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The consequences and antecedents of cognitive simplification processes in new product development teams

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Case Western Reserve University, 1994

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THE CONSEQUENCES AND ANTECEDENTS OF COGNITIVE
SIMPLIFICATION PROCESSES IN NEW
PRODUCT DEVELOPMENT TEAMS

by

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Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

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January, 1994
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J.C. Ranatunga
THE CONSEQUENCES AND ANTECEDENTS OF COGNITIVE SIMPLIFICATION PROCESSES IN NEW PRODUCT DEVELOPMENT TEAMS

Abstract

by

RAMKRISHNAN V. TENKASI

This study examined in twenty-five new product development teams of a pharmaceutical research and development center, the impact of cognitive simplification processes in scientific deductive and inductive action on the effectiveness of scientific work, and some contextual antecedents of cognitive simplification activity. Through a combination of qualitative and quantitative methods, the relationship of cognitive simplification processes to delays and project performance was significantly established. Results also indicated several contextual influences on cognitive simplification processes. Product development teams that evidenced higher levels of cognitive simplification activity also reported experiencing more and different types of delays in the product development process. Project performance ratings of teams experiencing higher levels of simplifications were lower than teams reporting a lesser incidence of simplification activity. Barriers to inflow of information and expertise, lack of integrative leadership and openness of group norms.
absence of shared language, imbalance in action and reflection, lack of analytical orientation, processes for accumulating prior knowledge and external knowledge linkages and perceived pressure were all significantly related to various types of cognitive simplification processes. These results generally support the importance of overcoming cognitive simplification processes by intervening into the content and processes of cognition and attending to the contextual environments of product development teams.
"No understanding of science will be complete unless it incorporates or is at least compatible with a well-developed understanding of the processes underlying human cognition."

- Rubinstein, McManus and Laughlin, 1984: p. 21

"Theories (Products) do not simply develop; they are developed through the cognitive activities of particular scientists."

- Giere, 1992: p. xviii

"At present scientific representational and problem-solving practices are largely underinformed by cognitive theories, making the fit between cognitive theories and scientific practices something that still needs to be determined."

- Nersessian, 1992: p. 7

Science (research and development) is a function of human cognition and thus a fuller understanding of science should necessarily include the investigation of human cognition. At least those cognitive processes that underlie scientific inquiry. This in essence summarizes the focus of this study.

My interest in the topic of this dissertation emerged over a period of time. The site for the study was an upstream research and development
division of a major corporation engaged in pharmaceutical research. My involvement with this organization came as an outcome of the division's decision to improve their strategic work processes using a non routine sociotechnical systems approach. An obvious work process they wanted to examine was the way they went about doing science, that is, the gamut of work activities entailed in the discovery and pre-clinical phases of drug development.

As a starting point we did a retrospective analysis of five drug development projects which had differing outcomes in terms of success (failure). The non routine sociotechnical approach employs deliberation analysis as the primary methodology to examine the core process of knowledge work systems. Deliberations are basic sense making devices that can be located in "encounters, exchanges, or reflections in general that help to resolve an equivocal topic" (Pava, 1983).

As we engaged in this analysis, some interesting insights came into focus. We found that major variations in project outcomes had to do with the quality of scientific reasoning and interpretive processes evidenced in these projects. One striking aspect of this exercise was the many simplifications of the task environment which the scientists engaged in, in their efforts to make sense and give order to an inherently complex and uncertain problem domain such as drug development. While the quality of cognitive activities was definitely influenced by the socio-structural context such as leadership style and group norms, the basic issues centered around questions such as how
effectively a problem or idea was formulated: how appropriate were the analogies employed in conceptualizing a new problem situation; what information sources were used in framing the problem; how trade-offs were handled; and how alternatives were evaluated. None of the existing management literature on new product development or innovation was able to throw much light on these considerations. The predominant structural, cultural, and information processing approaches appeared inadequate to directly examine these micro-level issues. Moreover, since these projects were all part of the same division and some scientists were involved in more than one project, there was some level of presumed uniformity in terms of culture, structure, and information processing patterns across these projects.

These early experiences led to an interest in trying to understand research and development as primarily a cognitive activity. In my search for an appropriate framework to make sense of my experiences, I came across conceptualizations (some relatively recent) of research as a cognitive activity in the philosophy of science and sociology of knowledge literatures. Also of special interest were the writings on cognitive simplification processes appearing mainly in the cognitive psychology, behavioral decision making, and to a limited extent in the strategic management domain. These varied sources were able to shed light on the anomalies observed in the retrospective analysis of five projects from a theoretical perspective. Further, they extended conceptual understandings of potential antecedents of simplification processes and their consequences. An outcome of this grounded theory building exercise (Glaser and Strauss, 1967; Martin and Turner, 1986) led to the next stage of
statistically examining these issues in the context of on-going, concurrent drug
development projects. The intention was to add further rigor and to validate
these qualitative understandings.

Grounded theory building approaches inquiry with a fairly open stance
as to the kind of general theoretical account likely to emerge from a particular
investigation. It is a process of discovering theory from qualitative data
gathered from observations, interviews, case study material, or other
documentary sources. Theory discovery is a process of moving from data to a
higher level of abstraction: one in which the data is given theoretical meaning
by the application of a name, concept, or label, to the action or object observed
or referred to. Grounded theory building can be a precursor to subsequent
large scale survey inquiries (Martin and Turner, 1986). Accordingly, this effort
represents what Martin and Siehl (1988) refer to as a mixture of qualitative and
quantitative approaches towards research.

Specifically the study had the following exploratory objectives in mind:

1. To propose a theoretic framework of
Research and Development as a cognitive
process with a particular emphasis on
understanding and explaining simplifications
in scientific work.

2. To examine if differences in the levels of
cognitive simplification activity is related to
indices of project effectiveness, particularly
project performance and product
development cycle time.
3. To examine if there is a relationship between socio-structural factors of the project team context and the level of cognitive simplification activity evidenced.

The rest of the dissertation is organized in the following manner.

Chapter 1 provides a broad overview of the theoretic rationale behind locating cognitive processes as fundamental activities in new product development.

Chapter 2 is a detailed review of the extant structural, cultural, and information processing models of innovation and some of their limitations with respect to illuminating the fundamental processes of knowledge creation in new product development, namely scientific reasoning. Chapter 3 is divided into two sections. Section 1 draws on theories from the philosophy of science and the sociology of knowledge to propose a conceptual framework of new product development as a cognitive process. Section 2 expands on the framework to explain simplification processes in scientific work and explores their consequences on project effectiveness as well as some potential antecedents.

Chapter 4 presents a description of the research site, interview methods, and two case studies of drug development efforts illustrating simplifications in scientific work. Chapter 5 is a synopsis of the survey methods and analytical strategy. Chapter 6 is a presentation of and discussion of the survey results. Chapter 7 extends final conclusions, explores implications of the study, and makes suggestions for future research.
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Chapter 1

A Theoretic Rationale - Cognitive Activities as Fundamental Processes in New Product Development

As we move towards the 21st century we are experiencing many unprecedented changes in the world of organizations and the nature of work. Intensified global competition and rapid technological and social changes require that organizations respond to a turbulent market environment with newer, better, and more innovative products and services faster than ever before (Purser and Pasmorne, 1992; Lawler, 1992; Purser, Pasmorne and Tenkasi, 1992; Von Glinow and Mohrman, 1989; Tenkasi, Boland and Purser, 1993; Galbraith and Lawler, 1993; Goldhar and Jelinek, 1983).

Two outcomes of this increased pace of environmental change and new product development are the gradual replacement of capital and labor intensive firms by 'knowledge intensive firms' (Starbuck, 1992) and a shift of employment from routine to 'knowledge or non-routine work' (Pava, 1983; Pasmorne, 1988).

Labelling of firms as capital intensive or labor intensive denotes the relative importance of capital and labor as production inputs. Accordingly, knowledge intensive firms denote a new species of organizations where knowledge has more importance than other inputs (Starbuck, 1992). The key input in such firms is expertise, both strategic and technical, which manifests
itself in new products and processes. This expertise, which is embodied in the specialized knowledge of individuals, enables such firms to outperform rivals who possess only commonplace market knowledge. As Starbuck (1992) comments on one such knowledge intensive firm (Garden); "The key labor inputs came not from the machinists in the plant, but from engineers and managers in the office building. These people had created monopolistic opportunities for Garden over and over again. Garden was the only producer of many of its products, and the dominant producer of all of them" (p. 715).

Examples of knowledge intensive firms are consulting organizations and high technology companies such as 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, such as traditional manufacturing, where the steps and procedures to transform inputs to outputs are known well in advance. Routine work can be well defined, is repetitive, and embedded in clear, shared goals (Purser and Pasmore, 1992). Building the one-thousandth car on the assembly line is not radically different from building the first car. In contrast, knowledge work such as new product 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). Requisite knowledge for new products is multi-faceted, multi-leveled, and detailed (Dougherty, 1992). It is typified by high task variability, uncertainty, and competing, multiple goals. The work process is incremental, exploratory, and often times moves in circles through multiple
pathways, where procedures for task accomplishment must be developed while the work is being performed.

While the core process in routine work involves the production or manufacture of some product or process, the core process in knowledge systems is one of producing ideas about products or processes. It is therefore natural that competitive advantage in this evolving global economy of high technology, knowledge intensive firms is ultimately dependent upon the quality of research and development activities that create the requisite knowledge necessary for continually spawning new products, services, and capabilities. Given the importance of research and development it is hardly surprising that these firms have a ratio of R & D expenditure to sales which is twice the average for all industries (Von Glinow and Mohrman, 1989).

In spite of the trend towards knowledge intensive firms and knowledge work, we know very little about how these tasks are performed or how we can facilitate their effective execution. As Purser and Pasmore (1992) note, if we consider research and development as an example, there is almost nothing in the management literature that relates directly to how the process of creation and application of knowledge takes place. "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" (p. 2).
A similar view is reflected in the philosophy of science domain. For example, Whitley (1972) states that, "The production of scientific facts is still a black box to social studies of science". Chubin and Restivo (1983, p. 71) concur in their critical observation:

"...science like any other institutionalized activity, should not be studied as a 'black box'... For the scientometrician fixes only what goes into the box-- the 'received view' of resources, people, and problems-- and what comes out in the other end-- papers, discoveries, citations, and prizes. Scientometricians celebrate these artifacts and grandly infer the processes they never observed."

A brief review of the traditional approaches towards understanding research and development and product innovation 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 being 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 had 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. Findings such as organic structures facilitate more innovations (Burns and Stalker, 1961), or innovation flourishes under climates which 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.

The core process in knowledge systems such as product development is one of producing ideas about products or processes (Purser and Pasmore, 1992). Thus, one can conceive the essence of knowledge work to be essentially a cognitive activity; a thinking, reflexive, reasoning, interpretive, sense-making 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 directly dependent on the quality of thinking and interpretive processes evidenced in these environments.

Cognitive processes are the 'engine of innovation'. While a study of the structural, cultural, and information processing contexts is no less essential to complete the circle of understanding of Research and Development and enhance its effectiveness, the workings of the 'engine of innovation', namely the cognitive components of science, have to be conceptualized and examined.
There has been a growing recognition that cognitive and interpretive processes play a significant role in research and innovation. Writers on the philosophy of science were the earliest proponents of this view. Ever since Kuhn's theory of scientific revolution (Kuhn, 1970), social studies of science have made a strong call for the cognitive aspects of science to be included in its empirical investigation (Nowotny, 1973; Elkana and Mendelsohn, 1981; de Mey, 1981; Rubinstein, Laughlin and McManus, 1984; Giere, 1992; Nersessian, 1992). "Theories do not simply develop; they are developed through the cognitive activities (emphasis added) of particular scientists" (Giere, 1992; p. xviii). "Scientific practice is marked by cognitive concerns, and we cannot hope to understand it without giving them due consideration" (Knorr-Cetina, 1981; p. 22). Looking merely at the social aspects of scientific organization and communication is insufficient.

For example, Knorr-Cetina (1981) in her book "The Manufacture of Knowledge" has convincingly argued that scientific products are first and foremost the result of a process of social construction. They are complex assemblages incorporating layers of selectivity among a range of possible choices. What gets selected is constituted mainly by previous selections and these selections affect subsequent ones by modalising the conditions for further decision making. The initial selections can have different roots and they arise from different points in the scientists' problematization or interpretations preceding a decision. Thus it becomes necessary to delve into the basic cognitive processes that lie behind these deliberate choices.
The importance of a cognitive/interpretive focus is gaining currency in the organizational literature and also in the context of product development and innovation, albeit in a limited way. Brown and Duguid (1991) note that innovation is a consequence of changes in a scientific community's "way of seeing" or interpretive view. Innovating organizations continually look for ways to impose new structures, ask new questions, and develop new views. By asking different questions, by seeking different sorts of explanations and by looking from different points of view, new answers emerge.

Moving away from the perspective of innovation as problem solving, Nonaka and Kenney (1991) reconceptualize innovation as an 'information creation' moment. They propose that information creation is synonymous with 'meaning creation' and product innovation can be viewed as a restricted subset of this process. The tools in this creation process are often metaphors and analogies or other such devices which help in examining current thinking practices, and facilitate rethinking or discarding old ways of thinking.

Henderson and Clark (1990) observe that nonroutine innovations require new "architectures" in which innovators break out of existing procedures and know-how and reconfigure components of design and procedure into a new framework.

Dougherty (1992) likewise makes a strong case for viewing innovation as an interpretive process, and emphasizes that the management of innovation
should pay attention to the interpretive schemes that shape and frame how people make sense of their work. The advocacy of rational tools and processes, the infusion of market research information, and the redesign of structures, while important, are not enough to manage innovation.

Her recent study of 18 new product efforts, the first field attempt at examining the linkage of interpretive schemes to product innovation, provides a good example of how intervening at the level of interpretive processes is critical for product innovations. The principal research question guiding the study was; why do innovators fail to develop a comprehensive appreciation and understanding of the product? Her findings suggest that, uniformly in all the unsuccessful cases, the key players involved in product innovation, namely the research scientists, field staff, manufacturing engineers, and business planners interpreted and understood issues around new products and technology-market linking in qualitatively different and limited ways from each other and were not able to reconcile these differences.

The differences in interpretation patterns emanated from different "thought worlds" which selectively filtered information and insights. However, successful product innovators created collaborative mechanisms that enabled surfacing and sharing of their unique interpretive dynamics and interactions at this core level of understanding which facilitated appreciation of each other's perspectives. Consequently, their unique knowledge could join together to produce new insights and facts.
Studying cognitive and interpretive processes is essential to understand how scientists produce the knowledge that manifests itself in new products and processes. Cognitive processes are the transformative core of new product development and innovation. They are the "engine of innovation". However, despite the obvious importance of thinking, reflection, and interpretation in scientific domains, "at present scientific representational and problem-solving practices are largely underinformed by cognitive theories" (Nersessian, 1992; p. 7).

Therefore, this study adopts a cognitive framework to understand new product development processes and outcomes. The underlying postulate of this framework is that scientific reasoning in its essence is a cognitive modeling process of the new problem domain. Success in scientific endeavors is attained when the complexity of the cognitive model optimally matches the complexity of the new problem domain to be explained, discovered, or invented. Complexity in knowing is a critical requirement for successful scientific innovations.

However, given the uncertainty of science, the representational process can become simplified and ignore the complexities of the problem domain, resulting in an ineffective model.

One approach towards studying the effectiveness of this cognitive modeling process is an examination of cognitive simplification processes in new product development efforts. Cognitive simplification processes are
reliance on simple decision rules to make sense of and deal with complex and fuzzy problems. Such simplification activity can manifest itself in, faulty framing of the problem, inadequate information search and evaluation of alternatives, and biased appraisal of consequences, and can come in the way of achieving the requisite complexity necessary for successful scientific outcomes. One frequent simplification process which contributes to faulty framing of the problem is inadequate analogical reasoning. For example, likening the flight of an airplane to a car that could be 'driven' into the sky, hampered many inventors from building an airplane that could fly.

A principal site for locating cognitive simplification processes in scientific activity is deductive and inductive action. Our thesis is that the complexity and uncertainty of scientific work induces various types of simplifications primarily with respect to the foundational structures of scientific reasoning, namely deduction and induction. Deduction entails the initial formulation of cognitive models and their subsequent ontogenetic development (or complexification) which in turn is based on inductive processes of taking in and evaluating information from the operational environment.

Therefore, an estimate of the level/severity of cognitive simplification processes in scientific deductive-inductive action can be a useful measure for determining the quality of cognitive activity in R & D efforts. And, a high incidence of such simplification processes can adversely affect the speed and effectiveness of new product development.
Finally, cognitive activities are embedded in a social fabric and certain socio-structural characteristics of the project team context can facilitate (or hamper) a conceptual system in attaining the 'optimal level of complexity' required for scientific success. Thus, the lack (or presence) of optimal complexity in features of the socio-structural organization can influence cognitive simplification (or alternately complexification) processes.

This research is one of the few attempts aimed at conceptualizing the cognitive components of research and development. The significance of the study arises from the fact that, it is to our knowledge, the first theoretically driven, field based, empirical examination of cognitive simplification processes and their consequences on project performance in the context of new product development efforts. In addition, the study contributes by investigating the relationship between the organizing context and cognitive simplification. The results of the research hold practical import for enhancing the effectiveness of new product development processes. It offers interventional potential into the cognitive activities driving scientific work and making more informed design choices about the contextual environments of product development teams.

In the next chapter, we will review in detail the structural, cultural, and information processing approaches used in studying R&D effectiveness and comment on their limitations in directly exploring knowledge production activities.
CHAPTER 2

Extant Theories of New Product Development and their Limitations

The extant theories of new product development can be roughly partitioned into three main approaches: structural, cultural, and information processing (Purser, 1990; Dougherty, 1992; Tenkasi, et al., 1993). However, it should be noted that this is purely a classificational scheme and there is considerable overlap among the three concepts. For example, structures have been viewed as manifestations of the organizational culture (Morgan, 1986). Likewise, it has been posited that the key function of organization design is to match the information processing capacity of the organization with the information processing requirements imposed by the environment (Galbraith, 1973; Tushman, 1978). We will examine these three approaches below, and in the final section comment on how they are disconnected from the fundamental activities in knowledge creation, namely scientific reasoning.
Structural Theories

The structural school concerns itself mainly with defining the optimal organizational structures that will result in successful innovation. Structure can be viewed as the sum total of the ways in which the organization divides its labor into distinct tasks (differentiates) and achieves coordination (integrates) among them (Mintzberg, 1979; Lawrence and Lorsch, 1967; Van de Ven, 1986). Others have relied on a more explicit information processing logic in their conceptualizations of structure (Galbraith, 1973, 1982; Tushman, 1978; Allen, 1986; Souder and Moenaert, 1992). For example, Allen (1986) suggests that, "The real goal of formal organization is the structuring of communication patterns..." (p. 213). Also, related to this latter structural tradition, a set of studies has examined the relationship between physical structure, communication patterns, and R&D effectiveness (Allen, 1976; Hatch, 1987).

In brief, four major approaches can be identified under the structural school: 1) Universalistic or archetypal structures for innovations; 2) Contingency structural framework; 3) Designing structures to balance contradictory requirements; and 4) Physical structure design and R&D effectiveness.

Archetypal Structures for Innovation

An example of the classic structuralist school is the pioneering study of Burns and Stalker (1961). This research investigated a number of Scottish
electronic firms faced with rapidly changing market conditions and new technical advances. Firms which were more successful at responding to market demands by generating innovations were structurally different from firms which failed to adapt to the changing environmental conditions. The innovative firms displayed a more 'organic' form of organization characterized by a network system of communication and control, with authority being commensurate with expertise. Individual tasks were continually redefined based on product concerns. Collegial relationships were fostered by overlapping roles and shared task responsibilities. Lateral communication was achieved through consultation and egalitarian relationships rather than directives. The innovation laggards, on the contrary, were encumbered by their 'mechanistic' form of organization. The tasks were very specialized and disconnected from overall product concerns. The definition of tasks as well as performance was determined by the supervisors. The structure of control, authority, and communication was primarily hierarchic, and authority was commensurate with one's position in the hierarchy. However, organizations which were able to change from a mechanistic to an organic structure were able to adapt to the requirements of the changing market environment (Burns and Stalker, 1961).

For some time the 'organic structure' was viewed as the appropriate R&D organization for enhancing research effectiveness (Schoonhoven and Jelinek, 1990; Purser, 1990). Increasing the amount of autonomy and freedom and decreasing the number of bureaucratic rules and procedures was the way to design the ideal R&D organization. However, Pelz and Andrews (1976) in
their comprehensive study found that scientists in settings with high levels of autonomy and freedom isolated themselves from their colleagues and focused their attention on their narrow areas of expertise. Based on their findings Pelz and Andrews (1976) suggested organizational structures which balance the creative tension between the need for security on one hand and the need for challenge on the other, were necessary to enhance researcher productivity.

*Contingency Structural Frameworks*

As an improvement on the universalistic approach of Burns and Stalker, a latter stream of studies adopted a contingency framework to examine the relationship between structure and R&D effectiveness (Duncan, 1976; Fischer, 1980; Galbraith, 1982; Johne, 1985; Allen, 1986; Souder, 1987; Schoonhoven and Jelinek, 1990; Souder and Moenaert, 1992).

For example, Duncan (1976), Fischer (1980) and Johne (1985) proposed that optimal structures for managing R&D organizations were contingent upon the stage of product development. Their main thesis was that idea generation/initiation and implementation stages demanded different organizational structures.

Structure was measured in terms of complexity, formalization and centralization. Complexity indicates a highly differentiated task structure with a number of diverse occupational specialties (Hage and Aiken, 1967). Formalization is a measure of the rules and procedures that must be routinely
followed during task execution. "The higher the proportion of codified jobs and the less the range of variation allowed, the more formalized the organization (Hage, 1965; p. 259). Centralization is the locus of decision making authority within an organization. When most decisions are made hierarchically, an organization is centralized (Van de Ven and Ferry, 1980).

Duncan (1976), based on a review of the literature on structure and innovation, came to the conclusion that different types of organization structures are best suited for different stages of the innovation process. "...the very structural factors that facilitate initiation may impede the implementation of innovations" (p. 172). While a structure exhibiting a low level of formalization and centralization can foster creativity during the idea generation stage, implementation requires consistency and a "singleness of purpose" (p. 178). Successful implementation needs clear procedures and standards for integrating the innovation into existing operations. Decision making has to be more centralized so that the inherent divergence of different occupational specialities, which is the complexity factor, can be managed and conflicts resolved (Duncan, 1976).

Galbraith's (1982) notion of differentiating the operating organization from the innovating organization is based on a similar premise. 
"...organizations that want to innovate or revitalize themselves need two organizations, an operating organization and an innovating organization. In addition, if the ideas produced by the innovating organization are to be implemented by the operating organization, they need a transition process to
transfer ideas from innovating organization to the operating organization" (p. 6). Reservations are the process through which differentiation is achieved. Reservations are organizational units, such as R&D groups, that are totally devoted to creating new ideas for future business. While the operating organization relies on traditional structural consideration such as division of labor, departmentalization, and span of control, the innovating organization emphasizes roles, opportunity, and autonomy.

