argue that to develop an effective absorptive capacity, organizations should develop interfaces with both the external environment as well as across and within sub-units. "Therefore, an organization's absorptive capacity does not simply depend on the organization's direct interface with the external environment. It also depends on transfers of knowledge across and within subunits...Thus to understand the sources of a firm's absorptive capacity, we [have to] focus on the structure of communication between the external environment and the organization, as well as among the subunits of the organization" (p. 131-132). This necessity for knowledge interfaces external and internal to the organization has also been the primary focus of the information processing school (Allen, 1977; Tushman, 1977). However, Cohen and Levinthal make the interfaces more specific in terms of relating these information processing patterns to requisite complexity for innovation in the form of optimal absorptive capacity since they add to the breadth and depth of available knowledge.

Janis (1989) similarly suggests that lack of communications, and not investing enough resources for gathering essential information, such as an absence of intensive deliberations with qualified experts within and external to the organization, can make cognitive constraints salient. Absence of knowledge and information interfaces can hamper carrying out a detailed analysis of the problem.

Thus, we can posit that the higher the level of external and internal knowledge linkages in a scientific work system, higher will be the quality of deductive and inductive action.

From an integration perspective the following variables can be identified**;**

Shared Language

Knowledge interfaces are important suggest Cohen and Levinthal. However, they argue that for the knowledge to be assimilated and internal communication to be efficient, the interacting actors should have some minimal sense of a shared language (Dearborn and Simon, 1958; Zenger and Lawrence, 1989). "If all actors in the organization share the same specialized language, they will be effective communicating with one another" (Cohen and Levinthal, 1990; p. 133).

Thus we can surmise that the more the sense of shared language in a scientific work system, higher will be the quality of deductive and inductive action.

Accumulating Prior Related Knowledge

Cohen and Levinthal (1990) emphasize the importance of accumulating prior related knowledge. As they clarify; "[One] premise of the notion of absorptive capacity is that the organization needs prior related knowledge to assimilate and use new knowledge. Studies in the area of cognitive and behavioral sciences at the individual level both justify and enrich this observation. Research on memory development suggests that accumulated prior knowledge increases both the ability to put new knowledge into memory, what we would refer to as the acquisition of knowledge, and the ability to recall and use it" (p. 129). One explanation extended by Cohen and Levinthal as to why prior related knowledge is necessary (to assimilate and use new knowledge), lies in viewing knowledge accumulation essentially as a set of learning skills. There can be a transfer of learning skills across bodies of knowledge that are organized and expressed in similar ways. Consequently, experience or performance on one learning task may influence and improve performance on subsequent learning tasks. Drawing on Ellis's (1965) findings, Cohen and Levinthal suggest that the development of learning sets provide a possible explanation for the behavioral phenomenon of 'insight' that typically refers to the rapid solution of a problem in successive trials.

Bowers and Hilgard (1981) in their experiments found support for this notion of learning skills. They discovered that memory development was self-reinforcing in the sense that more the objects, patterns and concepts stored in memory, the more readily was new information about these constructs acquired, and more facile was the individual in using them in new settings. The prior possession of relevant knowledge and skill is what gives rise to creativity, permitting the sorts of associations and linkages that may have never been considered before (Bradshaw, Langley and Simon, 1983). In summary, "the psychology literature suggests that creative capacity and what we call absorptive capacity are quite similar" (Cohen and Levinthal, 1990 ; p. 131).

Thus, we can surmise that *the higher the accumulation level of prior related knowledge, higher will be the quality of deductive and inductive action in scientific enterprises*.

Leadership Practices

Streufert and Swezey (1986) discuss leadership practices as one source of organizational complexity. Integrative processes can be aided by certain types of leadership practices. To manage people in complex environments requires certain essential integrative skills of the leadership function.

Leadership must possess a sufficient integrative overview of the organization. This calls for familiarity with the needs, views, concepts and vocabulary of the various organizational personnel, and an understanding of the work domain and perspectives of the various specialist personnel involved. Such an understanding permits leadership to optimize the capabilities of these persons and to optimize the interactive processes among them.

A second critical trait in complex environments is that the leadership function must be able to assemble obtained information from members into tentative conceptualizations. This in part, would include playing the role of a sounding board for ideas and providing interesting conceptualizations or fresh approaches to the information obtained, in an attempt to assemble the various components that underlie organizational decision making into a meaningful system.

In dealings with the various project members, the leadership function will encounter many conflicting interpretations, needs, demands and requirements. Just make an arbitrary choice will not be enough. Dealing with such complex activities requires high levels of flexible integration. The leadership function must be able to recognize and mediate the conflicts between groups and individuals to arrive at a sufficiently integrative conceptualization.