In his empirical test of Duncan’s (1976) framework, Johne (1985) examined sixteen product development organizations from the computer and electronics industry. In accordance with Duncan's postulates he found that the eight 'actively innovative' firms used looser structures during the idea generation stage and moved to tightly controlled structures when the project moved to the implementation stage. In contrast, the less innovative firms organized themselves more tightly during the idea generation phase and resorted to an ad-hoc loose operating structure during implementation.

A second stream of work examined the relevance of different structural configurations for different levels of technical and market uncertainty (Allen, 1986; Souder, 1987).

Allen's (1986) work, for example, concerned itself with determining the relative appropriateness of two alternative organizational forms (functional vs. project) for R&D organizations. Emphasizing the idea that the function of organization design is the structuring of communication patterns, Allen
contends that every R&D organization has to grapple with two types of communication issues; 1) management of communication regarding new knowledge and the acquisition of state-of-the-art technical information, and 2) management of communication having to do with the coordination of tasks. The functional organizational structure achieves the first goal by grouping technical specialists of the same discipline together allowing them to be well connected with their professional fields. The functional organization is very effective for specialists to keep current of advances in their respective fields and continually improve their knowledge base. However, this arrangement can pose major problems when it comes to coordinating the individual efforts of a diversity of experts, that is, individuals who are highly specialized and narrowly focused within their own technical sub-disciplines. Thus, the functional organization is strongly input focused but suffers on the output side.

The project organization overcomes the coordination barrier by grouping together functional specialists from different disciplines and in many cases in close physical proximity. The specialists report to a common project leader and focus their talents on the immediate needs of the project at hand. However, the project structure has its disadvantages also. If specialists are isolated too long from their functional cohorts, they will find it difficult to keep in touch with new developments in their respective disciplines.

Given this basic dilemma of R&D organizations, Allen proposes three parameters which mediate the choice between a functional or a project structure (Figure 1). The first parameter is the rate of technological
Figure 1: Parameters of functional vs. project structures

knowledge change, that is, the rate of development of the technologies being used in the project. Mature or well developed technologies are already well understood and their rate of development is relatively slow. Newer or recently developed technologies are less understood; their rate of development is more dynamic and rapid. In sum, this parameter considers the rate of change of knowledge \((dk/dt)\) associated with the technologies undergoing development.

The second parameter is task duration, that is, the duration of a project or product development cycle time \((Ti)\). Allen contends that projects with long development cycle times require that specialists be connected with their functional knowledge base and especially so if the technology is dynamic and complex. The third parameter is subsystem interdependence or the amount of coordination which is necessary among the different technical disciplines during the development of a product \((Iss)\). Projects with a high degree of interdependence need to be organized so that the tasks of different technical disciplines overlap sufficiently to provide integration.

The optimal organizational form can be determined by gauging the level of interaction among these three parameters. The schema is depicted as coordinates in a graph in Figure 1. In conditions where the technologies are stable, the project duration is limited and the requirement for coordination is high, the project structure should prevail. "In those situations, the benefits of better intraproject coordination should more than offset any loss of external technical support" (Allen, 1986; p. 214).
However, under conditions where the technologies are rapidly changing and the project duration is lengthy, the functional form is necessary to make sure that the specialists do not lag behind the developments in their technical disciplines. In most situations, however, hybrid forms of organizations could result given that most R&D organizations have project portfolios with a complex mix of technologies and multiple assignments of varying durations.

Souder (1987) collected data on 256 projects in ten industries in his investigation of the relationship between the commercial success rate of innovations and project structures. He found that the optimal structures for managing successful product innovations varied as a function of the technical and marketing uncertainty in the external environment.

When the technology being developed was well understood but the market was uncertain, a project based structure led by a marketing manager was most appropriate. Seventy-five percent of the projects employing this structure were commercially successful, whereas a top-down functional structure led by a technical manager resulted in commercial failures (though some were technical successes). For environments characterized by well understood markets, but poorly understood technology, projects organized and managed through teams and task forces performed considerably better with an 80 percent success rate. Where both the technology and market was poorly understood, project based structures led by a marketing project manager
displayed the highest success rate (72 percent). Projects which were primarily one-man shows and relied on traditional top-down structures fared very poorly.

*Structures to Balance Contradictory Requirements*

A third and contemporary line of thinking stresses the importance of balancing the requirements of 'stability' and 'change' (Tushman and Nadler, 1986) and 'efficiency' and 'flexibility' (Schoonhoven and Jelinek, 1990) in organizing for innovation.

Tushman and Nadler (1986) suggest that in order for a company to remain competitive, innovation must become a way of life. Sustained innovation requires both stability and change. The stability permits scale economies and incremental learning, while change and experimentation produce changes in products, processes, and technologies. There are two kinds of innovation: 1) product innovation, involving changes in the product a company makes or the service it renders, and 2) process innovation, involving changes in the way a product is made or the service provided. Each type has three degrees of innovation within them; incremental, synthetic, and discontinuous. Organizations need sufficient internal diversity in strategies, structures, processes and people to facilitate different kinds of innovation and enhance organizational learning.

Schoonhoven and Jelinek's (1990) study is a more recent attempt to understand how companies organize and reorganize for innovation. Based on
an eight year longitudinal analysis of five highly innovative U.S. electronic firms that compete in the semiconductor components, systems, and computer markets, they found that organizing for innovation was a complex organizational process - one that did not conform to dichotomous, simple, either/or conception of organization structures such as 'organic' or 'mechanistic' or organized for 'steady-state technologies and environmental stability' or 'changing technologies and environmental uncertainty'. As lucidly worded by Schoonhoven and Jelinek (1990):

"Neither of these simplistic recipes for organizing comes close to adequately describing the subtleties and nuances required to organize for a continuous stream of state-of-the-art innovations that also enjoy success in the marketplace." (p. 91)

These companies simultaneously structured themselves for efficiency as well as flexibility. They managed well the dynamic tension between requirements of efficiency and flexibility which allowed them to adapt effectively to changes in their technical and market conditions.

Efficiency was fostered by having clear reporting relationships and job responsibilities; "With explicit reporting relationships, there is little of the predicted ambiguity of organic systems, and none of the wasteful uncertainty about to whom to turn" (p. 98). The flexibility in responding to changed market and technical circumstances was achieved through frequent reorganizations of the formal structures. When the problems for which the current structure was designed had changed, they shifted from one existing clear structure to another clear structure designed for a different set of
problems. The reorganization was substantially participative. The changes in structure were customized to deal with each of the company's localized task environments, its markets, and its technologies through an active process of self-design (Weick, 1979). These companies could be self-designing because the people working within these organizations were highly self-critical regarding how they are operating and whether the current structure is facilitating goal accomplishment fast enough.

Another feature of these organizations was the use of an intermediate level of structure or 'quasi-formal structure'. This intermediate level of structure is not formally characterized in the organization chart, nor is it informal in the unsanctioned or social sense of the term. Quasi formal structures mainly consisted of extensive use of committees, task forces, teams, and dotted-line relationships. They were used in conjunction with the formal structure but did not replace it. They were not matrix or project structures. Dotted line relationships mostly designated a 'for information only' relationship. More specifically:

"...quasi-structures are both formal in their recognized status as problem-solving groups and less formal in their authority relationships. These are colleague-based, problem-focused entities that exist for the duration of the problem. They are also far more pervasive, more deliberate, and more explicitly used than "informal" relationships or "cultural" linkages" (p. 110)

In sum, these firms showed a consistent pattern of structure, formal, quasi-formal, and informal that facilitate innovative ideas and task relevant
cooperation. Continual restructuring helped them remain flexible to changing market and technical conditions.

*Physical Structure Design and R&D Effectiveness*

Given that the relationship between physical structures and R&D communication effectiveness forms one aspect of the structuralist tradition, a brief review is warranted.

Allen (1976) did a study on how to architecturally improve communication in R&D labs. The results suggested that communication was greatly enhanced by arranging offices in a square or circular configuration, rather than a linear one, with offices off a hallway. Vertical distance also impeded communication. It was best to limit R&D labs to locations of a single story with less than 10,000 square meters of floor space. If more space is needed, a three story building with elevators was found more facilitative for communication than a large single or double story. Interaction is promoted by shared spaces such as a common lounge or facilities such as a copying machine.

A field study was employed by Hatch (1987) to examine the relationship between physical barriers and amount of interaction. Common sense dictates that more interaction would be found in offices with fewer barriers. The opposite effect was found in this study undertaken in two high-technology R&D firms. Partition height, number of partitions, and the use of a
door or a secretary were all related positively to one or more forms of interaction activity. A desk positioned away from the office entrance was the only barrier found to be negatively related to interaction. The relationships were independent of variables such as task characteristics, job type, work experiences, demographic features and sociability of individuals.

Summary and Observations

Research examining the relationship between structure and new product development has progressed in conceptual terms and methodological sophistication. Burns and Stalker's (1961) generalized, universalistic approach towards innovation presumed that a single dichotomous variable (organic-mechanistic structure) could describe an organization and the manner in which it carried out a complex process (Tornatzky, et al., 1983). Duncan (1976) Fischer (1980) and Johne's (1985) attempts to operationalize and define structure on dimensions of complexity, centrality, and formality was a definite methodological improvement. Further, they recognized two distinct phases in innovation, idea generation/initiation and implementation, which required different types of organizational arrangements. Allen (1986) and Souder (1987) examined the relationship of different organizational forms for varying levels of environmental uncertainty. Souder's (1987) study further considered the context and importance of the marketing environment, whereas Allen's (1986) framework limited itself to technical uncertainty. Tushman and Nadler (1986) and Schoonhoven and Jelinek (1990) reconceptualized organizing for innovation as a complex process; one that has to balance the dialectics of
stability and change and efficiency and flexibility. Frequent reorganization through self-design processes and use of structures, formal, quasi-formal, and informal are all necessary to enhance R&D effectiveness. A related stream of work looked at issues of physical structure design and R&D communication effectiveness.

However, for all its conceptual and methodological improvements, the structural tradition remains far removed from providing any insights into the actual processes of science. What it provides in terms of explanations at best are weak general statements such as looser structures are related to better idea generation (Fischer, 1980; Johne, 1985) or organic structures (Burns and Stalker, 1961) are related to innovations. Structure is merely another input into the black box that is research and development. Deeper explanations of why a certain structural form is appropriate for research and development can only be fully understood if we are able to examine how it impacts knowledge creation activities. And for that we need to understand the workings of the black box—the processes of scientific reasoning.
Cultural Theories of Innovation

The word culture has been derived metaphorically from the idea of cultivation; the process of tilling, fertilizing and developing the land so that seeds may germinate and crops grow and flourish (Morgan, 1986). It is in this sense that culture has been used in examining its relationship to innovation. What are the overall contextual conditions that account for successful innovations and what are those that can contribute to failures (Pelz and Andrews, 1976; Maidique and Hayes, 1987; Kanter, 1983; Feldman, 1988; Kanter, 1988; Strebel, 1987; Nicholson, Rees and Brooks-Rooney, 1990; Demirag, 1992).

The cultural school can be broadly classified into four areas: 1) cultural conditions that stimulate and manage paradoxes; 2) cultural influences on the Japanese innovation process; 3) integrative cultures and innovation stimulation; and 4) contingency theories of culture and innovation.

Effective Research Cultures that Stimulate and Manage Paradoxes

A good example of the cultural tradition is Pelz and Andrews's (1976) pioneering study of 1311 scientists in 11 research and development laboratories. The R&D settings included: five industrial labs specializing in pharmaceuticals, glass and ceramics, electronics and electrical equipment; five government labs involved in weapons guidance, animal diseases, agricultural products and basic research in several physical sciences; and seven
departments in a major university engaged in the biological, physical, and social sciences. Their objectives varied from basic research to new product development.

The guiding research question was, what kinds of climate in research and development organizations are conducive to technical accomplishment. ".. R&D organizations provide more than facilities for their members. They also provide an environment (italics original) which may either stimulate or inhibit the scientists' performance" (p. 1).

Among their findings appeared a number of paradoxes. The optimum climate did not appear to be a compromise between extremes. "Rather, achievement often flourished in the presence of factors that seemed antithetical" (Pelz and Andrews, 1976; p. xv).

On the one hand, effective research environments were characterized by sources of disruption or intellectual conflict and on the other, by sources of stability and confidence. Pelz and Andrews's (1976) describe their findings succinctly:

"...technical men were effective when faced with some demand from the environment—when their associates held divergent viewpoints or the laboratory climate required disruption of established patterns. These might be called conditions of challenge. On the other hand, technical men also performed well when they had some protection from environmental demands. Factors such as freedom, influence or specialization offer the scientist stability and continuity in his work—conditions of security" (p. xv).
This 'creative tension' between sources of stability or security and sources of disruption or challenge was what promoted technical achievement and success. These eight creative tensions are summarized below:

- The first tension was between science-oriented and product-oriented activity. In effective scientific environments, scientists did not limit their activities to either pure science or to application but spent some time on several kinds of R&D activities, ranging from basic research to technical services. Why should such a tension be creative? A creative act occurs when a set of elements not previously associated is assembled in a new and useful combination. Diversity in technical activities can broaden the range of elements from which scientists can draw upon in synthesizing new combinations.

- The second tension was independence versus interaction. Effective scientists were intellectually independent and self-reliant; they pursued their own ideas and valued freedom. However, they also interacted vigorously with their colleagues.

- The third tension was around specialization versus generalization. In their early years, young scientists did well if they devoted primary attention to one main project. However, young Ph.d.'s. also achieved if they had several skills, and did better when they avoided narrow specialization. Among mature scientists, high performers had an interest in probing an issue rather deeply. At the same time, effective older scientists wanted to pioneer in broad new areas.

- The fourth tension was around autonomy versus coordination. In departments characterized by minimum coordination, the most autonomous individuals, with minimum challenge and maximum security, were ineffective. Most effective were scientists who experienced
stimulation from a variety of external or internal sources. In departments with moderate levels of coordination, the individual autonomy permitted a search for the best solutions to the problems faced by the organization.

- The fifth tension revolved around communication and mutual influence. Scientists contributed when they could strongly influence key decision makers and when other scientists had a voice in selecting their goals.

- The sixth tension had to do with similarity versus diversity. High performers derived personal support from colleagues with whom they shared similar sources of stimulation. But they also differed from colleagues in their technical style of working and strategy.

- The seventh tension was around age related specialization. R&D teams were most effective at the group age when interest in narrow specialization had increased to a medium level but interest in broad pioneering had not disappeared.

- The eight tension was conflict versus collaboration. In older groups, scientists preferred each other as collaborators. However, their technical strategies differed and they remained intellectually combative.

Maidique and Hayes (1987) interviewed over 250 executives from a wide cross-section of high tech industries- biotechnology, semiconductors, computers, pharmaceuticals and aerospace, as part of a large scale study of product innovation. The investigation was to identify the characteristics of these companies which made them successful product innovators. Very similar to the findings of Pelz and Andrews (1976), the researchers found that success
was stimulated by paradoxical conditions. "Some of the behavioral patterns that these companies displayed seemed to favor promoting disorder and informality, while others would have us conclude that it was consistency, continuity, integration, and order that were the keys to success" (Maidique and Hayes, 1987; p. 149). Continued innovation in a high-technology environment requires periodic shifts between chaos and continuity.

The characteristics of these firms fell into two apparently paradoxical groupings. The conditions of stability and conservatism were: 1) clear business focus (closely related products, focused R&D, consistent priorities); 2) organizational cohesion (open communication, job rotation, integration of roles, long-term employment); and 3) a sense of integrity (commitment to long-term relationships, self-understanding).

On the other hand, the conditions of disruption and change were: 1) adaptability (flexibility, agility, frequent reorganization of people); 2) entrepreneurial orientation (decentralized decision making, small divisions, tolerance of failure, variety of funding channels, freedom to pursue speculative projects); and 3) hands-on top management (direct involvement of top executives). The fundamental tension was between order and disorder, with half the factors pulling in one direction while the other half tugged the other way.

Feldman (1988) examined the influence of culture on attitudes towards the capacities for innovation in a medium size electronics company. The
primary argument put forth by Feldman is that for effective innovation to take place, an organization's culture should support and more importantly manage competing and contradictory values. Homogeneous cultures are antithetical to innovation because they limit the sources of creativity to top decision makers.

One such set of values is 'inner-directedness' versus 'other-directedness'. The inner-directed entrepreneur is motivated by internalized ideals of self-reliance, strict self-control, and a strong need for achievement. 'Other-directedness' reflects a greater sensitivity to interpersonal relations, where social acceptance by peers and superiors becomes the primary goal. Both orientations have positive and negative effects on innovation. Other-directedness benefits innovation since compromise is a stimulus for innovation. In many organizations, decision making in product development involves multiple specialities and functions. Nevertheless, the willingness to compromise has a negative effect on innovation because it undermines passionate commitment to goals, which is essential to overcoming the difficulties inherent in the innovation process. Inner-directedness can be a powerful stimulus to innovation because when individual desire is limited by little more than itself, the whole social and physical environment becomes open to change. In a culture of 'hyper-individualism', change and creativity are the only constants. However, the focus on one's needs makes the inner-directed individual wary of compromise and long-term commitments, both of which are needed for innovative activity. In addition, focus on one's own interest makes team-work all but impossible.
In his case study, Feldman shows how the cultural contradictions created by the founder's 'inner-directedness' and the employees' 'other-directedness' had a negative impact on the organization's ability to innovate. As Feldman (1988) elucidates:

"Thus the cultural milieu that developed at Smith Electronics encouraged employees to be sensitive to and follow Mr. Smith's lead. This sensitivity reflected a strong other-directed orientation; Smith, on the other hand, with his self-motivated style and commitment to the ideal of employee security, reflected an inner-directed orientation. Because of these differences in orientation, when Smith tried to set up a decentralized organization in the late 1970s by delegating responsibility for innovation to the divisions, the other-directed employees were not self-directed enough to innovate on their own. Smith's idealism had led to a positive work atmosphere, but it also encouraged his managers to become dependent on him." (p. 61)

Specifically, the cultural contradictions played out in the product development arena. Two of the founder's strongest ideals were his commitments to product quality and customer service. This idealism, however, led to an internal focus on the product engineering at the expense of an external focus on market dynamics and customer needs. Even though top management intellectually recognized this imbalance, the founder's ideals of product quality and customer service were used to block the development of marketing skills. The idealization of the founder's goals made them unchallengeable in the decision-making process. Managers were faced with conflicting goals such as service or profit, quality or timeliness, but because of the idealized commitments to quality and service, these conflicts were prematurely resolved before marketing issues were systematically considered.
By defining quality and service technologically and by idealizing them, the founder built a technological bias into the company's work culture. Marketing perspectives could not be effectively incorporated into product development concerns.

Further, the founder's 'inner-directed' tendency made him poorly equipped to listen to alternate perspectives. He was unable to broaden his own personal relationships to make a more diverse group of individuals feel comfortable in the company. The inherent cultural contradiction was manifest in the founder idealizing his own beliefs and at the same time trying to decentralize the organization.

*The Japanese Perspective on Innovation*

Another popular stream in the cultural school are writings on the Japanese innovation process and the unique cultural conditions which have contributed to successful Japanese innovations. In contrast to Feldman's (1988) thesis, the central theme in many of these writings stresses the homogeneity of culture and a collectivist orientation as the key forces behind successful Japanese innovation (Gerstenfeld and Sumiyoshi, 1980; Prochaska, 1980; Maruta, 1980).

Gerstenfeld and Sumiyoshi (1980) strongly emphasize the importance of the collectivist orientation of Japanese culture. The orientation towards the group, homogeneity of background, and high enthusiasm and loyalty
associated with lifetime employment are major factors in the Japanese culture that influence innovation. The collectivist orientation is well manifest in their decision making process. Group consensus is emphasized and understanding among all actors is a key concept.

Contrary to what many Americans believe, the Japanese system does not demand the all participants "sign off". Each participant must be satisfied that his or her point of view has been fairly heard, and while the person may not wholly agree with the decision, she is willing to go along and, even more important, to support it. For any decision, the group discusses the problem freely. They begin by generalizing to increase the recognition level of the problem to the members in the group. They then analyze the problem. Before making a decision, they spend a lot of time in explaining each person's rationale, listening carefully to what other members of the group are thinking. After making a decision, they spend absolutely no time "selling" the decision to each member of the group. In sum, the Japanese culture toward group cohesiveness is now and for the past several years has been expressing itself in innovation.

Prochaska (1980) contends that one reason for the success of Japanese innovation is their downplaying individual personal success, particularly as it relates to those individuals who are responsible for innovation and the development of new products and new businesses. In the United States, one tends to look for the product champion or the up and coming bright star who is put in charge of the new venture and held ultimately responsible. So it
becomes a win/lose situation in which the individual is betting a good part of his/her career on making the new venture a success. The concept can succeed at times, but too often it produces ventures from individuals who are too eager to succeed. They are apt to select the lower risk, more easily planned and achieved alternatives so that they can demonstrate to their superiors that he/she has made a significant personal contribution. It is difficult to make a short term, personal demonstration of success through the innovation of new products and the development of new businesses that normally require at least a five to seven year time span in going from the innovative concept to a commercially successful product or business.

In the Japanese environment there is no such concept because there is not as much risk or personal pressure from success or failure. It becomes the group that 'succeeds or fails', and the group has stability in the company. The group is not working for its individual success but for success of the venture in terms of how it will affect the success of the company.

*Integrative Cultures for Innovation Stimulation*

Based on extensive research of 115 innovations in 10 companies, which included products as diverse as futuristic X-ray machines, computerized data libraries, and underwater sensing devices, Kanter (1983) identifies the circumstances that make it possible for people to come up with and contribute new ideas. The purpose of the study was to understand the environmental conditions, that is, the specific factors in a company's structure and culture,
that stimulate people to act innovatively and gives them the power to "experiment, to create, to develop, to test--to innovate" (Kanter, 1983: p. 23).

The underlying difference between innovation-stimulating and innovating-smothering situations was a basic orientation towards problem solving. The entrepreneurial spirit, producing innovation, was associated with a particular way of approaching problems that she terms 'integrative'. This mode essentially is; "the willingness to move beyond received wisdom, to combine ideas from unconnected sources, to embrace change as an opportunity to test limits. To see problems integratively is to see them as wholes, related to larger wholes, and thus challenging established practices--rather than walling off a piece of experience and preventing it from being touched or affected by any new experiences." (Kanter, 1983; p. 27).

Integrative thinking is facilitated by cultures and structures which are also integrated. Such structures and cultures encourage the treatment of problems as 'wholes' and help consider the wider implications of actions. They reduce conflicts and isolation between organizational units; create mechanisms for exchange of information and new ideas across organizational boundaries and ensure that multiple perspectives will be taken into account in decisions. Differences are recognized and even encouraged, but mechanisms exist for transcending differences and finding common ground.

The innovation-smothering culture is termed as 'segmentalism'. This style relies on compartmentalizing actions, events, and problems and keeping
each piece isolated from the other. Segmentalist approaches see problems as narrowly as possible, independent of their context, and independent of their connections to other problems. Firms with segmentalist cultures have segmentalist structures, that is, a large number of compartments walled off from one another; department from department, and level from level. A minimum number of exchanges take place across segment boundaries, and each segment is assumed to stand or fall independently. Segmentalism assumes that the best way to solve problems is to carve them into pieces and assign each piece to a specialist who works in isolation. Segmentalism reflects the theory of 'local rationality' where any decision problem is factored into subproblems, with each assigned to a different sub-unit, so that each has only one goal and one piece of the problem. The integrative mode works in a diametrically opposite way. Subproblems are aggregated into larger problems so as to create unity that can provide more insight into required action. This enables creative leaps of insight that redefines a problem so that novel insights can emerge.

Segmentalist organizational cultures favor sorting issues into preexisting categories, such as the array of boxes in the organizational chart, or precedents and procedures. This tightly compartmentalized approach discourages actors to look beyond what already exists to find a novel solution. As Kanter (1983) comments:

"The principle of psychic economy means that if people find a solution near at hand, why expend the energy to look any further? If a precedent will do, why create novelty? At the same time, the isolation of
organizational segments also means that fewer alternatives will be known to the searchers, their choices will be severely constrained." (p. 30)

The major roadblocks to innovation in segmentalist corporations were tall hierarchies and a strict chain of command, poor lateral communication among departments, and limited tools and resources.

A number of cultural conditions fostered the integrative posture of innovative firms. Innovating companies provided the freedom to act, which in turn aroused the desire to act. The incentives for initiative emerged from a range of situational factors. Three key influences were: 1) broad job charters and assignments which were ambiguous, non-routine, and change directed; 2) intersecting job territories, so that there was interdependence in terms of others being affected by one's action as well as required for it; and 3) local autonomy which was strong enough so that actors could experiment and go ahead with large chunks of action without waiting for higher level approvals.

Specifically, broad job assignments stimulated a high proportion (51 percent) of all the innovative accomplishments studied by Kanter. As she clarifies:

"What is important is not whether there is an assignment, but its nature: broad in scope, involving change, and leaving the means unspecified to the doer. Characteristically, the manager's formal job description often bore only a vague or general relationship to the kind of innovative things that the manager accomplished." (p. 144)
Her point is that certain kinds of uncertainties create opportunities, even if they are perceived as uncomfortable.

Initiative was also encouraged by a combination of relative independence from higher levels and relative interdependence among peers across functions. A complex, matrix type of structure, with a network of intersecting lines provided an incentive for people to move beyond the narrow spheres of their own job to seek projects with broader relevance. A ubiquitous feature of the matrix structure was that actors from two or more functions would generally need to collaborate in reaching a decision or taking some action. Decision were usually made slowly in the matrix environment since it usually required a series of consultations. But in spite of the protracted nature of the decision making, managers could accomplish significant tasks in a relatively short period of time once the initial decisions were made.

The matrix element and the processes associated with it introduced a dimension of considerable complexity in these organizations. But as Kanter (1983) clarifies, this was a pre-condition for successful innovation:

"...to produce innovation, more complexity is essential; more relationships, more sources of information, more angles on the problem, more ways to pull in human and material resources, more freedom to walk around and across the organization." (p. 148)

Another incentive for enterprise stemmed from a company 'climate of success' and a 'culture of pride'. First, these organizations were symbolized by
an emotional and value commitment between person and the organization. People felt that they belonged to a meaningful entity and could realize their cherished values by their contributions. Second, innovative companies had norms which favored change. There was more impetus to seek change when it was considered desirable by the company. Pride in the company coupled with knowing the innovation is mainstream rather than countercultural, provided a strong incentive for initiative.

While the above two conditions created the desire to innovate, a third set of factors ensured that people got the power to innovate. Innovating organizations made sure that power was widely accessible. Organizational power tools consisted of supplies of three 'basic commodities' that can be invested in action: information (data, technical knowledge, political intelligence, expertise); resources (funds, material, space, time); and support (endorsement, backing, approval, legitimacy). To use an economic analogy, there were three kinds of markets in which the individual initiating an innovation had to compete. A 'knowledge market' or 'marketplace of ideas' for information; an 'economic market' for resources; and a 'political market' for support or legitimacy. Three broad aspects of innovating firms aided power circulation and power access: 1) open communication systems helped potential entrepreneurs locate information that can be used to shape and sell a project; 2) network-forming arrangements helped them to be in a position to build a coalition of supporters; and 3) decentralization of resources helped them to get the resources needed to mobilize action. These three clusters of structures and processes together created an empowering, integrative environment.
Contingency Theories of Culture and Innovation

Nicholson, Rees and Brooks-Rooney (1990) take a contingency approach towards cultures for innovation. They decry the universalistic and rather naive conceptions of the relationship between culture and innovation as found in the 'one-best-way' recipes pervading the popular writings (Peters and Waterman, 1982; Hickman and Silva, 1984; Kanter, 1983). As they comment; "...the theorizing is mostly monolithic and simplistic. The relationships are presumed to be direct and consistent: organic structures, coupled with person-centered management styles are recommended to foster a climate of innovation, facilitate proactive market orientations and achieve business success" (Nicholson, et al., p. 512).

A major postulate of their study is that the strategic orientation (culture) of the firm will be related to the level of innovativeness. Strategic orientation is the expression of a company's cultural values and thus dictates the firm's tendency towards innovation.

Building on Miles and Snow's (1978) strategic typology (Prospector, Defender, Analyser and Reactor) they apply a modified schema of strategic orientations in their investigation of eight companies in the wool industry.

Prospectors are strategic types where the emphasis is on finding and developing new markets and products. The administrative processes are
decentralized and coordination is dominated by marketing and R&D. The Defender stresses maintaining control of the market by sealing off the segment of the market from others. Efficiency in production is of utmost importance and the control is hierarchical dominated by production and financial functions.

In addition to Prospector and Defender, a new category of 'hybrid' is introduced. The hybrid form are enterprises which truly combine prospector and defender characteristics by means of a dual core in operations and strategy. They should be distinguished from analysers whose modus operandum is market analysis and imitation. The second revision which the authors propose to Miles and Snow's typology is the identification of the transformer type. This is a finer distinction of the original typology's 'Reactor' category which encompasses organizations who for diverse reasons are unable to formulate or implement a consistent strategy. 'Transformers' are companies which have inconsistent elements in their strategy because they are in a state of change from one strategic orientation to another.

A major thesis of the study is that the more successful companies with a prospector-type orientation would exhibit a high level of role innovation and innovativeness in organizational products and practices.

The results confirmed the predominant hypothesis. While they could not find any true Prospector types in their sample, the successful hybrid type reported a large number of innovations, both radical and non-radical. In
defender types, a few radical and a modest number of non-radical innovations could be found. Patterns were mixed amongst others. In one turbulent transformer type there was a high rate of radical innovations, both failed and successful. In the reactor type, there was a high rate of failure among a low frequency of radical and non-radical innovations.

Strebel (1987) also proposes a contingency model of 'cultures for cultivating innovation' depending on the stage of an industry's evolution. The basic hypothesis in the study is that a gap tends to develop over an industry's evolution between potential innovators in a company and the dominant company culture. Different kinds of innovation are required for long-run survival during an industry's evolution. However, the mainstream company culture and its disposition towards innovation can become counter to the requirements of innovation, especially as the industry matures.

In brief, the development/emergence phase of an industry requires fundamental (product) innovation; the growth/diffusion phase mainly incremental (process) innovation; the differentiation/maturity phase, mainly incremental (product) innovation; the decline/rejuvenation phase, fundamental (product/process) innovation. Competitive success is a function of both innovative ability and efficiency. However, as the industry matures the increasing demand for efficiency causes the mainstream organizational form to become increasingly mechanistic and bureaucratic and biased against innovation.
A framework is extended by Strebel for determining the appropriate culture for innovation, based on the interaction of two dimensions: nature of innovation required for survival, fundamental or incremental, and the innovative disposition of the main organization towards innovation, open or closed. Organizations open to innovation are characterized by low resistance to new ideas and change, whereas organizations closed to innovation are more rigid, resisting new ideas and change.

When fundamental innovation is required and the organization is open, 'widespread team competition' is the suggested culture. In this mode, autonomous teams compete against each other to sell their ideas to the sales force.

When incremental innovation is required and the organization is open, 'simulated entrepreneurship' is the best choice. The prototype here is the Japanese Ringi system which supports incremental innovation from bottom-up, within a well defined corporate culture. Employees are given autonomy to be innovative with respect to those activities over which they have some control, but always in harmony with the corporate strategy.

When fundamental innovation is necessary and the organization is closed, 'organizational spin-offs' will be most appropriate. Under this arrangement the parent company 'spins-off', under its financial umbrella, several internal innovators into divisions or firms of their own, while maintaining rights to the resulting technology.
For incremental innovation when the organization is closed, the recommended mode is 'independent task forces'. These task forces operate outside the company mainstream. They are often given a critical task to perform by top management with maximum possible freedom of action and access to needed resources.

For the four different phases of industry evolution, the following fit is suggested:

1. Emergence/development - widespread team competition
2. Growth/diffusion and differentiation maturity - simulated entrepreneurship
3. Decline/rejuvenation - independent task forces or organizational spin-offs

Summary and Observations

The cultural school similar to the structural school has advanced from universalistic theories (Pelz and Andrews, 1976; Maidique and Hayes, 1987; Kanter, 1983) to contingency approaches of appropriate cultures depending on the stage of the industry's evolution (Strebel, 1987) or strategic orientation (Nicholson et al., 1990). However, irrespective of the different conceptualizations of cultural requirements, whether it is one of stimulating and managing contradictions such as 'inner-directedness' versus 'other directedness' (Feldman, 1988) or supporting homogeneity and a collectivist orientation (Gerstenfeld and Sumiyoshi, 1980), culture appears to be another
input into the black box which is science. Questions such as why and how do 'organizational spin-offs' (Strebel, 1987) facilitate fundamental innovation are not raised. Alternately, it is not known as to why a Prospector orientation (Nicholson, et al., 1990) will necessarily result in more innovations. Or in other words, while culture offers another contextual condition for innovation, we still do not know why and how a particular context helps or hinders the quality of thinking, and thus innovations. Until, one is able to isolate and examine the fundamental activities of knowledge production, namely the processes of creating and applying knowledge, deeper insights on how the structural or cultural context impacts innovation will not be available.

However, we do have some emergent insights, albeit in a limited way, suggesting causal relationships between culture and cognitive processes in research and development. For example, Pelz and Andrews (1976) comment on the creative tension between science-oriented and product-oriented activity among scientists. To the question, why such a tension should be creative, they propose that a creative act occurs when a set of elements not previously associated is assembled in a new and useful combination. Diversity in technical activities can broaden the range of elements from which scientists can draw upon in synthesizing new combinations.

Likewise, Kanter (1983) suggests that successful innovation is primarily the result of an integrative approach to problem solving. This mode essentially is to conceptualize problems in a more complex fashion, as wholes, and related to larger wholes, and to be able to combine ideas from unconnected
sources. Integrative thinking is facilitated by cultures and structures which are also integrated.

While these insights are useful, a complete conceptualization of the knowledge creation processes in scientific settings is in order, so that we may obtain a more fuller understanding of Research and Development activities such as how culture influences cognition in new product development settings.
Information Processing Theories

A third track conceptualizes R&D as an information processing system. Most research under this framework has had 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. A major paradigmatic influence behind R&D as an information processing system can be traced back to Shannon and Weaver's (1949) "Mathematical Theory of Information". In basic terms, the mathematical theory of information provided a quantified method for calculating the efficiency of a channel's capacity through which information could be successfully transmitted and received. Commonly termed the 'source-message-channel-receiver' model of communication, this framework has allowed researchers to count discrete instances of information exchange by viewing the act of information transfer as flowing from one individual to another (Davis and Wilkof, 1988).

The information 'input focus' has been mainly explored in studies dealing with the technical information acquisition patterns of engineers and scientists (Allen, 1977; Chakrabarti, Feinman and Fuentevilla, 1983) and 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). The 'information exchange' focus has been the guiding framework for studies examining communication patterns, networks and information
processing internal to the R&D laboratory (Allen and Cohen, 1969; Allen, Tushman and Lee, 1980).

Technical Information Acquisition Patterns

A critical task in the product development process is the acquisition of technical information. There are principally two information related problems that a R&D organization must deal with. Linkages must be maintained to sources of new knowledge for future technological developments, and at the same time, an awareness of marketplace needs must be sustained. The dual requirements of new knowledge (technological push) and marketplace knowledge for specific product applications (market pull), is associated with different patterns of information acquisition. Similarly, information for fundamental innovations as in basic research and incremental innovations as in enhancements to existing products or processes have been shown to emerge from different information sources (Rosenbloom and Wolek, 1970).

Allen's (1977) study investigated 'information user' behavior among scientists and engineers. He found that scientists engaged in basic research acquired most of their information from the literature and professional colleagues in the external environment. The engineers who are concerned with operational improvements, however, acquired the information they needed from vendors and customers, and their personal contacts within the firm.
In a study by Rosenbloom and Wolek (1970), differences in information acquisition patterns were observed for tasks which were intended to make advancements in new knowledge, and tasks intended to support ongoing operations. Basic research activities employed more formal media sources, while development and operational support activities relied mainly on informal sources within the firm.

Chakrabarti, Feinman and Fuenterville (1983) found that information for operational applications in the form of facts and hard data was most frequently acquired through informal informational channels which were in close proximity to each other. Natural work groups were most frequently utilized due to their availability and ease of use. Channels for such communication occurred through either face-to-face contacts or the telephone.

Sources of Information Used in Different Stages of the Innovation Process

Numerous studies have examined the sources of information employed in the idea generation and problem-solving/implementation stages of new product development (Myers and Marquis, 1969; Utterback, 1971; Langrish, 1972; Rothwell, et al., 1974; Goldhar, et al., 1976; Allen, 1977).

Myers and Marquis (1969) investigated the information sources used in 567 successful process and product improvements during the different stages of the innovation process. Their sample covered 121 companies from five U.S. industries. In their examination of 153 major information inputs during the
idea generation stage, 39 percent originated from sources internal to the firm, 50 percent from outside the firm, and 11 percent from multiple channels. 414 major information inputs were observed during the idea implementation or problem-solving phase. 60 percent were derived from sources internal to the firm, 29 percent were obtained from external sources, and 11 percent from multiple channels.

In a study of 32 award winning scientific instruments, Utterback (1971) identified 47 information channels used in the idea generation stage. Internal discussions played only a marginal role (11 percent), other internal information channels, such as literature sources (16.3 percent), and preliminary research (28.4 percent) were used more for idea generation purposes.

Langrish (1972) in their study of 84 award winning innovations, traced the source of 158 key technical ideas employed in 51 of these innovations. 56 originated from within the firm, while the 102 remaining ideas were obtained from external sources.

Project SAPPHO (Rothwell, et al., 1974) compared 43 pairs of successful and unsuccessful innovations in the scientific instruments and chemical industries. 46 out of the 86 innovations originated from ideas derived from external sources.

The findings of Goldhar et al. (1976) suggested internal sources as key for idea generation processes. For the 300 technological innovations sampled,
78 percent of the respondents reported that internal sources supplied the most important information during the idea generation stage.

While many of these earlier studies were retrospective, Allen (1977) observed on a real-time basis the information consumption behavior in thirty-one matched pairs of R&D teams in the aerospace and electronics industry. Each matched pair was working on the same technical problems, and this enabled performance comparisons to be made. During the idea generation stage, less than 19 percent of the messages originated from consultations with a company's internal resources and technical staff. Yet it was precisely the utilization of internally generated messages which produced more highly rated solutions. Only 35 percent of the idea-generating messages used by higher performing teams came from external sources. In contrast, the lower performing R&D teams acquired 55 percent of their messages from external sources. During the problem solving stage, the higher performing teams engaged in increased consultation with their organizational colleagues. Personal contacts within the firm accounted for 48 percent of the communications.

In summary, the findings on information source utilization and idea generation show a mixed trend (Purser, 1990). The importance of external information sources versus internal information sources for R&D effectiveness and vice versa appears to be equally divided. While there may be several methodological reasons to account for the inconsistencies in the findings, it remains that both sources are equally important for innovation (Purser, 1990).
Communication Patterns, Networks and Information Processing

To be effective, R&D organizations must not only import information from the external environment but should also ensure that this information is accessible to and is easily assimilated by the average professional. Information exchange is as critical as information input.

This notion was supported in Pelz and Andrews (1976) classic study, where they found a significant positive relationship between the performance of a scientist and the frequency of communication with colleagues in one's group as well as outside the disciplinary group. Pelz and Andrews performed a subsequent analysis controlling for contacts initiated by others in order to rule out the possibility that frequency of communication was an effect, rather than a cause of high performance, simply because high performers may have been contacted more frequently for their advice. The relationship between performance and frequency of contact still held as they found that high performers initiated contacts with their colleagues to a greater extent than their less effective counterparts.

In efforts to improve information transfer across bureaucratic boundaries, a great deal of attention has been paid to "gatekeeper engineering" (Allen and Cohen, 1969; Tushman, 1977; Chakrabarti and O'Keefe, 1977).
Allen and Cohen (1969) hypothesized that the difficulties of translating and interpreting outside information could be surmounted by gatekeepers who maintained more extensive and long term contacts with various sources of external technical information. In order to test their hypothesis, Allen and Cohen (1969) conducted a sociometric study of two R&D laboratories. Technical professionals within each laboratory were asked to name colleagues with whom they talked to once or more per week on technical matters. Their findings revealed that a distinct communication network existed; some professionals were chosen more frequently as a source of technical information. Upon further analysis, it was shown that these 'sociometric stars' were heavy consumers of the literature, and maintained extensive, long term relationships with oral sources of external technical information. These key communicators also had their own networks, sharing information with each other. Thus, these technical gatekeepers confirmed Allen and Cohen's hypothesis that information from external environments flows through a two step process. Initially imported from the external environment by gatekeepers, it is subsequently passed on to other professionals.

As an extension of the gatekeeper concept, Tushman (1977) proposed that information transfer across intra-laboratory and intra-organizational boundaries was also facilitated by boundary spanning roles. Intra-laboratory boundary roles function to link the R&D laboratory to the larger organization in terms of interfaces with marketing, sales, and manufacturing. Further, Tushman predicted that the distribution of boundary roles within the R&D laboratory would vary as a function of the amount of work-related uncertainty.
These hypotheses were tested by employing a sociometric study in seven divisions of a large U.S. R&D facility. As hypothesized, Tushman found that sociometric stars served as key network nodes for mediating information across intra-organizational and laboratory boundaries. In addition, projects which faced substantial work related uncertainty used more boundary roles than projects with less complex information processing requirements.

Summary and Observations

The information processing approach, in contrast to the structural and cultural framework, adopts a more micro focus by tracking and identifying discrete instances of information transfer among scientist and engineers. This in someways illumines scientific processes by throwing light on considerations such as, where do scientists get their technical ideas from, scientific literature versus customers (Allen, 1977), and market potential versus technical opportunity (Baker et al., 1967; Goldhar, et al., 1976). However, the overall emphasis of the information processing approach is still prescriptions of a contextual nature. It relies on broad generalizations such as linkages to both external and internal sources of information are critical for R&D effectiveness (Myers and Marquis, 1969; Utterback, 1971; Rothwell, et al., 1974; Goldhar, et al., 1976; Allen, 1977); or emphasizes 'gatekeeper engineering' suggesting that projects with higher amounts of work related uncertainty should have more boundary roles (Tushman, 1977); and recommends ways for recognizing, rewarding, and supporting the gatekeeper role (Allen, 1977; Chakrabarti and O'Keefe, 1977).
Others have also commented on how the information processing framework falls short of examining the processes of science, or how information gets converted into knowledge. For example, Zeleny (1987) argues that "data and information are piecemeal, partial and atomized by their very nature," whereas "knowledge and wisdom are holistic...(and) integrative by definition".

By subscribing to the 'source-message-channel-receiver' model of communication, the information processing framework has relied on counting the number of communication transactions (signals) between a source and a receiver. Sociometric studies of R&D organizations performed this measurement feat, yielding measurements of information processing in terms of the volume, quantity, and patterns of information flow among organizational members. Further, based on these observations, recommendations were extended on appropriate volume, quantity, and patterns of information exchange necessary for successful innovations (Purser, 1990). Tornatsky et al., (1983) similarly observe that most research has been limited to analyses of sociometric links, which amounts to studying the residuals of "information exchange" relationships, rather than understanding the dynamics and characteristics of the innovation process. Obviously, much more transpires in R&D organizations than simply information exchange. The innovation process is essentially "a sequence of explicit or implicit decisions" (Tornatsky, et al., 1983).
Limitations of Extant Theories of Innovation - Context vs. Process

As we have observed from previous discussions, structural, cultural, and information processing theories restrict themselves to providing the social context for innovation. Organic structures, functional structures, project structures, cultures to stimulate and manage paradoxes, integrative cultures, internal versus external sources of information, and gatekeepers all indicate context and not process. This is not intended to downplay the role of context, because 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 principally contextual reasoners, and scientific knowledge is essentially socially conditioned. The context influences how they think, what they think, and what they choose to work on. A rather lengthy quote from Knorr-Cetina is reproduced below to illustrate the point.

"A close look at the research scene shows that laboratory selections are local depending both on the context of research and the concrete research situation. We see the idiosyncrasies involved in these
selections,.....I will use the term "indexicality" to refer to the situational contingency and contextual location of scientific action. This contextual location reveals that products of scientific research are fabricated and negotiated by particular agents at a particular time and place;... The opportunism I have in mind characterises a process rather than individuals. It refers to the indexicality of a mode of production from the point of view of the occasioned character of the products of research in contrast to the idea that the particularities of a given research situation are irrelevant or negligible." (emphasis added) (p. 33)

She goes on to demonstrate in specific terms how the context impacts the direction and type of research.