In essence, an integrative style is required of leadership whether it is a single leader or a group of individuals with varying expertise in the different arenas, to manage projects successfully in complex environments. And such integrative style requires the leadership function to have a good conceptual understanding of the individual members' work domain. Also, the ability to act as a sounding board for member ideas, providing fresh approaches to problems, and recognizing and mediating conflicts form an integral part of this integrative approach.

In summary, *we can infer that the more adept the scientific project leadership is at employing an integrative leadership style, higher will the quality of deductive and inductive action in a scientific work system.*

VI. CONCLUSIONS AND IMPLICATIONS

While there appears to be no specific empirical evidence linking cognitive simplification processes in scientific deductive and inductive action to poor quality scientific outcomes, there is evidence from domains such as policy making suggesting that there is a strong relationship between quality of cognitive strategies and favorableness of outcomes (Janis, 1989). Also qualitative evidence from the case studies presented suggests a similar relationship. Assuming that cognitive simplification processes can adversely impact product development time as well as scientific outcomes, it becomes necessary to explore the ways by which such simplification activity can be attended to.

From an interventional perspective, there are two distinct classes of action that can be undertaken to achieve this goal. The first set of actions entails intervening into the 'content' and 'processes' of cognition. The second set of actions has to do with making more informed design choices about the contextual features of scientific environments. However, since the relationship between context and cognition is still at the level of tentative conceptualizations we will restrict our discussions to the first set of actions.

Intervening in the 'Content' and 'Processes' of Cognition

We have observed previously that cognitive simplification processes can frequently operate outside the bounds of day-to-day consciousness (Rubinstein et al., 1984), can be based on repression of complexity and uncertainty (Schwenk, 1984), and can be open to but do not manifest total awareness (Count, 1974). As Rubinstein et al. comment, "If practicing scientists were more conscious of the processes of science, it would go a long way toward circumventing the epistemological inhibitions imposed by paradigms" (p. 138).

Likewise, Collins's (1983) notes the hidden nature of such processes. His view is that many times it is only when the rules go wrong that the scientist questions the nature of his or her interpretation. "Otherwise, our giving of meaning to objects- our interpretative practices are so automatic that we do not notice that any interpretation is involved" (Collins, 1983; p. 90).

A major requirement for overcoming simplification processes is consciously raising or bringing into awareness scientific deductive-inductive action. In Schutz's (1964) terms, it is the ability to periodically suspend our 'natural attitude'. Interpretations normally given in a matter-of-course, taken-for-granted 'natural' way should be suspended so that we will be able to notice and understand the ways in which our scientific worlds are constructed and interpreted and can change them appropriately (Collins, 1983).

Rubinstein et al. (1984) posit that understanding (becoming aware of), evaluating, testing, and modifying of cognitive models is required for maintaining adaptive isomorphism, and thus scientific success. In their words:

> " [scientists] are capable of transcending constraints imposed on their own cognized environments by normatively accepted cognized logics, and hence entering into a direct and complex interaction with the operational environment...The result of such an activity ought to be a more effective and complex modeling of the operational environment, and thus the development of more fully isomorphic models of the environment. **Certainly one way of facilitating this inquiry is by examining the cognized logic that recognizes the limits it places on inquiry**." (p. 35)

There appears to be two distinct ways of raising awareness of, and testing, evaluating, and modifying understandings. For this we have to differentiate between the *content* of cognition and *process* of cognition.

In a basic sense, the content of cognition is a person's ideas about the world, and cognitive processes are the mechanisms by which such ideas arise, are maintained and transformed (Scott, Osgood and Peterson, 1979). While many psychologists subsume both content and process under a single category called cognition (since the distinctions are amorphous and content and process merge into each other), it might still be useful to use separate terms to refer to them (Scott et al., 1979). Both these interdependent aspects of cognition require careful consideration for understanding this abstract field of study of human thought.

Scott et al. (1979) argue that since the content of cognition is based on the individual's own experience, a person, in theory, can give fairly accurate reports of his or her cognition. An investigator with the right tools and questions can attempt to gain access to the content of a person's cognitive construal of the world, and bring it to the person's awareness.

Cognitive processes on the other hand are not typically available to immediate awareness (Nisbett and Wilson, 1977). For example, if an investigator asked an individual; "Is your friend Charles intelligent?", it is reasonable to assert that the answer reflects the content of cognition. However, a question concerning cognitive process such as, "By what processes of reasoning did you conclude that Charles is intelligent?", might be rather difficult to answer. The individual might not know how he or she came to that opinion.

Scott et al. maintain that the task of studying cognitive content is different from that of studying cognitive processes. To describe the contents of cognition is to describe a representation of reality, and thus to describe facts from an individual's point of view. Cognitive processes on the other hand, involve not beliefs and representations, but mechanisms, procedures, and processes.