"....the occasioned character of research first manifests itself in the role played by local resources and facilities. For example, in the institute I observed, the existence of a large scale laboratory in which proteins could be generated, modified, and tested in large volumes was treasured as a valuable opportunity because it would be difficult or impossible to carry out certain kinds of research without such facilities. The laboratory was well equipped, well staffed, and supervised by an experienced older technician described as extremely reliable and clever. As a result, a lot of scientific energy was spent in gaining access to this laboratory in order to 'exploit' this resource. Research which required the use of this laboratory was eagerly sought or invented (emphasis mine). A newly purchased electron microscope utilising laser beams exerted a similar attraction." (p. 32)

Ideas which are less tangible than research products were also circumstantially determined. Many ideas were triggered by the resources and facilities available as well as the dynamics of interaction between the researchers. Some were the contingent result of other factors such as leadership influences.
The primacy of situational contingencies is an all pervading theme in the philosophy of science literature. It appears to be a common element across different schools of thought who may have differences of opinion as far as other issues are concerned. For example, there is an on-going debate between the cognitive philosophers of science (Giere, 1992; Tweney, 1992) and philosophers concerned with the sociology of scientific knowledge (Collins, 1983; Mulkay et al., 1983) on the very fundamentals of what is knowledge.

The sociologists, especially those from a social constructionist camp, typically deny or claim indifference to any genuine representational connection between the claims of the scientists and an independently existing world. By contrast, connections with the world are built into the cognitivist's construction of scientific knowledge. However, even the purists among the cognitive philosophers of science acknowledge the role of 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)

While an understanding of the context is indeed critical, 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. Improvising on Giere's rationale, this dictates that social models of science should be supplemented with cognitive models.

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)

An analogy will clarify the principal argument in the preceding statement. For example, focusing merely on structural, cultural, or information processing contexts is akin to trying to make a car race faster without understanding or paying attention to the workings of the engine. In a structural sense, it would be to say "let's give the car's body an aerodynamic shape so it will go faster, because I have observed that generally car's with aerodynamically shaped bodies go faster" (and thus the organic structural thesis of Burns and Stalker who observed that innovating companies were characterized by an organic structure). While this may help the car go faster up to a certain extent, just an aerodynamic body in itself cannot and will not do the job. On the other hand the car with a aerodynamic body may not go faster because of the unique interaction effects between the workings of the engine and the shape of the body, which has to be understood first to design the most effective body. In any case, it is the engine which is the principal component that generates power and hence moves the car. So while the aerodynamic
structure is certainly useful, it cannot be studied or designed in isolation of knowledge of workings of the engine.

Using the same analogy, from a culture or climate perspective, it is like suggesting that the car races fastest when the temperature is between 70 to 80 degrees Fahrenheit. Or from an information processing, information source utilization sense, the analogy would be that the car's speed is enhanced when a certain type of gasoline from a certain gas station is used. Again, while these different factors may contribute to the speed of the car and are worthy of study and analysis, they in themselves will not suffice. To really increase the effectiveness of the car, one has to understand the workings of the engine and further understand how these various contextual factors specifically interact with and affect the workings of the engine.

While the above analogy may sound rather simplistic, the key point is that to complete the circle of understanding of Research and Development and enhance its effectiveness, the workings of the "engine of innovation", namely the cognitive components of science, have to be conceptualized and examined. The cognitive reasoning and reflexive processes by which equivocal and chaotic information inputs are transformed into a codified and valued set of concrete outputs have to receive attention.

Further, to develop deeper insights into how context impacts innovation, and to move beyond such general statements as organic structures lead to higher innovativeness, we should specifically relate the contextual
factors to the workings of the "engine of innovation". Then probably, we could come with better explanations as to why and how a structural form or cultural pattern leads to innovation, or alternately does not.

The current state of theorizing in these matters is rather inadequate. To paraphrase Poole, Seibold and McPhee (1986):

"An adequate explanation must lay out the generative mechanisms whereby causes have their effects... [for example] any generative mechanism for the explanation of group activity must be tied to an account of member's (italics original) activity and interaction,...it is not satisfactory simply to assert that the decision structure, contingency factors, and the phases relate to each other." (p. 45)

It is these sort of assertions we find in statements such as looser structures lead to more idea generation and a prospector orientation results in more innovativeness.

In conclusion, a conceptualization of the cognitive components of science appears essential, something which has been commented on for sometime. For example, Weingart (1976) has remarked that cognitive sociology of science is still waiting for a "systematic (and presumably) satisfactory conceptualisation of the cognitive components of science" (p. 51). Likewise, Pasmore (1993) has commented that the next major step in enhancing the effectiveness of R&D lies in our ability to understand and facilitate the dynamics of scientific thinking.
In the next chapter we will try to locate the 'engine of innovation' by drawing on theories from the philosophy of science and the sociology of scientific knowledge to propose a conceptual framework of Research and Development as a cognitive process.
CHAPTER 3

Research and Development as a Cognitive Process - Understanding the "Engine of Innovation"

Before delving into conceptualizations of science as a cognitive process, a brief review of the major streams in the philosophy of science dealing with the nature of scientific work is appropriate.

The intent of this review is two-fold. The first is to give the reader a cursory exposure to this literature, considering that at least some of these writings might be unfamiliar to the management scholar. The second is to point out the major arguments in the field for and against an inquiry into the cognitive components of science. I felt that the latter discussion was especially warranted given the fact that it is one of the central debates in the philosophy of science literature.

Accordingly this section is divided into three parts: 1) macroscopic views of scientific knowledge; 2) emergence of microscopic views; and 3) the recent resurgence of cognitive approaches.
The Nature of Science

Increasingly over the past decades, the question "what is the nature of science?" had been asked of the philosophers of science. The fifties, sixties and the seventies saw a rapid growth in explanations about the nature of science. At that time, it appeared that the outlines of a coherent philosophical analysis of science was set out. "For a while at least, it looked as though the major obstacles to an understanding of science had yielded to philosophical analysis" (Rubinstein, Laughlin, and McManus, 1984; p. xviii).

Macroscopic Views of Scientific Knowledge

The main thrust of these early explanations centered around larger problems such as science policy, history of science, or more broadly, what is known as Science, Technology, and Society (STS) studies (Latour, 1983). Knorr-Cetina (1983) classifies this era as mainly preoccupied with 'macroscopically' oriented models of scientific knowledge.

Two representative streams of this framework include 'scientometrics' (Chubin and Restivo, 1983) and influences of the wider socio-political structure on legitimating scientific knowledge claims (Collins, 1981; 1983).

'Scientometrics' (Hargens, 1978; Chubin and Restivo, 1983) is a study of macro issues such as computing gross national product percentages, citations, and rewards and so on mainly for purposes of science policy making
and applications (Latour, 1983). This approach relies mainly on archival sources for data collection and analysis without direct observation. It includes bibliometrics (citation and productivity studies), science manpower histories, and science indicator compilations for making predictions about forthcoming trends, patterns and relationships. Examples include the annual NSF science indicator report (e.g., National Science Board, 1979) and commentaries on such reports (Elkana, et al., 1977; Zuckerman and Miller, 1980). It also covers more basic bibliometric analyses of the behavior of scientific journals (Narin, 1976), authors (Mullins, et al., 1977; Lindsey, 1978) and evaluations of whole disciplines and specialty areas within them (Chubin, 1982).

A second stream of work focuses on the relationship of the wider social and political structure to scientific knowledge. Studies under this domain demonstrate how political processes of one sort or another inform scientific views about the natural world.

For example, a study done by Collins (1981) examined the gravitational radiation controversy. The controversy involved two opposing viewpoints from different scientific camps on the existence of high fluxes of gravity waves. One party claimed the existence (of high fluxes) of gravity waves while the other denied it. Ultimately, the denying camp came victorious in the debate in terms of affecting the opinions of the scientific community and, more importantly, the funding agencies.
Collins (1981) attributes the success of this camp at least partly to their access to publicity. While scientists on one hand had to work with the minimal resources of a university science department, the other side had at their disposal the resources of a large industrial company. Thus scientists on one side of the controversy were able to make their views widely known by taking advantage of secretarial, printing, and mailing resources and through the offices of a public relation's department with a press officer. The other camp's counter-arguments were broadcast only in the conference setting and regular scientific journals.

Another political factor which impinged on the outcome, Collins speculates, was the vested interests of the industrial sector. The non-existence of high flux gravity waves would preserve the greatest body of current scientific understanding and agreements. Whereas, if the high flux hypothesis turned out to be correct, "the work of the scientific sector of industry would be thrown into chaos on many fronts. What had been previously taken to be adequate understandings of the behaviour of materials, signal processing techniques, thermo-dynamic noise etc. could (italics original) all have been thrown into doubt." (Collins, 1983; p. 97).

If this were the case, then confidence in the established way of doing things would have been shattered. Therefore Collins concludes, it is not surprising that the conservative view emerged from, and was heavily supported by the current successful elements of the industrial sector.
There are several other studies which have a similar focus on questions of ethical decision-making in science, such as disputes among experts regarding the nature of cancer causing carcinogens and acceptable levels of risk (Gillespie, et al., 1979); the role of courts in regulating risk (Bazelon, 1979; 1980; Lave and Seskin, 1979; Gori, 1980); and cancer controversies over whether the cancer rate is increasing or decreasing in the U.S. (Smith, 1980).

Emergence of Microscopic Views

Rubinstein et al. (1984) posit that this era of scientific explanation was an immaculate reflection of the views of some of the early philosophers' of science such as Reichenbach (1938) who strongly felt that; "philosophers should confine their inquiry into the nature of science to the examination of the context of justification...and leave the study of the context of discovery to others." (p. xix).

The context of justification is that portion of scientific enterprise where well-formed theoretical propositions are evaluated, whereas the context of discovery is that portion of the scientific enterprise wherein theoretical propositions are formulated (Rubinstein, et al., 1984).

As Latour (1983) concurs, many analysts of Science, Technology and Society were "proud of not entering at all into the contents of science" (Latour, 1983; p. 142). This bias originated with the early philosophers such as
Reichenbach, who argued that discovery was an inexplicable process that did not follow any logic or pattern, and therefore could not be subject to guidance (Bradshaw, 1992).

This 'removed' and 'received' view of science was challenged by the younger philosophers such as Hanson (1958) and Kuhn (1962) because it did not help or even apply to the work of practicing scientists; "In practice the behavior of scientists—even in the context of justification—did not appear to fit well the descriptive and normative offerings of the received philosophical accounts of science." (Rubinstein, et al., 1984; p. xix).

As a result of these challenges the inadequacies of this macro, removed approach towards the explanations of science came under closer scrutiny. The shift, mainly in the late seventies, eighties, and continuing in the nineties (Giere, 1992) was the move towards sensitive methodologies which could cope with the concrete course of human conduct in scientific settings, and the rejection of theorizing which is detached from close empirical study of the complexities of social action (Knorr-Cetina and Mulkay, 1983).

Generally termed as 'microscopic' approaches (Knorr-Cetina, 1983) most studies under this realm emphasize the content and processes of science and frequently stress direct observation of the actual site of scientific work in order to examine how objects of knowledge are constituted in science.
The 'microscopic' approaches towards the philosophy of science can be broadly partitioned into two distinct arenas; historical studies of science and social studies of science (Rubinstein, et al., 1984; Knorr-Cetina and Mulkay, 1983; Giere, 1992).

The historians of science have preferred to do detailed studies of a particular period of scientific work or of a particular scientist's life mainly from archival and secondary sources (Latour, 1983).

The second domain is primarily represented by the sociology of science with cognitively oriented approaches of the philosophy of science, such as cognitive sociology (Weingart, 1976), cognitive anthropology (Rubinstein, et al., 1984) and cognitive psychology (Quine, 1969; Giere, 1992) being located in the periphery.

The sociologists of science, while they may adopt different methods, such as analysis of scientific discourse (Mulkay, Potter and Yearley, 1983) or ethnomethodology (Lynch, Livingston and Garfinkel, 1983) all share a common characteristic. Most studies are systematic field investigations of the technical activities - judgements and interpretations of natural and technological scientists from a sociological perspective, or as termed by other studies, 'science in the making' (Chubin and Restivo, 1983; Knorr-Cetina and Mulkay, 1983).
While the sociology of scientific knowledge was definitely concerned with understanding the 'context of scientific discovery', a section of the sociologists' increasingly started adopting an 'epistemic relativist' approach towards the study of scientific knowledge (Knorr-Cetina and Mulkay, 1983). In essence, epistemic relativism asserts that knowledge is rooted in a particular time and culture and thus knowledge does not mimic nor replicate nature. There are no natural laws of the universe to be discovered. Thus the issue of facticity does not lie in the relation between the products of science and an external nature. All forms of knowledge are equally valid, and we cannot compare different forms of knowledge and discriminate among them.

Given this rationale, the content of cognition is a reflection of the contexts of activity within which they are situated. Thus, any evaluative distinctions between knowledge and belief is irrelevant. Realities are entirely equivalent to the way they are accounted. Thus explanation A is as valid as explanation B. Traditional scruples about addressing what is true or valid, or rationally justified, is not an issue (Barnes, 1983). Studies of science should refrain from examining the content of cognition and describe the social context within which scientific activity is situated.

Giere (1992), a cognitive philosopher of science, laments on this extreme position of the epistemic relativists:

"There are of course philosophers of science for whom the very idea of a "cognitive approach" to the philosophy of science represents a regression to the ways of thinking that were supposed to have been
decisively rejected by the early decades of the twentieth century... The idea that how people actually (italics original) think might have any relevance to the question of how they should (italics original) think was labelled "psychologism," and catalogued as an official 'fallacy'." (Giere, 1992; p. xv)

Thus while some of the earlier work was ('paradoxically' in Barnes (1983) words) inspired by the need to account for erroneous or distorted cognition, gradually the emphasis shifted towards understanding the social "basis of our own routine, 'rational' cognitive processes" (Barnes, 1983).

The general consensus was that since there is no true knowledge to be discovered, or right versus wrong cognition, social studies of science should give priority to "HOW scientists go about talking and doing science over the question WHY they act as they do" (Knorr-Cetina and Mulay, 1983: p. 7). Only in this way can there be laid down a routine basis for further work unhampered by the remnants of the earlier, "unduly individualistic habits of thought" (Barnes, 1983; p. 20).

*Cognitive Processes in Science- a Recent Resurgence*

However, since then, the cognitive approach has received a resurgence, albeit recent. For example in 1992, the Minnesota Studies in the Philosophy of Science released a special issue on "Cognitive Models of Science". The reason for the resurgence can be attributed to two factors; a sense of growing
dissatisfaction with the epistemic relativists (Woolgar, 1983) and the increasing maturity of the cognitive sciences (Giere, 1992).

_Epistemic Relativism and the Use of Irony_

Woolgar (1983) makes some interesting observations on the arguments of the epistemic relativists. He suggests that the analytical perspective which falls under the rubric of a relativist approach has achieved considerable advances in making the detailed contents of science amenable to social study. However, it has reached a stage where the social studies of science are "in danger of becoming bogged down by constructivism" (p. 239).

Woolgar's principal arguments are as follows. Every act of interpretation and explanation can be cast in terms of a perceived relationship between 'surface documents' and associated underlying realities. The constructivist's position is that explanations or accounts are not straightforward representations of external realities. It holds that there is nothing inherent in the character of real-world objects which uniquely determine accounts of those objects. Scientific explanations and accounts, theories and descriptions of the world, experimental results and interpretations of phenomena, are all undetermined by the natural world. This means that there can be alternative interpretations or accounts of the world.

Scientific explanations can be thought of as the products of social, cultural and historical circumstances (conditions which intervene between
conceptions of reality and the produced account). Thus scientific explanations are to be understood as actively constructed accounts, rather than passively received reflections of an external world, and they are to be understood in terms of the social circumstances which shape their construction.

Central to the sociologist's methodology in 'demystifying' the scientist's explanation of science is the use of irony. To practice irony is to say of something that appears one way, that it is in fact something other than it appears. To ironize an account produced by an actor is to say that his account is not an accurate account of reality; although the underlying reality appears as account A1, the ironist would wish to argue that the reality is in fact better accounted for by A2. It is these ironies which enable the constructivist sociologist to advance knowledge claims about knowledge claims.

As Woolgar states succinctly;

"In the sociology of science, this least subtle tendency is manifested in attempts to contrast what scientists say with what they (actually) do; what scientists write about their work with what (actually) goes on in the laboratory and so on.." (p. 252)

However, these alternative accounts are fraught with problems. To begin with the question to what extent is the social world regarded as a full substitute for the natural world in knowledge determination, is a debatable point; "The evidence is admittedly equivocal but adherents to the position tend to hedge their bets on the issue" (Woolgar, 1983; p. 245).
Second, and more importantly in providing the alternative account, the sociologist's purpose is to essentially undermine and discredit the achievements of science. The underlying conjecture is in the ironist's assumption, that his/her alternative account (A2) is better than the account (A1) he/she is ironizing. And, by the very implied argument that account A2 is better than A1, the ironist contradicts his/her notion of 'epistemic relativism'. A position that argues against the notion that some explanations are better than others, that there are right ways of thinking about science versus wrong ways.

The view that all forms of knowledge will be equally successful in solving a practical problem, equally adequate in explaining a puzzling phenomenon, or in general, equally acceptable to all participants, at least in the natural and physical sciences, has to be considered carefully (Latour, 1983; Charlesworth et al., 1989). There have been numerous scientific achievements and very specific explanations of their veracity.

Some philosophers of science such as Charlesworth et al. (1989) have taken a rather strong view against this sort of sociological accounting of scientific knowledge. They feel that this extreme position "leads inevitably to a form of pernicious relativism which radically devalues scientific knowledge" (p. 12). The argument that scientific knowledge is socially and culturally constructed, and therefore such knowledge is wholly relative to the particular circumstances that give it meaning would suggest that none of the findings of
science— from Boyle's law to the Crick and Watson theory of DNA have any universal or trans-cultural validity. This implies what we call 'science' is nothing more than an expression of particular, Western European culture, just as the use of oracles is an expression of the Azande culture (Evans-Pritchard, 1937), and rain making rituals are an expression of the Australian Aranda culture.

In one sense, the sociologist accounts are useful in showing that scientific products are related to or relative to a given social and cultural context. But this is a different form of relativity than the "absurd form of relativism which would deny value to the findings of science" (p. 13). So while the sociological interpretations show the relativity of science, "this does not lead to an 'anything goes' kind of relativism. "Relativity, yes: relativism, no" (p. 13).

Woolgar (1983) feels that the sociologist's active use of irony is motivated by political interests to demystify the process of science; "much ironizing of science is in trying to demystify, driven by political interests" (p. 254). For example, there is no accounting for the fact to what extent is the contrasting account more explanatory of the achievements of science. How is the contrasting explanation of the processes of science more adequate or relevant with regard to explaining a specific goal or scientific outcome is for the most part left unexplained.

As Woolgar comments on this process:
"The irony I have conceived here is called 'instrumental irony';... It acts as a tool for preconceived analytical purposes. This kind of irony is an instrument whereby alternative accounts are contrasted but where the business of accounting is passed over. Irony in this sense is not only a methodological convenience; it is a way of doing sociological analysis without attending to the difficult problems involved in description and explanation." (p. 258)

As Woolgar concludes with a telling statement on the suggested future direction of microscopic studies;

"My point is not, of course, that we should embark on a social study of science with a priori assumptions about the superiority of its methods and achievements. But, by the same token, we need to be wary of the reductionist tendencies evident in treating science in the same way as deviant behaviour, official statistics, social problems and so on. In each case, the constructivist perspective essentially derives from the analyst's (sociologist's) concerns rather than being informed by the particular phenomenon under study. This persuades me that we should now aim beyond the continual ironizing and sociologizing of science involved in using preconceived analytical perspectives; we should ask how our study of science might inform our notion of understanding...Perhaps it is time now to try and make science talk to sociology rather than the other way around... For unless, we are to be guided solely by some political motive for the 'demystification' of science, constructivism can only be a distraction from any attempt to come to terms with the fundamentals of knowledge production" (p. 262-263).

In brief, the crux of Woolgar's arguments can be summarized as pointing out the weakness of the extreme relativist position of the constructivists. A position where scientific processes have been compared to 'tinkering' (Knorr-Cetina, 1981); as driven by personal and political interests
where scientific papers are not designed to promote an understanding of alternatives but to foster the impression that what "has been done is all that could be done" (Barnes, 1983; p. 42).

This position, combined with their political interests in demystifying science, has done disservice to the achievements of science. Their perspective becomes more problematic given the fact that their alternative (and presumably superior) explanations of the 'processes of science' do not account for the outcomes or products of science (especially in successful cases). While there has been much writing about the irrational and illogical processes of scientists, by the same token successful innovations remain unaccounted for, or are glossed over (Knorr-Cetina, 1981).

Further, the relativists' claim that scientific knowledge originates in the social world rather than the natural world is highly debatable. Even the relativists' are not completely clear as to what extent the social world can be regarded as a full substitute for the natural world in knowledge determination. Thus, in some places, it is said that explanations are products of both reality and of prevalent social circumstances (Barnes, 1974). This also seems to be implication of the statement that, "It is of course self-evident that the external world exerts constraints on the conclusions of science" (Mulkay, 1979; p. 61).

In conclusion, the overemphasis on the context and social circumstances in explaining science can be viewed "as a means of deflecting
the direction of the connection between an underlying reality and a particular account" (Woolgar, 1983; p. 247).

_The increasing maturity of cognitive sciences_

The second factor which contributed to locating the centrality of cognitive processes in the studies of science has to do with the increasing maturity of the cognitive sciences. Cognitive philosophers such as Rubinstein et al. (1984) and Giere (1992) trace the early attempts of the cognitive theorists in trying to make a place for themselves in the main stream studies of science.

The legacy goes back to Kuhn's (1962) questioning of the separation of psychology from the philosophy of science. Hanson (1958) inspired mainly by Wittgenstein, had reached similar conclusions somewhat earlier. Likewise, Quine (1969), had attempted to make psychology the basis of a "naturalized epistemology" for the study of science. Similar ideas were championed in related fields by such pioneers as Donald Campbell (1959) in social psychology, and by Herbert Simon (1977) who represented economics, psychology and computer science.

Although very influential, these works did not quite succeed in making psychology a fundamental resource for the philosophy of science. One of the main reasons for the constructive attempts of Kuhn and Quine not having much impact was simply that neither of the psychological theories to which
they appealed was adequate to the task. For example, Kuhn's (1962) account of
science invoked notions from gestalt psychology and the early 'new look'
psychologists associated with Jerome Bruner (Bruner, Goodnow and Austin,
1956). Quine's (1969) foundation was behaviorism which was also extremely
limited (For a statement on how behaviorism was an inadequate foundation to
approach the dynamics of human thought, please see Dennett, 1978; Bruner,
1990; Tenkasi and Boland, 1993).

Giere (1992) argues that this situation has changed. Since the 1960s the
cognitive sciences have reached a sufficient state of maturity that they can now
provide a valuable resource for philosophers of science who are developing
general theories of science as a human cognitive activity. The cognitive
sciences are now beginning to have considerable impact on the content and
methods of philosophy, particularly the philosophy of language and the
philosophy of mind (Dennett, 1978; Fodor, 1987; Churchland, 1989) and also
are an emerging influence on the philosophy of science (Giere, 1992).

Summary and Observations

After a critical review of the philosophy of science literature and
specifically attending to the arguments for epistemic relativism, the ontological
position adopted for the purposes of this research is a marriage between
cognitive and constructivist approaches.
The primary view adopted here is that there is a correspondence between scientific explanations and understandings, and laws of the natural world that inform discovery. Thus, some explanations account for some phenomena better than others and thus there are right ways of thinking about science and wrong ways. The study of erroneous and distorted cognition and attempting to correct them is worthwhile and can contribute to the betterment of science, at least in relation to specific goals.

From a constructivist angle, the social context can play a role in influencing reasoning processes, and features of the context could account for inappropriate accounts as well as appropriate accounts in problem solving in science.
'Sciening' as Processes of Human Cognition in Scientific Activity

"Science is not merely a collection of facts and formulas. It is pre-eminently a way of dealing with experience. The word may be appropriately used as a verb; one sciences."

- Leslie A. White, 1938
"Science is Sciening."
Philosophy of Science, 5: 369-89.

In this section we will be relying principally on the expositions of cognitive philosophers of science such as Rubinstein et al. (1984), Giere (1992) and Nersessian (1992) to understand the processes of 'sciening', or those specific activities of the human cognitive system that facilitate (or alternately hamper) the invention/discovery of the products and processes of science.

Science as a cognitive process is a relatively recent conception. Though exciting and potentially significant, the literature is exploratory in nature. Most writings are restricted to conceptual arguments and propositions, and empirical evidence for the most part is still forthcoming.

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, 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.

A fundamental theme in all these approaches is that sciencing as an activity is not essentially different from the structure and operation of cognitive systems in general. "Science is but one product of the interaction of the human mind with the world and other humans" (Nersessian, 1992; p. 5). "Science extends in a specific formalized system, structures and processes that are basic to human cognition and behavior (Rubinstein et al., 1984; p. xx).

Seen in this way, the task is in major part to reveal in a systematic fashion the manner in which human cognitive systems interact with their environments and to see what implications this holds for an understanding of the specific processes of sciencing.

*The Creative Heart of Scientific Reasoning*

While the nature of specific representations are still undergoing formulation (Nersessian, 1992; Gooding, 1992; Gorman, 1992) , most cognitive theories 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; Dougherty, 1992; Kuhn, 1970; Wimsatt, 1981; Simon, 1966; 1973a; 1973b).
For example, Nersessian (1992) argues that a scientific theory is a kind of representational system. Several forms of representation have been proposed by cognitive scientists (for example Johnson-Laird's (1983) concept of 'propositional' representation or see Eysenck and Keane's (1990) distinctions between 'pictorial', 'linguistic', 'symbolic', and 'distributed representations'). However, 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. While scientific concepts may be encoded propositionally (language-like) or imagistically (pictorially), understanding them involves interpretation, i.e., constructions of a mental model of the entities or processes they represent.

Simon's (1966; 1973a; 1973b) model of scientific discovery (invention) entails the construction of a problem-solving model of a wider problem space. Confronted with a problem, people often engage in a mental search, where a series of alternatives will be considered, a plan devised and actions carried out (Bradshaw, 1992). To expand and illustrate, confronted with anomalous data such as the behavior of liquids in nature, or a specific problem such as making possible 'manned flight', the problem-solving model of discovery (invention) views scientists as engaged in a search for hypotheses, data, and laws to explain the data or the phenomenon to be realized (such as manned flight). In the case of the behavior of liquids, the initial model may incorporate everything the scientist knows 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 goal state might be
something like a law that describes the final temperature as a function of initial
temperatures, quantities, and types of liquid. The scientist then engages in a
process of confirming (or disconfirming) the model by activities such as
making new instruments, heating liquids, conducting experiments and so on
(Bradshaw, 1992).

Rubinstein et al. (1984) call this process 'scientific model building'. A
scientific model may be defined as a set of propositions that describes entities,
and relations between entities. While such models are generally modeled using
symbols or other formal sign systems, scientific model building remains the
basic function of human cognitive activity in scientific processes.

Fleck's (1979 cited in Dougherty, 1992) concept of 'thought worlds' is a
similar notion. As structures which encapsulate an individual's or a
community's 'funds of knowledge' (what they know) and 'systems of meaning'
(how they know), thought worlds embody the fundamental reasoning processes
of the individual or group.

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 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.

This 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).

For example, Weick (1979) comments on the social basis of sense making in organizations. Organizational environments are by nature highly equivocal, are composed of streams of experiences and a swarm of events. Organizational sense making involves decomposing the chaos and trying to sort "this chaos into items, events, and parts which are then connected, threaded into sequences, serially ordered, and related" (p. 148). This sense making activity entails a three stage process of enactment, selection, and retention. Enactment can be viewed as bracketing some experience from the stream to give further meaning to. Weick argues that the basis of such bracketing rests in the schemas and cognitive structures of organizational members. Selection is the process by which the enacted meaning is made sensible by producing occurrences which correspond to the enacted meaning. In other words, selection is a process of choosing information which can
validate the enacted meaning system. Retention is a process of storing the successful enacted environments.

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).

We have to differentiate between psychological reality and physical reality, the psychological plane and the physical plane (Bohm, 1977; Bateson, 1988). In contrast to the relativistic nature of the social world there is an element of realism attached to laws of the natural world. It is argued that there is a genuine representational connection between the knowledge claims of the scientist and an independently existing world (Giere, 1992).

As Rubinstein et al. (1984) clarify; "Yet there are good reasons to suppose the existence of such an objective world, a world of complex
processes in dynamic interaction, changing through time. This is clearest through example. Tiny mesobiota, nematodes are so numerous that they cover virtually all solid surfaces on earth. Overgaard-Neilsen (see Odum 1971:369) estimated their population can be so dense that between one and twenty million may live within a square meter of soil. It has been said that if everything on earth but nematodes were to vanish suddenly, we would see the outline of everything through the veneer of nematodes remaining" (p. 21).

Operational Environment and Cognized Environment

The distinction between the world composed of models within our cognition and the world that is objectively real and moldable is fundamental in an attempt to understand how we come to know what we know. For this reason we differentiate between the cognized environment and the operational environment. 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.

While the cognized environment refers to a broader and holistic concept such as the total of one's cognitive construal of the world, a cognitive structure or cognized model, is the formal organization of an aspect of the cognized environment. It is the organization of thought in relation to a specific domain. Very similar to Taylor and Crocker's (1981) general classes of social schemas, (such as person schemas, role schemas, and event schemas) there can
be different cognitive structures for different domains and can further vary in their degree of complexity, stability and adaptability.

A second level of cognitive structure which some theorists have identified is the cognized logic, while others use the broader notion of cognitive models. Cognized logic can be loosely defined as the different hypotheses or cause and effect relations predictive of the 'truth state' of a particular operational environment. A cognized logic lies in the principles of information processing of a cognized environment. "For any domain there is [presumably] only one operational logic, but potentially many cognized logics" (Rubinstein et al., 1984; p. 33). By shifting cognized logics the individual may shift the constraints in understanding the nature of the operational environment (Tart, 1975 cited in Rubinstein et al., 1984).

The construction of knowledge about the scientific operational environment is the key aspect of the cognitive modeling process in scientific inventions. Let us draw upon an example to illustrate the process. Bradshaw (1992) focuses on the much-discussed historical question concerning why the Wright brothers were more successful at solving the 'problem of manned flight' (the problem space or the operational environment) than their competitors. He locates the crucial difference in the differing heuristics (cognitive models and cognized logics) of the Wright brothers vis-a-vis their competitors.

In a rather comprehensive account, Bradshaw attempts to account for the question, why were the Wright brothers so successful in conquering the
challenge of manned flight, while so many others failed. From almost any perspective, their effort was a long shot, opines Bradshaw. Wilbur finished just high school, while Orville never did. They were bicycle mechanics, with no formal training in engineering, fluid mechanics, or physics. They had no external support but funded their research from proceeds generated during the summer months when they made, sold and repaired bicycles. Many of their contemporaries such as Dr. Samuel Langley of the Smithsonian Institution enjoyed more promising circumstances such as better training, a large staff of supporting mechanics and shop workers, and extensive funding.

Drawing on Charles Gibbs-Smith (1965), Bradshaw suggests that there were two different cognitive models in operation; 'airmen' models of flight and 'chauffeurs of the air' models of flight. Chauffeurs of the air 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. Airmen often sought to build gliders in advance of attempts to construct powered planes. Members of this tradition recognized that flying was quite different from driving a car, and needed to be understood on its own terms.

Bradshaw feels that although this distinction is apt, it is not sufficient to distinguish the Wright brothers from other unsuccessful inventors. Many others such as Otto Lilienthal, Percy Pilcher, Octave Chanute, and Sir George Cayley all developed gliders. None of these attempts was entirely successful,
while the Wright brothers invented a record-breaking glider in 1902. Their unparalleled success can be attributed to specific heuristics or the cognized logics the Wright brothers' invoked in their research.

The unsuccessful inventors of the 'airmen' tradition used a pattern which Bradshaw characterizes as 'design-space search'. The propensity here was to construct complete aircrafts that exemplified different designs 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.

To guide their search in design space, these investigators focused on two global measurements; time and distance in flight. Time and distance in flight are functions of many factors including characteristics of the design (stability, wing lift, drag) as well as factors outside experimental control (wind velocity, air turbulence). Design-space research was inefficient for two principal reasons; the design space is large and the global measurements used provided little guidance in moving through space. The global metrics of time and distance in flight were not very informative in terms of design choices. Looking at time and distance in flight was not sufficient to determine the characteristics of the aircraft. For example, this approach did not provide answers to questions such as "why did a particular configuration fly [only] two hundred feet in eight seconds?" (Bradshaw, 1992; p. 248). There could be a number of explanations such as, the wings may not have generated much lift or
may have been too flexible, the pilot's position could have caused too much drag and so on. "Without more diagnostic information concerning factors that contributed to various aspects of the craft's performance, investigators could only guess about better alternatives" (p. 248).

The Wright brothers, Bradshaw argues, used a method that can be characterized as 'function-space search'. Their major concern was how to achieve certain functions in the airplane such as lateral control, sufficient lift, a reduction in drag etc. They isolated a smaller number of these functional problems that they proceeded to solve one at a time. The pattern in their work was to explore solutions to subproblems using directed experiments. For example, a kite was built to explore lateral control and lift and thrust were solved through the use of wind tunnel experiments. Another characteristic of the Wright brothers research was the extensive testing performed on each model; "By testing the 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" (p. 246-247). Thus, only when each problem was understood and solved, did the Wright brothers invest time and energy in building a new craft. In summary, through the 'function space' concept the brothers' modeled and developed more complex understandings of the workings of aerodynamic laws. In contrast, their competitors were exploring a much larger design space with minimal understandings of aerodynamic laws, and relied on trial and error, hoping one of the models would fly, without having any conception of why.
Scientific Success as 'Adaptive Isomorphism'

As evident in the previous example, the construction of knowledge about the operational environment in the form of the cognized environment model and cognized logics is complex and open to selection. And individuals may construct models that have little or no correspondence to the 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).

In other words, for successful scientific innovations (at least in relation to specific outcomes), the cognized model should progressively become 'adaptively isomorphic' with the operational environment. The progressive realization of adaptive isomorphism is a consequence of two factors. One is the innate cognitive limits of human beings who have to progressively complexify their understandings to achieve an approximate understanding of a complex operational domain. Second is the necessity to keep pace with changes in the operational environment. Operational environments are subject to fluctuations in novelty and in the face of such shifts, 'adaptive cognitive isomorphism' is maintained by modeling the shifts themselves. This tendency has been termed 'diaphasis' by Laughlin and Brady (1978).
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). Thus the cognized environment is never more than partially isomorphic with the operational environment. For example, the relationship between signs and symbols on a road map, and towns, roads and other objects in the geographic area covered by the map is partial at best; "The road map then is only partially isomorphic with the operational environment being modeled...By extension, the entire cognized environment is at best only partially isomorphic with the operational environment." (Rubinstein et al., 1984; p. 24). Hence the cognized environment is 'adaptively isomorphic' with the operational environment when the degree of 'fit' between the cognized environment model of the operational model leads to the individual's survival and production.

Complete isomorphism is both physically and theoretically impossible and at any moment our knowledge of the operating environment and operating
structures are fallible and partial at best (Rubinstein et al., 1984). For one, there are issues of interpretation and language between the natural world and the human world. As Rubinstein et al. (1984) comment; "Of course, while there exists a correspondence between the organization of one system vis-a-vis the other, the actual elements and relations constituting each system are different. When we describe the relationship between nematodes and bacteria, the elements and relations constituting one system (our descriptions) are signs (words; numbers, and the like) and logical relations, while the elements and relations constituting the other system are organisms and biotic relations" (p. 23-24). Thus we can only in some sense match the signs and relations in the human representational system with the arrangements of organisms and biotic relations in the true world.

Second and more importantly, the state of the true world exists in an indeterminate contingency space (Knorr-Cetina, 1981). This essentially means that it is a world of complex processes in dynamic interaction changing through time. They are open systems that are continually evolving (Star, 1993). Thus, what we can hope for is an approximate understanding (Gadamer, 1975) of its true state, where at different stages we can attempt to be more or less adaptively isomorphic with the operational environment. While we may have gained an understanding at a point in time, enough to solve a particular problem that is relevant to concerns in a particular time and space, in no way can this awareness be equated with complete understanding. For example, we know that many of the problems we experiencing today are the results of prior 'solutions'-- or previous problem-solving attempts-- what professionals have
come to refer to as "iatrogenic problems". A classic example is the pesticide DDT. While solving one problem, the unforeseen side effects of DDT caused even worse environmental hazards (Purser, 1993).

However, in spite of all these limitations and constraints, successful sciencing depends on progressively bringing the cognized models of the [scientific] operational environment into the most adaptive possible alignments with the actual entities and relations within the operational environment.

*Constructing Complex Models of a Complex World*

Another implied postulate of the 'adaptive isomorphism' principle is that the more complex the operational environment, the more complex the cognitive model required. As Wimsatt (1981) emphasizes; "sciencing requires the construction of complex models of a complex world".

Rubinstein et al. (1984) stress the same point in their notion of 'cognitive zone of uncertainty'. One consequence of the partial isomorphism (or lack of complexity) of cognized models with the operational environment is the resultant disparity between individuals' abilities to experience events, with a relative inability to understand cause and effect relationships. For example, the ancient Egyptians were aware of the yearly flooding of the Nile valley, but had no direct knowledge of the cause of that flooding and consequentially attributed the annual flooding to the gods.
The need for complex models of a complex operational environment is also evident from the Wright brothers' example. These inventors were able to construct a more complex and intricate model of aerodynamic laws and their impact on manned flight which took into consideration such factors as lift, thrust, wind velocity and air turbulence. On the contrary, the unsuccessful investigators' models showed minimal understandings of aerodynamic laws (cause and effect principles) and thus were not 'adaptively isomorphic' with the natural laws of flight. They relied on trial and error processes by building complete air crafts that exemplified different designs, and then testing which one would fly. If one did fly, then they could not account for it.

*Science as Inductive-Deductive Alternation*

What are the day-to-day, basic processes in science through which scientists attempt to progressively bring their cognized models into a state of adaptive isomorphism with the operational environment. In order to understand that, we have to examine the notions of induction and deduction.

Science is a process of inquiry that progressively explores the operational environment via a (presumably) systematic alternation of deduction and induction for purposes of cognitive adaptation (Rubinstein et al., 1984; Merton, 1973; Eysenck and Keane, 1990).
Deduction is that phase of the cycle of inquiry during which the models are initially formulated 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 labelled as cognitive model 'formulation and reformulation'.

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 being either 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). Labelled the 'information input evaluation phase', this process may result in deductive model reformulation depending upon how the information is evaluated and incorporated.

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. For a visual depiction of the process see Figure 2.

There are two caveats to the model presented above. Even though the deductive-inductive distinction is often used to organize and draw distinctions
Figure 2: Science as deductive-inductive alternation

between reasoning tasks, they are not steadfast categories. Many tasks involve a mixture of both (Eysenck and Keane, 1990).

Second, the process of model construction is not as simple as depicted in figure 2. It is not a linear, straightforward or logical process; "scientific truth as actually created is not a point-by-point elegant creation" (Star, 1993; p. 97). Cognitive strategies "are not always the most streamlined. Indeed it appears they often turn out to be surprisingly clumsy and indirect" (Rubinstein et al., 1984; p. 74). Further, it is not an individual activity. On the contrary, it is profoundly influenced by the social context.

However, the lack of linearity and the influences of the social context do not suggest elements of epistemic relativism. Irrespective of whether the processes are linear or disjointed, streamlined or clumsy, individual or social, scientific success in relation to specific outcomes is ultimately dependent on being able to progressively mirror and reclaim the natural laws governing the operational universe.

**Deductive and Inductive Processes- their Basis**

By what processes are new scientific representations constructed or what is the process of model formulation in the deductive phase? Rubinstein et al. (1984) suggest that cognized environmental models are founded upon other primary model's that form the individual's (and the culture's) ontology and epistemology. Nersessian (1992) concurs in that 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.

In other words, new cognitive models are constructed using analogical reasoning based on metaphors, images, past models, hypotheses etc. It is widely recognized that analogy is the primary means through which we transfer knowledge from one domain to another. For example, Kosetler (1964) in his famous work on the act of creation suggests that deep analogies form the basis of solutions to unfamiliar problems.

Various theorists have characterized this analogical thinking as being the result of processes that map the conceptual structure of one set of ideas (called a base domain) into another set of ideas (called target domain). Technically, this is called an analogical mapping from a base domain to a target domain (Gentner, 1983; Holyoak, 1985; Keane, 1988).

Analogical reasoning can take place in the form of 'imagistic reasoning' (Kosslyn, 1980), metaphorical reasoning (Knorr-Cetina, 1981) and thought experiments (Nersessian, 1992). It has to be pointed out that these forms are conceptual classifications at best, with a considerable amount of overlap. They are all part of analogical reasoning or similarity classifications in general (Eysenck and Keane, 1990).
Imagistic reasoning is the prominence of reasoning from pictorial representations in the constructive practices of scientists attempting to articulate new conceptualizations (Kosslyn, 1980). Metaphorical reasoning is very similar, though metaphors need not be distinct pictorial representations, they can be visual words (Paivio, 1986).

According to Knorr-Cetina (1981), the metaphor theory is the dominant theory of innovation. She draws upon Nietzsche, who said the equating the unequal was the origin of all ideas. Nietzsche further went on to argue that truth itself is nothing more than a "mobile army of metaphors, metonymies, anthromorphisms" whose origins in "making equal" have been forgotten (p. 49). The essential feature of our thought is fitting new material into old schemas.

Rutherford is reputed to have used a pictorial representation of the solar system, in viewing the electrons as revolving around the nucleus in the same way that the planets revolve around the sun. Gentner (1983) explains the process of analogical transfers employed by Rutherford, specifying his base domain as the solar system and the target domain as the atom:

**Analogy 1**  
The sun attracts the planets.  
The nucleus attracts the electrons.

**Analogy 2**  
The sun is larger than the planets.  
The nucleus is larger than the electrons

**Analogy 3**  
The planets revolve around sun.  
The electrons revolve around the nucleus.
Analogy 4  The planets revolve around the sun because of the attraction and weight difference. The electrons revolve around the nucleus because of the attraction and weight difference.

Nash (1993) reports on a recent research project where man-made analogues of spider silk will be put to an astonishing variety of heavy duty uses, from reinforcing fibers in aircraft doors to ski suits. The analogical transfer for this interesting innovation in material sciences came from observing spiders called golden orb-weavers. Material sciences is trying to extend its range of products by asking fundamental questions of the workings of nature. As Nash clarifies;

"What gives spider silk its impressive array of qualities? What, for that matter lends crack resistance to horses' hooves and adhesiveness to the secretions of mussels and barnacles? ...By answering such questions, Lewis and other researchers hope to usher in an exciting new era in materials science, one based not on petroleum products like nylons and plastic but on proteins synthesized by living, growing things" (p. 58).

Thought experiments entail the construction of mental models by a scientist who imagines a sequence of events. She or he then uses a 'narrative' form to describe the sequence in order to communicate the experiment to others (Nersessian, 1992). Einstein is supposed to have performed thought experiments based on analogies about riding on a light beam and travelling in elevators (Eysenck and Keane, 1990).

Nersessian (1992) provides a very interesting example of a thought experiment used by Galileo (Galilei, 1638 cited in Nersessian, 1992) in
arguing against the Aristotelian theory that heavier bodies fall faster than lighter ones. Galileo's contention was that this belief rests on a purely qualitative analysis of the concepts of 'heaviness' and 'lightness'. The outline of his thought experiment is well illustrated by Nersessian (1992; p. 28);

"He [Galileo] calls on us to imagine we drop a heavy body and a light one, made of the same material at the same time. We would customarily say that the heavy body falls faster and the light body slower. Now suppose we tie the two bodies together with a very thin --almost immaterial--string. The combined body should both fall faster and more slowly. It should fall faster because a combined body should be heavier than two separate bodies and should fall more slowly because the slower body should retard the motion of the faster one. Clearly something has gone amiss in our understanding of 'heavier' and 'lighter'. Having pinpointed the problem area, Galileo then goes to show that it is a mistake to extrapolate from what is true at rest to what happens when bodies are in motion....He then goes on, using the methods of thought experiment...to show that the apparent difference in the speed of falling bodies is due to the effect of the medium and not to the difference in heaviness between bodies."

Induction in its essence is 'information evaluation' based on an operative action of the cognitive model on the operational environment. So it would include interpreting and evaluating inputs from the operational environment in terms of findings, anomalies, and the like. Induction should be able to facilitate the incorporation of potential material from the environment enabling the system use of novel information (Furth, 1969). Induction is a processual notion, the manner in which information is evaluated and used by individuals (Price-Williams, 1969; Kagen et al., 1978).
Induction and Deduction 'Qualified'

It should be noted that the deductive-inductive cycle is a descriptive model of the process of scientific inquiry used in constructing successful models and rejecting inadequate ones. However, being able to engage in the processes of deduction and induction themselves are not guarantors of scientific success. It is a question of whether these processes enable progressive 'complexification' of the cognitive model by facilitating 'equilibration', so that the model can attain adaptive isomorphism with the operational environment. We term this quality 'deductive-inductive complexity'.

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. A process which also implies the ability to respond to shifts and fluctuations in the novelty of the operational environment by modeling the shifts themselves (a tendency termed as diaphasis).

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.

As Rubinstein et al. (1984: p. 42) describe the necessity of and the process of complexification:
"Before concrete operational thought is reached, an individual operates on the operational environment in terms of its figural aspects and focuses particularly on one aspect of the stimulus situation at a time. Coordination between various aspects of a stimulus are lacking, limiting the individual's adaptive flexibility. One indication of this level of failure is to understand concepts that require such coordinations... The final period, formal operations, is characterized by the capacity for reasoning from propositions and constitutes genuinely abstract intelligence".