In summary, content is a description of "How do I see the world?", and processes are the mechanisms through which the content is made possible, or rather, "how did I come about to see the world as I do?". A study of, and intervention into both these complementary aspects of 'thought' are required to obviate simplification and facilitate complexification.

Intervening into the Processes of Cognition

Inquiry into the *processes* of cognition, or the reasoning patterns and procedures which people engage in to construct their understandings of a situation, is best facilitated by asking questions (Janis, 1989) on the types and adequacy of the processes individuals employ to come to know what they know (or the content of cognition). In essence, this would implicate processes such as analogical reasoning, reliance on various information sources, and rules used in evaluating alternatives, and the adequacy of such processes.

Examining the processes of cognitions is the primary focus behind Janis's (1989) vigilant problem solving model for effective policy formulation. His central thrust is to direct attention to the processes (and their adequacy) which go into determining how we come to know what we come to know - which is our cognitive construal of the world, or the content of cognition that becomes the basis for our actions. His central argument is that the quality of reasoning procedures used to arrive at fundamental policy decisions is one of the major determinants of a successful outcome. And a pertinent area of inquiry in this regard has to do with the processes of arriving at crucial policy decisions, including analysis of the conditions under which miscalculations, faulty implementation, inadequate contingency planning and other such errors are most probable.

Intervening into the Content of Cognition

Raising awareness of the *content* of cognition is facilitated by employing self-reflective artifacts such as cognitive maps (Boland, Tenkasi and Te'eni, forthcoming; Weick and Bougon, 1986; Weick, 1990; Eden, 1992), or being able to capture actors' narrative streams and discursive practices (Tenkasi and Boland, 1993; Mulkay, Potter and Yearly, 1983; Knorr-Cetina, 1981).

Cognitive maps are graphic representations that locate people in relation to their information environment. They provide a frame of reference for what is known and believed and thus exhibit the reasoning behind purposeful action (Fiol and Huff, 1992). Likewise, Eden (1992) suggests that cognitive maps can be seen as a picture or visual aid in comprehending an individual's or group's understanding of particular and selective elements of a situation. They represent the 'elements of thought' rather than thinking. Thus cognitive mapping is essentially a device for displaying through the use of a map like diagram, "a collection of items that are taken as elements of thinking at a given time" (Eden, 1992; p. 262).

Weick and Bougon (1986) suggest that building a cognitive map can be evocative for the map creator, as well as informative to its recipient. Creating cognitive maps can reveal personal cause and effect logic, which in turn forces the individual to confront the reasonableness and validity of previously tacit cause-effect assumptions. A cognitive map provides an occasion to think carefully, deeply and deliberately about a situation. Weick (1990) similarly argues that the act of creating maps (or other rich representations) of one's understanding of a problem domain and reflecting on them can facilitate new and more complex understandings of the situation at hand, improving the chances for scientific success.

As Weick (1990: p. 314-315) comments on this process:

> "Not much attention has been paid to the issue of how to move beyond simplicity and reverse the tendency of organizations to encourage and operate on increasingly impoverished views of the world...If we want to make organizational members more complicated and reverse some of the effects of simplification, then somehow we have to make it possible for members to reexamine original rich displays and come away from those reexaminations with different interpretations of what they might mean. If uncertainty can be regenerated as well as absorbed, then theoretically it should be possible to recomplicate original observations that have become simplified. And if original complicated observations can be reinstated, then the organization has the opportunity to experience some of those original data and become more intelligent in handling them."

Another approach toward understanding the content of cognition is paying attention to the narrative streams and discursive practices of actors in social settings.

For example, Knorr-Cetina (1981) argues that to get at the 'meaning systems' of scientists we must rely on their talk:

> "Strictly speaking, it is not really scientific action we have to confront in direct observation, but the *savage meaning* on ongoing events *for and by* the scientists. To get at this meaning we have to

> rely on talk. Without it, not even prolonged visits to the laboratory and training in the discipline at stake will make the rationale behind laboratory moves apparent...An understanding of these processes cannot be gained from observation alone. We must also listen to the talk about what happens, the asides and curses, the mutterings of exasperation, the questions they ask each other, the formal discussions and lunch time chats." (p. 21)

Mulkay et al. (1983) suggest the use of 'discourse analysis' to capture the cognitions, meaning systems, and interpretative repertoire of scientists. They present discourse analysis as a powerful methodology which can be used to provide closely documented descriptions of scientists' recurrent interpretative practices which are essentially embodied in their discourse. Further, such analysis can also show how these interpretative procedures vary in accordance with variations in the social context.

In conclusion, all these issues are directions for future research. Understanding the relationship between the efficacy of cognitive procedures and their relationship to scientific outcomes and the relationship between social context and cognitive processes, can significantly enhance our understanding of those elusive knowledge production practices in scientific environments.

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