Equilibration

The fundamental mechanism of ontogenetic development or complexification is 'equilibration' (Piaget, 1977). Equilibration is the dynamic balance created when the individual 'assimilates' sensory input into the existing cognitive model, while 'accommodating' the model to the characteristics of the input. "When in balance, the assimilation-accommodation interplay allows reorganization of the internal structure of the cognized environment, thus making its modeling of the operational environment richer and more complex" (Rubinstein et al., 1984; p. 41).

In other words, for cognitive model complexification, equilibration processes are required, which results from the complementary processes of assimilation and accommodation. Assimilation occurs when an individual uses and incorporates into his/her cognitive structure information input from the environment; "Assimilation is the incorporating processes of an operative action. A taking in of environmental data" (Furth, 1969; p. 260). Accommodation is the alteration of an existing structure in such a way that it
creates a better 'fit' between the individual's cognitive structure and the operational environment.

Assimilation and accommodation are mutually interdependent processes. They are a circle. The interdependence implies that it is a process of being open to operational environment input and further gauging how this informational input relates specifically to the cognitive model deductively constructed.

Thus, inductive processes that are assimilative, and deductive processes that are accommodative in terms of being relatively open to information input and action output vis-a-vis the operational environment, result in equilibration and therefore complexification (which in turn leads to adaptive isomorphism and scientific success). We can summarily term this process as a system's deductive-inductive complexity' similar to Collins's (1983) notion of 'interpretative competence'. Breaking it down one level further we can attribute deductive-inductive complexity to the constitutive practices of deduction namely problem formulation through analogical reasoning and the quality of information evaluation.

In the Wright brothers' example, we can see elements of assimilation, accommodation, equilibration and complexification. Their cognitive model of manned 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.

On the contrary, their competitors did not exhibit complexification, nor assimilation and accommodation. They failed to understand the concepts requiring coordination, which according to Rubinstein et al. (1984) is an indication of a low level of ontogenetic development or complexification. A weak cognitive model of manned flight (especially in the case of those inventors who likened flying to driving a car) did not allow them to assimilate information from the flight tests of their gliders, and thus they could not accommodate the model based on the new information input; "Without more diagnostic information about factors that contributed to various aspects of the craft's performance, investigator's could only guess about better alternatives" (Bradshaw, 1992; p. 248).

**Scientific Innovation - the Process Summarized**

In the preceding sections we have drawn from various sources and invoked numerous terms to develop a preliminary understanding of 'sciencing' or those specific activities of the human cognitive system that are necessary to contribute to scientific success and innovation. To extend clarity, we will summarize these ideas below in the form of the following nine postulates:
1. The creative heart of scientific reasoning is a cognitive modeling process of the new problem domain to be discovered, explained or invented.

2. The attempt at creating the cognitive model is to try and construct knowledge about the workings and underlying natural laws of the scientific operational environment.

3. Gaining complete knowledge about the operational environment is impossible, since the true world exists in an indeterminate contingency space. Only approximate understandings are possible given the particular concerns of a time and place.

4. Scientific success is achieved when the cognitive model can be adaptively isomorphic with the operational environment, or the complexity of the cognitive model appropriately matches the complexity of the problem domain.

5. However, adaptive isomorphism or complexity is realized over a period of time by a process of complexification or ontogenetic development.

6. Equilibration is the fundamental mechanism that facilitates complexification and is achieved through interdependent processes of assimilative induction and accommodative deduction.

7. Deductive and inductive processes are the foundational activities by which scientists attempt to bring their cognized models into a state of adaptive isomorphism with the operational environment. Deduction is the process of cognitive model formulation and relies principally on analogical reasoning. Induction is the activity of evaluating information from the operational environment.

8. Assimilative induction is manifest in being relatively open to information input from the operational environment and accommodative deduction is gauging this information in relation to the original cognitive model and making alterations in order to achieve a better fit between the cognitive structure and the operational environment.

9. The quality and complexity of deductive (problem model conceptualization through analogical reasoning) - inductive (information evaluation) processes ultimately dictate scientific innovation since they drive equilibration, complexification, and adaptive isomorphism.
The Paradox of Complexity and Simplifications in Scientific Deductive-Inductive Action

In the previous section we related the factors that drive scientific innovations. In this section we will attend to barriers that can hamper the invention of the products and processes of science. In our estimate, the principle barrier arises from what we will term as the 'paradox of complexity' in scientific environments.

As we have mentioned previously, 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, Pasmor (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 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 judgements 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. Paradox comes out of the Latin root which denotes 'apparent contradiction' (Smith, 1987). It is the simultaneous presence of contradictory elements (Quinn and Cameron, 1988) and that can trigger a vicious circle (Hughes and Brecht, 1975). For example, this can be viewed as a pattern of, the more the demand for complexification, the more the tendency toward simplification, and the more the state of simplification, the more the demand for complexification for scientific success.

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).
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. And use of this model may constrain the functioning of the system to those simplified elements and relations.

A distinction has to be drawn here. There exists a normal level of simplification in any scientific work, or for that matter other non-routine work such as strategy formulation. These are simplifications that the scientists or decision makers are very aware of and are a result of choiceful action. Scientists must draw boundaries and exclude some kinds of artefacts and complications from consideration (Star, 1983). Such efforts might include methods to condense information. This is often accomplished through the development of a more efficient language for describing the scientists' relevant body of knowledge. For example, translating verbal descriptions to mathematical formulae can accomplish condensation (Faust, 1984). However, such choices are based on sound procedures of planning, information search and appraisal (Janis, 1989). But, the kind of cognitive simplification processes which arise in response to environmental complexity can be outside the bounds of day-to-day consciousness (Rubinstein et al., 1984), can be based on repression of complexity and uncertainty (Schwenk, 1984), can be open to but do not manifest total awareness (Count, 1974).
Relationship Between Environmental Complexity and Cognitive Functioning

One of the early research efforts examining the relationship between environmental complexity and the functioning of cognitive systems was conducted by Schroeder, Driver and Streufert (1967), who proposed the interactive complexity theory. They found an inverted U-shape relationship between the level of environmental complexity and the organism's ability to respond functionally as measured by its level of information processing capacity. Beyond an optimal point in the level of environmental complexity, organisms' regressed to lower levels of adaptive functioning in terms of their information processing capacity.

Studies by Schroeder et al. (1967) and subsequent extensions of the interactive complexity theory (for good reviews see Streufert and Streufert, 1978 and Streufert and Swezey, 1986) examined the interactive effects of environmental complexity and differences in individual cognitive complexity on decision making outcomes. However, many of these studies did not engage in specific processual descriptions of the difficulties individuals experienced when confronted with complexity. For the most part, they empirically examined how variations in environmental complexity input and level of individual cognitive complexity (independent variables) and their interactions affected decision performance (dependent variable) usually measured by a decision task.
Of more recency is a study done by Dorner (1987) who examined specifically the types of difficulties people experienced in dealing with complexity. His objective was to analyze and describe the confusions of human subjects when tackling problems in complex, non-transparent and dynamic environments. Human thinking and action in very complex areas is not easy to analyze since it drags over long periods of time and is only casuistically observable. For this purpose, he simulated on the computer the task of running a city. He defined social, psychological, economic and ecological relations of a small city and represented them as a network of relations. The city had 3,500 residents and lived mainly from a municipal industrial enterprise, a manufacturing plant producing watches. In addition, there was a city administration, doctor's practices, retail stores and shops, a bank, schools etc. There were many different measures possible. Subjects were given the task of running this town as mayor. They could influence production and sales policies of the city factory, vary rates of taxation, create employment positions etc.

He observed a series of mistakes (confusions) which almost all subjects experienced when dealing with complex systems. Some of these difficulties were:

1. Difficulties in dealing with exponential developments. People had no intuitive feeling for processes which developed exponentially even though they were surrounded by many.

2. Another general pattern was that people tended to think in causal series and not causal nets. That is, they could see
only the main effect of an action and not the side and sometimes contradictory effects which also appeared.

3. Thematic vagabonding is when subjects tend to jump from one topic or action to another, treating all of them superficially. Whenever subjects had difficulties dealing with a topic, they left it alone or came back to a comfortable topic, so that they did not have to face their helplessness more than necessary.

4. Encystment where subjects stuck to a subject matter, enclosed themselves in it, treating very small matters very fondly, and not taking on anything else. The pattern was enclosing oneself in those area's that did not seem to offer one any difficulty. These were the least problematic and unimportant areas.

5. Reduction in the number of self-reflections, in which subjects decreasingly analyzed their own past actions, rationales for such actions, and consequences of action.

6. Hypotheses formation became increasingly global when subjects reduced more and more characteristics to fewer and fewer causes. These reductive hypotheses were very attractive, says Dorner, for the simple reason that they reduced insecurity with one stroke and encouraged the feeling that things were understood.

7. An increased tendency to look for information which confirmed their hypotheses while at the same time avoiding disconfirming data.

While the above studies provide a general description of the relationship between environmental complexity and cognitive functioning, in the next section we will look specifically at the complexity factor in relation to the cognitive components of scientific work.
Complexity and Its Relation to Scientific Functioning

How does environmental complexity affect (or simplify) the processes of sciencing. In what domains of scientific activity can simplification processes be located. Our thesis is that complexity induces simplification principally with respect to the creative structures of scientific reasoning which would entail the initial formulation of cognitive models and their subsequent ontogenetic development (or complexification). And deductive-inductive action is the site for locating cognitive simplification activity.

As Rubinstein et al. (1984) have noted, under conditions of complexity the cognized environmental model can construct itself in terms of simplified cause and effect relations of the operational environment. 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). This phenomenon has been called 'schema perseverance' (Ross, 1977) or alternately the inertial quality of schema processing (Scotland and Canon, 1972).

Janis (1989) for example, has observed the phenomenon of schema perseverance in his studies of national policy making. As Janis comments; "Ideological assumptions as well as beliefs about other nations, concepts like 'the need to demonstrate resolve to protect our vital interests,' and many related cognitive schemas can be regarded as forming the policy makers 'mind-set,' functioning as a filter for information processing. Right at the beginning of their deliberations policymakers usually have recourse to schemas that embody notions about 'what will fly'- preconceptions about what actions will be appropriate and which will not be appropriate, legitimate, feasible, and acceptable to others in the organization. They immediately exclude certain alternatives and thereafter are not at all inclined to look into the supposed crippling objections to them, to find out whether judgements made at the outset were correct. As a result, the policymakers' initial beliefs and attitudes...tend to restrict their search and appraisal activities to a very limited set of alternatives, sometimes precluding ones that would be better solutions to the policy problem than any of the preferred candidates" (Janis, 1989; p. 98).
Schema (cognitive model) perseverance in light of the inherent complexity (including changes) of the operational environment, (or lack of ontogenetic development) has been implicated as a primary cause for organizational decline (Starbuck and Hedberg, 1977; Barr, Stimpert and Huff, 1992).

Some observers have identified an interesting pattern named the 'Turiel effect' (Turiel, 1966), with regards to the tendency toward distorting information as a way of maintaining the integrity of the conceptual system. Turiel (1966) in his study of the reasoning processes of children, found that the subjects had a unique way of dealing with arguments which were complex. What generally happened was that the children would reinterpret the more complex arguments in terms of their own level of cognitive organization, often drastically altering the meaning of the argument. Turiel's findings are suggestive note Rubinstein et al. (1984). Scientists tend to interpret the operational environment in terms that are constrained by their own level of intellectual-affective functioning and can drastically change the meaning to suit their cognitive organization.

In summary, the complexity induced simplification in the construction and complexification of cognitive models is attributable to non-equilibriative, maladaptive, assimilation and accommodation processes. This in turn would implicate the quality of scientific deductive-inductive processes which are the fundamental activities of assimilative and accommodative action. Thus, the principal domain of scientific activity in which simplification processes are to
be located are deductive action (model formulation and reformulation) and inductive action (information and alternatives evaluation).

In the next section, we will examine more specifically the nature of simplifications that are possible in deductive-inductive action.

*Cognitive Simplification Processes in Deductive-Inductive Action*

In this section we will be relying primarily on sources from cognitive psychology, behavioral decision making, and strategic management to identify (some) types of simplifications in deductive-inductive action. While many of these simplifications or cognitive biases (Tversky and Kahneman, 1982) have been noticed in simpler problem solving situations their applicability to scientific problem solving can be gleaned from the observed similarity between the two domains. As Nersessian (1992) observes:

"Problem solving in science differs from ordinary problem solving only in the sense that scientific problems are more complex and less well-defined and the solution is not known in advance to anyone." (p. 12)

Simon, Langley and Bradshaw (1981; p. 2) agree in their statement that:

"the component processes, which when assembled [that] make the mosaic of scientific discovery, are not qualitatively different from the processes that have been observed in simpler problem-solving situations."
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).

As we have noted before, deduction and induction are mutually interdependent activities and strict delineations are impossible. Both are needed for equilibration. 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 equilibration) by Rubinstein et al. (1984). Enduring schema perseverance (discussed previously) which rejects all sorts of information from the operational environment is an overemphasis on deduction. As Rubinstein et al. (1984) comment on this polarization:

"cognized logics [similar to cognitive structures, although they are a finer distinction that indicate multiple hypotheses about the workings of the operational environment] grounded in an empirical
examination of operational [environment] logics tend to be fully isomorphic with them than nonempirically and often normatively derived cognized logics" (p. 33)

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. For example, Charlesworth et al. (1989) conducted an anthropological study of a community of Australian scientists who were primarily involved in research on the human immune system, including the impact of AIDS on the workings of immunity mechanisms.

As Charlesworth et al. (1989; p. 148-149) comment on this proclivity;

"What impresses me more and more about a good deal of science at the Institute is the concentration on 'getting data'. Everything seems subordinated to the production or generation of data--putting the appropriate experimental apparatus in place and ensuring that it 'works'; coping with the raw materials (mice, rats, gels, blood sera); having people on hand with the right skills and techniques; establishing social networks among the scientists. Of course theories [cognitive models] have their role, but is mostly a secondary role. One of the young overseas Ph.D. students finds this obsession with data generation difficult to cope with. He had been used to a deliberately planned approach to a research problem--reading himself into the literature and thinking at some length about it before settling down to carefully thought-out experimental work at the laboratory bench. But when he arrived at the Institute, Marvell insisted that he plunge in straight away to get some data by doing experiments. 'I relate best to data', Marvell says, 'Nothing speaks like data', although of course he admits that you have to analyse and think about data. The Assistant Director puts the same kind of emphasis on the generation of data. For him science is basically doing ('looking down a microscope eight hours a day'), and thinking and reflection come after doing."
Data-driven inquiry without adequate problem conceptualization has been frequently observed in other scientific environments also. A recent study (Groenminger et al., 1993) conducted by a group of research scientists came to the same conclusion. 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" (Groenminger 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 thought 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 any clear-cut ideas on 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.

*Metaphorical Recognition versus Primary Recognition*

Knorr-Cetina (1981) argues that while metaphorical reasoning has been viewed as the primary driving force behind scientific innovations, people tend to overlook the fact that it also carries the possibility of failure:
"The metaphor theory of innovation has rediscovered the source of the new in figurative discourse, but seems to have forgotten that 'making equal' is the process of work involving force and thus carries the potential for either success or failure." (p. 49)

What could be some reasons for failure? Normally through metaphor two phenomena not usually associated with one other are perceived to have some kind of correspondence. The intimation of similarity between previously unrelated ideas allows the systems of knowledge and belief associated with each conceptual object to be brought to bear upon the other which results in a creative extension of knowledge. Famous examples of such association include Newton's analogy between projectiles and the moon ('law of universal gravitation') and Darwin's analogy between selective breeding and reproduction in nature ('law of natural selection'). Another example we discussed earlier was Rutherford's connection between the structure of the solar system and the configuration between subatomic particles ('organization of the atom').

However, metaphorical 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. Primary recognition refers to something as something; that is, "to the recognition of differential segments of our natural and social environment by identifying them in either our natural language or a professional idolect" as being one and the same (Knorr-Cetina, 1981; p. 50). Metaphorical classification is not primary recognition. Rather it
implies a degree of distance or independence between the two conceptual systems brought together by similarity classification.

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 metaphorical 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, "which means that the observed situation tends to be absorbed in the similarity class applied to it".

Metaphors classify occurrences as similar, but not actually the same. They should be seen as a form of similarity classification which involves "the greatest distance between the conceptual objects involved, since it would be absurd or false to take the proposed conjunction literally" (p. 51). However, a metaphor can become a literal interpretation over a period of time.

As Knorr-Cetina (1981) cites one such example: "Note that when Walter first heard about the enzymatic procedure, he immediately saw it as the key to solving the problem of solanine elimination, despite the fact that the procedure has been established for use with a different plant and a different toxic compound" (p. 55).
One could infer from Knorr-Cetina's statement that considerable care has to be exercised with analogical transfers. Confusing metaphorical 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.

Other studies in the social sciences have reached similar conclusions. Tenkasi et al. (1991) did a study where they compared the inferences about organizational phenomena among two groups of organizational consultants. One group framed organizations' with the metaphor 'the glass is half full' while the other group framed organizations with a contrasting metaphor 'the glass is half-empty'. Interestingly enough, in their diagnosis of the state of the
organizations, the initial framing determined whether the consultants' addressed the strengths and enabling forces of the organization or the weakness and debilitating forces of the organization.

Boland and Greenberg (1992) used a similar approach where they primed subjects to frame organizations as 'organic' entities or 'mechanistic' entities. As predicted, the inferences made about the organization were driven by whether they employed an organic or a mechanistic metaphor.

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).

Janis in his studies of policymaking found a similar effect. When a (mis) diagnosis was made, policymakers tended to draw incorrect inferences about what was at stake and they framed the ill-defined problem in a way that mislead them in the wrong direction for the solution. When that happened, they failed to request the most essential kinds of information and misinterpreted whatever cogent information they received. Faulty framing of the problem at the outset resulted in "gross miscalculations concerning the expected consequences of alternatives" (p. 121).

Schwenk (1984) argues that inadequate analogical reasoning is one of the major simplifications in problem conceptualization. Inadequate
applications of analogy involve the application of simple analogies and images
to guide problem definition. It typically entails the application of analogies
from simpler situations to complex strategic problems. For example, in
international relations the image of falling dominoes helped shape American
policy toward South-east Asia (Steinbruner, 1974).

*Other Types of Simplification 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).
Of particular relevance is an excellent summary by Schwenk (1984) of
simplification processes affecting strategy formulation for which laboratory
evidence exists and field examples can be identified. His framework looks at
simplifications in problem conceptualization and information and alternatives
generation and evaluation. However, as we have stressed before, such pure
distinctions are artificial, as deductive-inductive action is a cycle. In this and
the next section we will present some of these simplifications although we do
not stick completely to Schwenk's (1984) classification of processes that
correspond to problem conceptualization and information and alternatives
evaluation.
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, values, 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 labelled 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. Langer (1975) through a number of laboratory studies showed that subjects in decision making tasks expressed an expectancy of personal success which was higher than what objective probability would warrant. They overestimated their skill and/or the impact of their skill on making possible a successful outcome. Schwenk posits that this tendency may account for ill-fated takeovers where the acquiring company can overestimate its capacity to turn around declining companies it takes over.
Tversky and Kahneman (1974) have pointed to a cognitive process called **representativeness bias** which can result in simplistic predictions of the consequences of alternatives. It 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 solutions offered for 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). Einhorn and Hogarth (1978) have labelled this process 'overconfidence in the illusion of validity'.

Schwenk (1984) describes the example of Montgomery Ward as a case in point. Seawell Avery, as CEO of Montgomery Ward, believed that a depression was imminent at the end of World War II. He derived his belief from the fact that there had been a depression after World War I. He so strongly drew upon this past pattern that it influenced his decision to not allow Montgomery Ward to expand to meet the competition from Sears. This decision led to a permanent loss of market share to Sears.
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.

Schwenk suggests that a single vivid case of a new venture's success (or failure) in an industry might influence the decision about entering the industry when there is abundant statistical evidence suggesting high failure (or alternately success) rate for the industry.

Another type of simplification which has been researched widely is the notion of escalating commitment (Fox and Staw, 1979; Staw, 1981; Duhaime, 1981). It has been consistently found that once an individual commits significant resources to a project, he/she will tend to invest more and more in the project, despite feedback that the project is failing. One reason attributed for this pattern of escalating commitment is a sense of a personal responsibility
for the outcome of the project in spite of evidence that it is failing, and which is exacerbated by the fact that there is substantial investment already involved (Staw, 1981). Escalating commitment can also be influenced by a sense of personal control or overconfidence in prediction.

A good example of escalating commitment, Staw (1981) argues, are the decisions of various American presidential administrations on successive escalations of conflict in the Vietnam war. Once the United States committed a large number of troops and heavy casualties were sustained, a process of escalating commitment was started which was very difficult to reverse.

*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, as the previous section would reveal, a lot of the simplifications included there have to do with processes of information evaluation. Deduction and induction are interdependent, iterative, and cyclical.

Adjustment and anchoring is a simplification proposed by Tversky and Kahneman (1974) and is similar to single or prior hypothesis bias, but has to do with information evaluation. Individuals often have to make initial judgements (understandings) about values of variables and are expected to revise these judgements as new data comes in. However, when this simplification is in operation, the adjustments are insufficient and final
estimates of values are biased towards the initial values. That is, decision
makers, while they may attend to negative information about the success of the
present strategy they may not make full use of it or may actually disregard this
information in regard to their initial estimates. Further, they may seek and use
information consistent with these initial estimates and reject disconfirming
information 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.

An example provided by Schwenk is illustrative. Convair company
started development of their 880 craft in the late fifties and early sixties. While
the aircraft was in the designing and testing stage, the sales and profit forecasts
were optimistic. However, subsequent events such as the backing of potential
buyers from purchase commitments seemed to suggest a need to revise the
initial forecasts. But they were not heeded; reports indicating high cost
overruns were not paid attention to. On the contrary, the earlier profit forecasts
were exemplified by the company top executives in their assertion that the 880
aircraft was potentially one of their most successful ventures.

Bolstering or magnifying the attractiveness of preferred alternatives is a
tendency initially noted by Festinger (1956). Steinbruner (1974) who draws on
Festinger, argues that contrary to normative models of decision making,
uncertainty is often not resolved by probabilistic calculations of the outcomes
of alternatives. Frequently, favorable outcomes are inferred at the outset for preferred alternatives while unfavorable outcomes are projected for non-preferred alternatives. In essence, when making decisions under uncertainty, it is usually a process of settling on a single-valued problem and a single preferred alternative to which the decision maker is committed from the outset of the decision process (Steinbruner, 1974).

In a series of laboratory experiments Festinger (1956) demonstrated that one way of promoting a preferred alternative 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 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 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. 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.

Schwenk (1984) brings in the example of the DeLorean K-car proposal to illustrate this simplification. According to John DeLorean, GM corporate management demanded inordinate amounts of documentation on project proposals before accepting them. When he made a proposal for the K-car to the board, they made demands for more thorough information and finally shelved the project in late 1970. Schwenk argues that one reason why DeLorean's K-car proposal was not accepted was because it was less well documented in terms of completeness of information compared to some other proposals. The result was that GM was unable to supply the light, fuel-efficient cars American consumers demanded after the oil embargo in 1973.
Figure 3 summarizes the various types of simplification processes that can impact deductive-inductive action.
Figure 3: Cognitive Simplification Processes in Deductive and Inductive Action

**Deduction**
- Inappropriate analogical reasoning
- Prior hypothesis bias
- Problem set
- Single outcome calculation
- Illusion of one's personal control
- Illusion of another's personal control
- Representativeness bias
- Illusion of prediction
- Escalating commitment

**Induction**
- Adjustment and anchoring
- Bolstering a preferred alternative
- Inferences of impossibility
- Denying value trade-offs
- Devaluation of partially described alternatives
Consequences of Cognitive Simplification Processes

What are the consequences of cognitive simplification processes? From the many illustrations listed in the previous section we can surmise that they can contribute to poor outcomes. Tversky and Kahneman (1982) suggest that the cognitive biases which come into play in simplifying uncertainty can lead to negative consequences such as poor and faulty decisions. In the next two sections we will review some general evidence relating simplification to outcomes, and also evidence bearing on the connection between simplification and unsuccessful scientific outcomes.

Cognitive Simplification Processes and Decision Outcomes

There is some indirect evidence from a number of studies suggesting a relationship between defective cognitive procedures and favorableness of outcomes (Janis, 1989). However, one of the few systematic studies which established a direct relationship between cognitive simplification processes and quality of decision outcomes was conducted by Herek, Janis and Huth (1987). In their comparative case-study research on foreign policy decisions made by United States presidents and their advisors during major international crises, Herek et al., investigated the presence or absence of what they term as symptoms of defective decision making and the nature of decision outcomes in terms of whether the outcomes were favorable or unfavorable.

As they clarify:
"The main purpose of the study was to determine the extent to which favorable outcomes in international crises affecting the United States are related to the quality of policymaking by the nation's leaders. In order to investigate the relationship between quality of decision making processes and outcome of policy decisions, we assessed the U.S. government's management of each of 19 international crises by making detailed ratings of the presence or absence of each of the seven symptoms of defective policymaking." (Janis, 1989; p. 123).

The seven symptoms of defective decision making (or otherwise simplistic cognitive decision rules) identified by Janis (1989; p. 32) are:

1. **Gross omissions in surveying objectives**: A group subject to this cognitive constraint never explicitly discusses objectives, or gives objectives a brief or cursory consideration. As a result, actors fail to specify some of the major requirements for a satisfactory choice that takes into account important goals or values implicated by the policy problem. In other words it is inadequate problem domain conceptualization.

2. **Gross omissions in surveying alternatives**: The group neglects to consider a number of viable alternative policies, limiting its discussions to only one alternative. If any of the additional alternatives are mentioned at all, they are immediately excluded or dropped without discussion.

3. **Poor information search**: The group fails to obtain available information necessary for critically evaluating pros and cons of the preferred course of action and other alternatives. If it does engage in any information search at all, the group does so in a perfunctory and incomplete manner. As a result, it fails to obtain a number of important pieces of information that would have been available if requested from experts and other appropriate persons inside and outside the organization.

4. **Selective bias in processing information at hand**: This is a tendency to accept new information from various sources such as intelligence reports, experts and critics only when it supports the preferred alternative. The group generally
ignores or refutes a number of important pieces of non supporting information to which they are exposed.

5. **Failure to reconsider originally rejected alternatives**: The group fails to reexamine the consequences of previously considered alternatives, or reexamines rejected alternatives in a biased manner by discounting favorable information about the rejected alternatives and giving disproportionate weight to their negative consequences.

6. **Failure to examine major costs and risks of the preferred choice**: This is a failure to consider the negative consequences of the preferred alternative, or examine them incompletely that a number of important consequences are overlooked even though information about these consequences are available.

7. **Failure to work out detailed implementation, monitoring, and contingency plans**: The group neglects to take into account possible problems in implementation and does not develop monitoring or contingency plans. If the group does discuss implementation, monitoring and contingency plans, it does so in a vague or incomplete manner that a number of important difficulties or contingencies that are likely to materialize are overlooked.

The study by Herek, Janis and Huth (1987) involved four steps. First, on the basis of independent ratings by three outside experts on international conflicts, a sample of 19 major crises since World War II was selected. Some crises included in the sample were Greek civil war (1947), Cuban missile crisis (1962), Invasion of South Korea (1950), Vietnam Air war (1964-65), and Indo-Pakistani war (1971).

Second, bibliographic sources describing the decision making process in each crisis was collected and the adequacy of these sources as representative of decision making data was rated. Memoirs and biographies were excluded since they were likely to include biased accounts. Instead, scholarly accounts
by political scientists and historians analyzing the decision making process were considered.

Third, the source materials judged to be of high quality were employed to score the decision making procedures during each crisis in terms of the seven symptoms of defective decision making. Finally, two outside experts who remained blind to the hypothesis of the study independently rated the crisis outcomes as either favorable or unfavorable.

For rating the quality of decision making processes during each crisis, detailed definitions together with coding instructions were developed. The coding scheme was used for ascertaining whether or not each of the seven symptoms of defective decision making were present or absent. After the coding was completed, each crisis was assigned a composite score for use of simplistic cognitive decision rules. This score consisted of the total number of symptoms present in the policymaking process during handling of the crisis.

Considerable variability was evidenced in the quality of the policy making processes. Eight crises (42%) were characterized by high-quality cognitive strategies, four crises (21%) displayed two or three symptoms and were classified as entailing medium quality decision making processes. Seven crises (37%) which showed more than four symptoms were categorized as involving poor quality cognitive decision rules.
To examine the main hypotheses of the study, namely whether poor quality cognitive strategies are predictive of unfavorable outcomes, ratings of the outcome of each crisis were obtained from two experts who had conducted extensive research on international crises and were blind to the hypotheses. Further, these experts represented opposite ends of the conservative-liberal continuum in their views about the cold war. Ratings on two criteria were obtained from the experts. First, they rated each crisis outcome’s effect on U.S. vital interest in terms of whether they were advanced, hindered, or unaffected during the days and weeks following the crisis. Second, the experts rated the level of international conflict during the period following the end of the crisis, in terms of whether there was an increase, decrease, or no change in tension, stability, hostility or the likelihood of war between the United States and the Soviet Union or China. The two experts' ratings were combined to yield a score of -1 if both agreed that the crisis outcome was negative, +1 if both agreed that it was not negative, and 0 if they disagreed. Such scores were computed for both the measures.

The results are displayed in Table 1 and Table 2 (which is a graphical display of the relationship between process and outcomes). As predicted, a strong relationship between use of poor quality cognitive decision rules and unfavorable outcomes was found. Correlational data showed that the higher symptom scores were significantly related to more unfavorable outcomes for U.S. vital interests ($r=0.64$, $P<.002$), and to more unfavorable outcomes for international conflict ($r=0.62$, $P<.002$). The results clearly indicated that when
Table 1: Symptoms of defective cognitive procedures in international crises.*

<table>
<thead>
<tr>
<th>Crisis</th>
<th>Quality of Process</th>
<th>Total Symptoms of Defective Policymaking</th>
<th>Intraservice Conflict</th>
<th>U.S. Interests</th>
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<tr>
<td>Indochina (1954)</td>
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<td>Quemoy-Matsu II (1958)</td>
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<td>Laos (1961)</td>
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<td>Greek Civil War (1947)</td>
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<td>Quemoy-Matsu I (1954-51)</td>
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<td>Berlin Wall (1961)</td>
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<td>Cuban Missile Crisis (1962)</td>
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<td>Yom Kippur War (1973)</td>
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<td>Invasion of South Korea (1950)</td>
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<td>Suez War (1956)</td>
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<td>Jordan Civil War (1970)</td>
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<td>Berlin Blockade (1948-49)</td>
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<td>Tonkin Gulf Incidents (1964)</td>
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<td>Vietnam Ground War (1965)</td>
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<td>Vietnam Air War (1964-65)</td>
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<td>Arab-Israeli War (1967)</td>
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<td>Cambodian Incursions (1970)</td>
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<td>Korean War Escalation (1950)</td>
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<td>Indo-Pakistan War (1971)</td>
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Table 2: Relationship between quality of decision process and outcomes.*

- **High-Quality Process (n = 8)**
  - 75% **INTERNATIONAL CONFLICT**
  - 25% **U.S. INTERESTS**

- **Medium-Quality Process (n = 4)**
  - 50% **INTERNATIONAL CONFLICT**
  - 25% **U.S. INTERESTS**

- **Low-Quality Process (n = 7)**
  - 43% **INTERNATIONAL CONFLICT**
  - 57% **U.S. INTERESTS**

**KEY:**
- EXPERT AGREEMENT: NON-NEGATIVE OUTCOME
- EXPERT DISAGREEMENT
- EXPERT AGREEMENT: NEGATIVE OUTCOME

defective cognitive procedures were used, the crisis outcomes tended to have more adverse effects on U.S. interests and were more likely to increase international conflict.

*Cognitive Simplification Processes and Relationship to Scientific Success*

As in the case of policy formulation we can expect a relationship between the quality of cognitive strategies and scientific outcomes. New product development has been likened to policy and strategy formulation since both activities are characterized by uncertainty (Moenaert and Souder, 1990; Souder, 1987) novelty, complexity and open-endedness (Mintzberg et al., 1976).

Our premise is that in the case of scientific enterprise, the prevalence of cognitive simplification processes could result in *delays* as well as *unsuccessful scientific outcomes*. As we observed in the Bausch and Lomb experience (Groenminger et al., 1993), one of the major contributory factors behind a high incidence of rework (delays) was inadequate problem conceptualization including not paying enough attention to principles of experimental design and control. Purser (1990) has also noted the relationship between poor problem conceptualization and delays in product development cycle time.

While there appears to be no study specifically linking the quality of cognitive activities to scientific outcomes, indirect evidence on this
relationship can be gleaned from various examples. For instance, poor cognitive strategies can be implicated on the part of the unsuccessful innovators in the Wright brothers' case.

A rather vivid case example of scientific failure and development delays which well illustrates cognitive simplification processes in operation, is provided by Knorr-Cetina (1981). While Knorr-Cetina uses this example to suggest the 'tinkering' nature of science and scientists, a close examination of the case reveals a number of simplification strategies covered in the previous sections.

By characterizing scientists as 'tinkerers', Knorr-Cetina essentially proposes that scientists do not work in any systematic fashion. As she clarifies; "...a tinkerer does not know what he is going to produce but uses whatever he finds around him...to produce some kind of workable object. What he ultimately produces, is generally related to no special project, and it results from a series of contingent events, of all the opportunities he had- often, without any well-defined long-term project, the tinkerer gives his material unexpected functions to produce a new object" (p. 34). However, the same example can be interpreted as also conveying an instance of scientists using poor quality cognitive decision rules in trying to achieve their research objectives.
A case example of development delays and scientific failure arising from cognitive simplification processes (Adapted from Knorr-Cetina, 1983; p. 63-64)

The problem was one of precipitating (isolating) protein from waste water. The first reagent chosen was Phosphoric acid because the method's efficacy to precipitate protein had just been published and documented in a biochemical context. Further, the major author and originator of the method in the biochemical context was also part of the research center.

However, it was known the previous biochemical context did not really match the new situation since:

1. The experiments had to be conducted under Nitrogen which was difficult in the large scale laboratory needed to generate large quantities of protein
2. Another paper suggested Phosphoric acid had toxic side effects
3. The method could prove very expensive on a large scale

However the method was pursued for quite some time until one scientist happened to read about "ferric chloride", which "immediately" struck him as a "better idea" (p. 64).

Very soon phosphoric acid was replaced by Ferric chloride and it was made to work in subsequent experiments. The resulting proteins were highly
soluble, which was a highly desirable property. A paper was quickly published dedicated to the promotion of the method.

However this initial success was threatened as long as the protein could not be adequately purified. The task was now to find a means of purification.

One idea was suggested in a somewhat ad hoc fashion when, on the eve of a large scale experiment, it was discovered that the laboratory had run out of the planned adsorbing agent (a chemical which absorbs impurities).

In the somewhat nervous discussion which followed, one researcher suggested an adsorbent which had worked on his previous research on proteins. The other scientists did not seem intrigued with the idea expecting that it would be difficult to remove this adsorbent from the protein.

However once they got started attempts to purify the protein with this adsorbent agent went on for several months. At one point the results were described as positive. However this success was short-lived. After they looked at the results of the chemical composition tests, the scientists qualified it as an artifact. Shortly thereafter the attempt to work with this adsorbent agent was abandoned altogether.
Observations

While in one sense this example reveals scientific activity as a process of tinkering, one could also infer a number of cognitive simplification processes in operation. In fact, the notion of tinkering itself could be equated with a simplified approach towards doing science.

For instance, the choice of phosphoric acid can be viewed as an inappropriate analogy consciously applied to a dissimilar context. It was clear right from the outset that the previous biochemical context did not match the new situation. One could also infer that there was a certain element of an illusion of personal control, since the originator of the method which was successful in the biochemical context was also part of the research team. Further, there appears to be a tendency to downplay certain costs associated with the chosen reagent phosphoric acid, namely not considering evidence from the paper that suggested phosphoric acid had toxic side effects.

The decision to switch to Ferric chloride also shows elements of simplification. It suggests a tendency to oversimplify the problem and focus on the first and single alternative which came into view. Further, it conveys the use of a favored information source.

The decision to use the adsorbent agent also came about in an adhoc fashion. There was not much examination of the cost trade-offs of this alternative even though many of the scientists were not intrigued with the idea,
expecting that it would be difficult to remove the adsorbent from the protein. The fact that attempts to purify the protein with the adsorbent agent went on for several months once they got started, suggests a pattern of escalating commitment.

Overall, one could infer that the problem domain was not effectively defined. While the problem was understood as one of precipitating protein from waste water, beyond that there does not seem to a deeper conceptualization of the issues involved. Methods and substances were chosen on an adhoc fashion without much informed reasoning. The principal rationale was one of trial and error, where materials and methods were arbitrarily chosen and tested if they worked or not. Further, the scientists seem to be engaging in this simplification process rather automatically without really being conscious about it.

_The Relationship Between Cognitive Simplification Processes and (Product) Development Delays_

While it seems obvious that one of the highest leverage points in organizations for shortening product development cycle time would be to minimize delays (Stata, 1989), there is a paucity of research on the topic (Tenkasi and Purser, 1992). Product development delays have been a relatively recent area of investigation.
Therefore, in order to develop an understanding of the nature of delays, both the extant literature on strategic decision making and the burgeoning writings on new product development delays come in useful. Strategic decision making, particularly unstructured decision processes, closely parallel the product development process given the similarity between both domains in terms of being characterized by conditions of high technical, organizational and market uncertainty (Moenaert and Souder, 1990; Souder, 1987; Emmanuelides, 1991). A brief review of the literature pertaining to delays is presented below.

In their examination of one hundred and fifty strategic decisions, Hickson, Butler, Cray, Mallory and Wilson (1986) found nine types of delays which impeded decision making processes: 1) sequencing delays; 2) coordinating delays; 3) timing delays; 4) searching delays; 5) problem-solving delays; 6) supplying/ resource delays; 7) recycling delays; 8) internal resistance delays; and 9) external resistance delays. Of the nine impediments, the most frequently occurring delays were found to be the result of unsolved problems resulting from a poorly defined search for information and considering alternatives.

Mintzberg, Raisinghani and Theoret (1976), in their examination of twenty-five unstructured decision processes recorded six major delays which constrained development. One set of delays they observed were what they classified as 'external interrupts' (or delays) in responding to changes in the task environment. Stalk and Hout (1990) observed similar delays in
responding to new options introduced by senior managers in the product, which they referred to as 'feature creeps'. 'Internal interrupts' (Mintzberg et al., 1976) were delays to the product development process, either because of new options being introduced late in the development process or because of political impasses.

'Timing delays' were a second set of disturbances noticed by Mintzberg et al., (1976). These delays involved incidences when the development process was intentionally slowed down by decision makers or involved delays in responding to unrealistic time schedules. 'Scheduling delays', a third type of disturbance, occurred when tasks could not be performed because they were waiting in sequence. Developers were waiting in queue to get a work request approved. 'Feedback delays' amounted to waiting for results of previous work steps. In the most complex and novel decision situations, a fifth set of disturbances- 'comprehension cycle delays' -- were observed to have occurred with the greatest frequency. The development process was stalled as decision makers recycled back to earlier stages in order to more fully comprehend technology and design issues.

Gupta and Wilemon (1990) based on interviews of 38 managers and technologists involved in new product development projects across 12 technology based firms, identified several types of delays. Similar to comprehension cycle delays, they observed that most product development delays arose from poor definition of product requirements, which can be attributed to cognitive simplification processes.
Other major delays included, delays arising from unwillingness to accept that prior solutions were sub-optimal, delays in trying to obtain senior management support, delays in assembling sufficient resources, and delays from poor project management.

There have been direct observations in the literature implicating defective cognitive processes as a major source for delays. For example, Mintzberg et al., (1976) have noted that in complex decisions the choice situation is subject to distortion due to cognitive limits and unintended biases. Further, adoption of higher aspiration levels in terms of fast cycle goals can inadvertently reduce the need to search for information and evaluate alternatives (Hogarth, 1987). Purser and Pasmore (1992), in a similar vein, contend that cognitive biases and faulty decision heuristics can potentially lead to bottlenecks and mistakes in the knowledge conversion process.

In contrasting the 'variety amplification' abilities of Japanese product development teams to those in the United States which are biased towards action and 'variety reduction', Imai, Takeuchi and Nonaka conclude that a 'bias for action' which results in premature convergence on the first available alternative can have consequences both in terms of delays and product development success.
In summary, there has been a uniform call for exploring the impact of cognitive processing limitations on product development delays, although no specific empirical studies examining the relationship have been documented.

Cognitive Simplification Processes - the Ideas Summarized

In the preceding sections we have explored the notion of cognitive simplification processes in some detail. Below we have summarized the main ideas presented previously, in the form of these eight postulates.

1. One principle barrier which can hamper the invention of the products and processes of science are cognitive simplification processes in scientific work.

2. Cognitive simplification in scientific enterprise is a result of the 'paradox of complexity' of scientific environments. While at one level successful sciencing demands 'the construction of complex models of a complex world', at another level the imposition of complexification results in a tendency towards simplification.

3. The tendency towards simplification is driven by the innate human cognitive limitations in dealing with complexity. Under conditions of uncertainty, actors can repress awareness of the uncertainty and act on a simplified model of reality that they construct.

4. Cognitive simplification processes which arise in response to environmental complexity can operate outside the bounds of day-to-day consciousness.

5. Environmental complexity induces simplification principally with respect to the creative structures of scientific reasoning which would entail the initial formulation of cognitive models and their subsequent ontogenetic development or complexification.

6. The primary domain of scientific activity in which simplification processes are to be located are deductive
action (model formulation and reformulation) and inductive action (information and alternatives evaluation).

7. Inadequate analogical reasoning is one of the major simplifications in scientific model formulation or deductive action. Selectively evaluating alternatives is a primary simplification in inductive action.

8. In the case of scientific enterprise, the prevalence of cognitive simplification processes could result in development delays as well as unsuccessful scientific outcomes.

In the early sections, we had discussed rather extensively the importance of socio-structural 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 development of a cognitively based understanding of scientific innovation. 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.

We took recourse in the ideas of cognitive philosophers such as Giere (1992), who emphasized that cognitive activities of scientists are embedded in a social fabric. Thus 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 scientific reasoning processes. In other words, we can view the contextual features as *antecedent conditions or 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 contextual environment.

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 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.

Blackburn (1971: p. 1007), a noted philosopher of science, has also spoken of the relationship between complexity of the perceiving system and scientific success;

"What is urgently needed is a science [scientist] that can comprehend complex systems without, or with a minimum of abstractions. To "see" a complex system as an organic whole requires an act of trained intuition, just as seeing order in a welter of numerical data does..The intuitive knowledge essential to a full understanding of
complex systems can be encouraged and prepared for
by: (i) training scientists to be aware of sensuous clues
of their surroundings; (ii) insisting upon sensuous
knowledge as part of the intellectual structure of
science; and (iii) approaching complex systems openly,
respecting their organic complexity before choosing an
abstract quantification space into which to project
them."

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).

Conceptual structures of differing complexity have different modes of
information interpretation. 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 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 logics 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] judgements 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 lower level of cognitive simplification processes in their various work activities.

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 antecedentary conditions or variables influencing the quality of cognitive processes in scientific environments (This would be in contrast to other approaches for measuring the differentiative/integrative capacity of conceptual systems; for a review see Streufert and Swezey, 1986).

This explanation also provides 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 simplification (or alternately cognitive complexification) processes.
In summary then, one approach for understanding the relationship between context and cognitive activities lies in comprehending the extent to which varied features of the context can be expected to show a relationship to the occurrence of cognitive simplification processes in the actions of a conceptual system. Thus one can posit that the presence, absence or varying levels of these contextual features will show a relationship to the absence, presence or varying levels of cognitive simplification processes in the actions of the conceptual system. (We may infer that the absence or minimal incidence of cognitive simplification processes can suggest cognitive complexification).

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 'whole' 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 some specific contextual variables which have been implicated as potentially impacting the quality of cognitive activities in various task domains.

**Group Deliberative Norms**

Janis (1989) suggests that one observable antecedent 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, the lower the level of cognitive simplification processes._

**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' (which can be equated to cognitive modes and styles) 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:

"Little attention has been paid in social science research to discern when policymakers' faulty assumptions and other conceptual errors are likely to be corrected and when they are likely to persist unchanged. One variable that appears to be relevant is the degree to which the leaders in a policymaking group share essentially the same views of rival and allies, the same operational code and beliefs, and the same ideological attitudes....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.

Pasmore (1990) has differentiated between four types of cognitive modes of engagement in scientific and other non-routine work task situations. His theoretical premise is that all modes are required for effective scientific work. There has to be an adequate balance of the four cognitive modes - analytical, intuitive, active, and reflective for scientific success.

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 cognitive simplification processes in scientific work.
Shared Language

Knowledge linkages 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 (or the lower the perceived level of language barriers) in a scientific work system, the lower the level of cognitive simplification processes evidenced.

Leadership Practices

Streufert and Switzey (1986) discuss leadership practices as one source of organizational complexity. Differentiative and 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 project leadership is
at providing fresh approaches to problems, acting as a sounding board for
new ideas, recognizing and mediating conflicts and possessing a good
conceptual understanding of member work, the lower the level of cognitive
simplification processes.

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, the lower the frequency of cognitive simplification processes in scientific enterprise.
Knowledge Linkages

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 linkages 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 linkages more specific in terms of relating these information processing patterns to requisite complexity for innovation in the form of optimal absorptive capacity.

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 linkages 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, the lower the level of cognitive simplification processes.

Perceived Pressure

Janis (1989) posits that different types of perceived social pressures can contribute to simplified cognitive processes. Pressures in the form of role demands, time pressures from schedules, and pressures in the form of lack of resources for information search and appraisal have all been attributed as impacting the quality of decision making.

Thus, we can surmise that the higher the level perceived pressures in the work environment, the higher the level of cognitive simplification processes in scientific enterprises.
Overall Summary

Before proceeding ahead with the description of the research site and detailing the specific research questions investigated, a brief recapitulation of the information presented thus far seems in order.

We started with the observation that my interest in the topic of this dissertation was piqued when we analyzed some cases of scientific failure in a Research and Development organization. The retrospective analysis suggested that many of the scientific failures appeared to result from defective scientific reasoning processes. In an attempt to make sense of this phenomenon we resorted to the existing management literature on innovation. However, they appeared inadequate to explain the phenomena at hand which seemed to be rooted in the cognitive processes of the scientists.

We realized that while common sense may dictate that research and development is an intensely cognitive activity, the management literature suffered from a lack of an adequate conceptualization of the cognitive components of science. A review of the predominant theories of innovation appearing in the management domain showed that the focus was only on the context of innovation. The emphasis on context suggested a need for attempting to develop a cognitively based understanding of science (partly to explain the phenomena at hand and partly to enhance our understanding of science), and further comprehend the nature of relationship between context and cognition. For this we resorted to the philosophy of science literature.
However, before delving into a description of the cognitive components of science, a general review of the writings in the philosophy of science was extended. We also attended to the contentions of the epistemic relativists who argue that all forms of knowledge are equally valid and contextually based, thus there is no erroneous cognition to be studied or changed. We adopted the primary view that there is a correspondence between scientific explanations and understandings, and laws of the natural world that inform discovery. Thus, some explanations account for some phenomena better than others and therefore there are right ways of thinking about science and wrong ways. The study of erroneous cognition and attempting to correct them is worthwhile and can contribute to the betterment of science, at least in relation to specific goals. From a constructivist angle, the social context can play a role in influencing scientific cognition and reasoning processes.

The aforementioned discussion set the background for the next section, where based on integration of disparate streams of writings we proposed a cognitively based understanding of the scientific process. We suggested that the creative heart of scientific reasoning is a cognitive modeling process of the new problem domain to be explained, discovered or invented. The attempt at creating the cognitive model is to try and construct knowledge about the workings and underlying laws of the scientific operational environment. Scientific success is achieved when the cognized model of the operational environment attains the most adaptive possible alignments with the actual entities and relations in the operational environment.
The day-to-day, basic interdependent processes in science through which scientists attempt to progressively bring their cognized models into a state of adaptive isomorphism with the operational environment is deductive and inductive action. Deduction can be roughly equated with cognitive model formulation and reformulation, while induction is the phase of inquiry during which information pertaining to the operational environment is collected and evaluated. Ultimately, the quality and complexity of deductive and inductive processes dictate the success of scientific innovation.

We then suggested that the quality and complexity of deductive and inductive action can be influenced by the inherent complexity of scientific work, leading to simplifications in these foundational processes (the 'paradox of complexity'). Types of simplifications were elaborated upon and we proposed that such simplifications can adversely impact scientific success as well as contribute to delays. Finally, we suggested that the relationship of context to cognition has to be viewed in terms of whether the context facilitates a conceptual system in attaining the 'optimal level of complexity' required for scientific success and posited that features of the social context can influence cognitive simplification [or alternately complexification] processes. Drawing from the literature we identified some potential contextually based antecedents of cognitive simplification processes.

Now that we have a preliminary theoretical framework to work from, in the next chapter we will focus on applying this conceptual framework
towards explaining the patterns observed in our retrospective analysis of drug
development projects. In essence, the framework provides us with a 'language'
to give meaning to and describe some patterns of activity and allows us to
locate specific types of simplifications. After a brief description of the
methodological framing and research site, we will present two case studies of
unsuccessful drug development efforts and attend to some cognitive
simplification processes which affected deductive and inductive action in these
projects.
Chapter 4

A Retrospective Analysis of Two Case Studies

The overall methodological framing of this chapter is one of grounded theory building (Glaser and Strauss, 1967; Martin and Turner, 1986). As had been alluded to earlier, grounded theory building approaches inquiry with a fairly open stance as to the kind of general theoretical account to emerge from a particular investigation. It is a process of discovering explanations from qualitative data gathered from observations, interviews, case study materials and other documentary sources.

The central strategy behind this approach is movement from data to concept. Concept discovery refers to the strategic process of moving from data to abstract categories. As Martin and Turner (1986: p. 147) clarify: "Movement from data to concept is appropriately viewed as a movement across levels of abstraction...The researcher seeks to discover (identify) a slightly higher level of abstraction--higher than the data themselves--that allows the application of a name to the action or object observed or referred to".

A common source for giving meaning to the incidents observed is to draw upon the extant literature. The integration of theory with the literature is required prior to completion of the theory's formulation (Glaser and Strauss, 1967: Turner, 1981).
When encountered with data from our initial inquiry of five different drug development projects, the grounded theory building approach came in useful to provide plausible explanations for unsuccessful outcomes as well as the delays experienced in these projects.

In the subsequent sections a description of the research context and an analysis of two select case studies will be extended.
Research Context

The site of the study was the research and development center of a major Fortune 100 corporation. The center specializes in upstream pharmaceutical research which is primarily the discovery, testing, and validation of new drugs. It employs approximately 200 employees with over fifty percent of the scientists having Ph.D or M.D degrees. Even among the Ph.Ds there is a wide range of specializations ranging from life sciences, chemistry, biopharmaceutics and toxicology.

There are two distinct phases in drug development; pre-clinical and clinical. The discovery or the pre-clinical phase is the development and testing of a drug before it can enter human clinical trials. The discovery phase entails the processes of initial idea generation, formulation and evaluation of basic hypotheses on disease mechanisms (referred to as structure activity relationships), and sites of intervention. Once basic hypotheses are formed, the next stage in the discovery process is the identification, selection, and synthesis of various chemical compounds as potential drug candidates, and testing them in in-vivo and in-vitro models.

Drug development is a very uncertain science and involves input from multiple disciplines which have to be creatively integrated. In addition to the intricacies associated with a multidisciplinary project team, there are several other factors which contribute to the complexity of pharmaceutical research.
First, there are limited means to directly comprehend the mechanism of action of a particular drug, or in other words it is difficult to precisely understand how a drug works in the body to cure a disease or symptom. Frequently, the scientists offer a number of plausible hypotheses and develop various assays for testing these hypotheses. In fact, some proven drugs can be based on tentative assumptions about how and why they work. Many times drugs may be validated based on an input-output model with only partial understandings of the black box, that is, drug X may cure a disease or counteract a symptom, but knowledge on the processes by which this is achieved may be only partial. A quote from a scientist explaining this uncertainty is revealing:

"We have a hypothesis - might identify a drug to test the hypothesis - then we test it - then we might have a candidate which turns into a lead compound - which then becomes the project - we pick what is readily/remotely available to test the hypothesis. In fact the drug may not have tested the hypothesis - 'we don't know the mechanisms of action."

A second factor has to do with the clinical validation of preclinical understandings. As mentioned before, there has to be considerable development of the drug candidate before it can reach human clinical trials. And the attempts at modeling the underlying laws of the human system rely on non-human analogues. There is always the chance that the analogue does not mimic the workings of the human body. Thus each clinical trial carries a considerable risk of failure which is further exacerbated by the lengthy clinical
development time (some running into years) and the substantial financial investments.

In summary, pharmaceutical research is characterized by high levels of complexity thus making it a prime candidate for complexity induced simplifications as will become evident in our presentation of the case studies.
Retrospective Analysis

As mentioned previously, my involvement with this organization came as a result of the center's decision to improve their strategic work processes. One work process they wanted to examine was the way they went about conducting research. As an initial starting point we decided to do a retrospective analysis of some past projects using a non-routine socio-technical systems approach. The retrospective studies involved investigation of five projects using the deliberation analysis methodology. Deliberations are basic sense making devices that can be located in conversations, exchanges, encounters and reflections people engage in to resolve an equivocal topic (Pava, 1983).

The projects represented the various focus areas and types of research being carried out in the center. Out of the five projects, only one project represented a total success. One project failed at clinical trials, two project were shelved after some development time, and the last project after many years of deliberate efforts was redirected for potential application in another area.

Key deliberations in each project were identified and team members who were associated with these projects were interviewed around these deliberations. The principal responsibility for conducting the interviews rested with a 'design team' (who operated collaboratively with the researchers) made up of scientists who worked in the center. Approximately 70 interviews were
conducted across the five projects. The interview methodology consisted of a structured interview protocol and use of other documentary sources such as project reports. Based on the interviews and these other sources case descriptions of the projects were written up.

The case studies are presented in the succeeding section. However, the description of the technical details are kept to a minimum given the sensitive nature of the data and that such details are not required to comprehend the issues involved.
The Mita Project

The Mita 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 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.

Based on our conceptual framework we can deduce that the major reason for failure of the Mita 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 metaphorical reasoning implies a degree of distance or independence between the two conceptual systems brought together by 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 - which in the cognitive psychology literature has been termed as adjustment and anchoring (Tversky and Kahneman, 1974).

Two factors in the context, namely management pressure to advance the project and the group deliberative norms seemed to promote this cognitive simplification activity.

As the interviews revealed, the strict time table caused the team to compromise on some of the tests;

"there were long debates about what tests were not necessary".
A similar piece of insight provided by some other members were;

"most team meetings were run like 'clinical teams'; planning what has to get done to move into clinicals."

The group norms against open sharing seemed equally contributory. For example, when some of the members were asked as to why they did not express their reservations about the basic hypothesis, a sample response offered was;

"when you come into a project, you are an expert in the area--J was brought in to help with the formulation--J said he felt he would be disruptive asking a lot of questions--that he should trust other's expertise".

Thus a set of group norms which did not favor openness stifled the surfacing and questioning of assumptions and contributed to defective cognitive procedures. Further, the notion of each person being an expert in his or her domain precluded the others from asking what they felt were legitimate questions. Such questions were perceived as intrusions into another's area of expertise. Thus, the life scientist's choice of a rat model went unquestioned as it was deemed to be his area of expertise.

Another factor which may have impinged directly upon the inadequate reasoning was the absence of a shared language. The interviews revealed that the team members really did not understand each other's points of view. Project members, especially those who joined the investigations subsequently, were never really fully brought on board. There was no common point of
reference around the product concept or the project hypothesis. As scientists commented on the need for a shared language:

"there are multiple perspectives in the way we explain our research. This lack of common focus arises because we do not have enough time to discuss science in projects which prevents us from exchanging and exploring different views and coming to a common understanding. Therefore we do not listen to each other and become advocates of our parochial, polarized positions. [The focus should be] what procedures and processes will enable us to come to a common understanding based on adequate exchange and exploration of all perspectives and parties";

"[we should] try to help see other person's perspective- [we should be] together at all presentations- [be] required to present information together- life scientists and chemists"

A debrief session with several members of the project also suggested that a major difficulty with the project was that new members brought on board were required to be more "in a 'do mode'; do their own piece." There was not enough sharing of the data or joint sense making.
The Vita Project

This project came out of an accidental finding. A scientist when handling a certain chemical discovered that it produced a (xxxx) sensation in those parts of the body that had come into contact with the chemical, and thus the Vita project was born. The idea was to develop an (xxxx) with non-narcotic side effects; a product with morphine like (xxxx) properties without any addictive repercussions for the user. The product, if successful, carried very good market potential.

The initial intent was to go for a regional application either in an injectable or topical (for example ointment) form. This decision appeared to be partly influenced by the fact that the chemical showed some toxic side effects. Toxicity was established as a concern very early on in the project. However, at this stage they did not have the requisite expertise in terms of a toxicologist who could firmly establish the consequences of the toxicity.

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;
"they felt an oral drug, a cure all, widely useful, safe and 
(yyyy) like, with narcotic-like (yyyy) could lead the 
market".

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. As 
tellingly commented by some scientists;

"Lot of downward pressure to make it oral; find one 
drug and ask/force it to do everything we want to do";

"[There was] blind insistence on a particular drug 
delivery form, e.g., oral, oral, oral!"

Further, tests conducted suggested that the chemical showed only 
minimal evidence of (yyyy) properties if orally administered (though there 
were some concerns about the method used to determine this). As one of the 
scientist's interviewed stated;

"There was no technical basis for oral efficacy- but we 
agreed to go oral to keep it [project] alive".

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. One scientist's comment on this was;

"They [management] want quick/short term results, they do not understand science- want to make a lot of money".

In fact, the project leader coined the objections as an 'academic debate' and hired an outside consultant to convince the Center director to go oral, and not waste time with regional applications. Based on our conceptual framework 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 and the weak (xxxx) effects (of the oral form) were uncertain. There was a need to push the drug to clinical **human** trials to determine the real impact.
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;

"data which does not tell you [management] what you want to hear is discounted".

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. As one scientist commented on this product champion position in the company;

"Product champion [in this company] is messiah".

We can infer from this emphasis on being the product champion that the project leader was potentially subject to a certain illusion of personal control, or the tendency to overestimate the extent to which the outcomes of a strategy was under one’s personal control. The assumption is that through additional effort, one can make the strategy succeed should problems arise. Interviews with the project leader and others suggested that this was indeed the case;

"The [Project leader] got frustrated trying to work with the project team; "difficult when you know what is needed but they don't want to do it".

Several people apparently suggested that the project should be stopped based on the lack of evidence for the proposed application. However, the
project leader felt that this was a "test of his ability to manage". He felt a strong personal charge to make sure this valuable piece of science was made available to humanity and is not lost: "[it is] my personal charge and I'm fanatical about it".

One reason extended for this behavior of the project leader, by the team and the key scientist who was working on the toxicity issues was that the project leader did not have any conceptual understanding of the issues involved, especially this scientist's work around toxicity. He did not have even minimal knowledge which precluded from understanding the gravity of the issues at stake. An interesting comment in this regard was:

"Management needs more understanding of drug development; [] has a 'fix-it' approach- feels that toxicity can be fixed."

Meanwhile, the team and especially this key scientist was convinced that the toxicity issue had to be resolved before the drug could be moved to clinicals and were working hard to understand the issues involved. Their fear was that if the drug goes to clinical, it may be rejected by FDA (due to the toxicity issues) and this may jeopardize the whole class of compounds (potential drug candidates) which they had developed based on this chemical. Some comments in this regard were:

"A project has one shot at clinical - if this shot fails the project is doomed";
"Management pushes for clinical as soon as possible, while scientists believe that we need good science/understanding at pre-clinical stage- good science at pre-clinical improves chances of success at clinical";

"you can't fool mother nature- management does not understand this, focuses on short term results"

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. They wanted to move to clinicals as fast as possible. This pressure to push ahead came in the way of developing the required understanding around toxicity and related issues; it prevented the carrying out of 'good science';

"Time pressure... prevented complete understanding of effects of compound- resulted in not factoring in attributes critical to making of drug";

"when pressured by time, decisions are based on very little data"

The drug was submitted for clinical tests and as predicted by some of the scientists, the result was an IND hold. This was FDAs way of flagging toxicity problems. Thus, as in the case of the Mita project, we can deduce that undue management pressure adversely impacted scientific reasoning processes.

Also, as in the previous example, the group deliberative norms were a contributory factor. The scientists recounted that the project leader enforced a
set of norms that did not allow the expression of different views; there was no open communication, no data sharing. He was directive and did not want active debate unless it supported his position. Scientists' recounting this experience made the following comments:

"[We] operated on the 'power of positive thinking'- a little positive data went a long way- but it took a shitload of negative data to do the same;"

"If science does not tell them what they want-people are labelled as negative";

"conflicting views were not encouraged in decision-making forums";

"speaking your mind was dangerous";

"differences in interpretation became personal vendettas; the naysayers suffered accordingly""

Subsequently, the drug candidate was moved back to preclinals 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 (xxxx) effect. New consultants brought in by the team also pointed out that the oral delivery form was infeasible. One vivid comment attributed to a consultant in this regard was;

"You don't have a snowball's chance in hell of developing an oral drug."
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".

Finally, the project started going well, where; "the methods and concepts were sound; the results were clearly understood; cause and effect relations were established; and the right conclusions were reached, based on GOOD SCIENCE".

The new leadership (in the form of the section leader) used a team concept in planning, encouraged open communication, open data sharing, and wanted the expression of different and conflicting views. He acted as a sounding board for new ideas and often provided fresh approaches to problems, which all indicate what Streufert and Swezey (1986) call integrative style leadership, a preferred mode of leading in complex environments.

In other words, this final phase was an instance of being able to muster the requisite complexity whereby the cognitive model was progressively
becoming adaptively isomorphic with the operational environment, based on high quality and sufficiently complex deductive and inductive action.

This latter successful phase, similar to the Wright brothers' example (Bradshaw, 1992), can be viewed as characterizing a 'function space' approach towards research. It was an instance of isolating, understanding, and solving each problem and in the process developing more complex understandings of the (xxxx) chemical's mechanisms of action, structure activity relationships, and toxicity effects; just as the Wright brothers' isolated, understood and solved one problem after another such as lift, thrust, drag, and lateral control and in the process gained more complex insights into the workings of aerodynamic laws that finally allowed them to build the first successful airplane.

The earlier phases of the Vita project can be characterized as involving 'design space research'; where as in the case of the unsuccessful inventors the propensity was to build complete models (with minimal understandings of aerodynamic laws), and test them with the hope that they would fly. If they did fly, they could not explain why and if they did not, neither could they explain that. Impelled by the project leader and management, a similar approach was found in trying to push the drug candidate to clinical trials without resolving issues around mechanism of action, toxicity, or structure activity relationships. The stress was on taking a chance and seeing if the drug candidate would work in human trials.
One contextual feature which showed a direct relationship to the
development of requisite complexity (in the subsequent phases) was the
project team progressively being able to incorporate requisite expertise. The
need for requisite expertise in terms of the essential knowledge domains has
been underscored by many scholars (Ashby, 1956; Cohen and Levinthal 1990;
Walsh et al., 1988) for achieving complexity in conceptual systems and thus
warrants some discussion. The VITA project demonstrated both lack of requisite
expertise in its early stages, when there was a high incidence of cognitive
simplification processes, and an adequate level of requisite expertise in its
latter stages, when the project progressed smoothly based on tenets of 'good
science'.

As briefly stated in the description of the case, during the early stages,
the project lacked the requisite expertise and was not able to fully establish the
consequences of toxicity. Further the team also did not have the expertise to
design the right assays to comprehend the mechanisms of action of the drug
compound, that is, they could not completely understand how the drug worked
in the human body to counteract the disease or the symptoms. In fact this
tentativeness in conclusion brought about by lack of requisite expertise may
have contributed to the project leader labelling the findings as uncertain and
pushing for the oral delivery form as well as imposing pressure to go for
clinical trials. This can be considered as a case of devaluing partially
describing alternatives a cognitive simplification activity discussed by Yates et
al. (1978).
However, in the latter stages the requisite expertise was brought in both in terms of project members and external consultants, when the effects of toxicity were firmly established and it was concluded that "there was no way of separating the (xxxx) effects from the toxicity". Further, the mechanisms of action were better understood, thanks to a new member who developed more knowledge on the appropriate assays; As he stated "the earlier (xxxx) testing was not reliable".
Summary and Other Observations

The purpose of this chapter is an attempt at grounded theory building in order to understand some encountered instances of scientific failure and product development delays in a pharmaceutical research and development center. The process undertaken here is one of giving explanations to the qualitative data observed, by moving from data to concept. It is an act of identifying a higher level of abstraction that allows the application of a name or concept to the action or object observed or referred to (Martin and Turner, 1986).

In that sense, the grounded theory exercise seeks to locate cognitive simplification processes in scientific deductive and inductive action as a principal contributory factor for scientific failure and delays. Further, some contextual features (antecedentory variables) appear to be related to the occurrence of cognitive simplification processes in scientific deductive and inductive action.

We extend as an explanation that defective cognitive processes were the major reasons for the unfavorable outcomes in the Mita and the Vita project. Inadequate analogical reasoning (Nersessian, 1992; Knorr-Cetina, 1981; Steinbruner, 1974) in terms of using a rat model to understand the workings of the human (xxxx) and adjustment and anchoring (Tversky and Kahneman, 1974) which is attending to information that confirmed to the initial framing of the problem caused the Mita project to fail at clinical trials.
Denying the cost trade-offs (toxicity) of the preferred alternative (Steinbruner, 1974; Jervis, 1976), and emphasizing only the benefits (market potential of oral delivery form) contributed to delays and failure at clinicals of the Vita project. Other related simplification processes in evidence were magnifying the attractiveness of the preferred alternative (Steinbruner, 1974; Festinger, 1956), amplifying negative aspects of the non-preferred alternatives (Steinbruner, 1974), devaluing partially described alternatives (Yates et al., 1978), adjustment and anchoring or attending to only the information that confirms one's initial understanding (Tversky and Kahneman, 1974) and illusion of personal control (Langer, 1975; Langer and Roth, 1975; Larwood and Whittaker, 1977).

A number of contextual conditions influencing cognitive simplification processes (including some that were observed in the literature) showed up in the case studies. Imposed [Management] time pressure (Janis, 1989) to 'save time versus understand', norms that hindered surfacing and discussion of assumptions (Janis, 1989; Walsh et al., 1988), and lack of a shared language (Cohen and Levinthal, 1990) were evidenced in the Mita case. In the Vita case, in addition to imposed time pressures and closed norms, lack of requisite expertise (Ashby, 1956; Cohen and Levinthal, 1990; Walsh et al., 1988; Janis, 1989), and poor conceptual understanding (Streufert and Swezey, 1986) on part of the group leader of member work were salient.

Other contextual features identified in the literature were also evidenced. For example, the importance of accumulating prior related
knowledge to aid requisite complexity has been stressed by Cohen and Levinthal (1990). This was an issue which had a pronounced impact in one of the cases studied (not presented here). In this project which was terminated before it entered clinical trials, interviewees identified what they labeled as the "Forever young and stupid syndrome" suggesting that they kept on repeating the same mistakes over and over again. This 'syndrome' was precipitated particularly by a lack of transfer of knowledge when there was a change in project leadership or when members left. As an interview quote confirms:

"staff and leadership turnover and loss of information hurt the project, lack of knowledge transferred slowed things down- caused [us] to recycle through old issues."

Also contributing to this act of "constantly reinventing the wheel" were inadequate systems for retrieving learnings from past related projects, not engaging in technical documentation which captured learnings and understandings from the past, and failing to incorporate knowledge from past failures into new hypotheses.

The importance of external and internal knowledge linkages has also been stressed by Cohen and Levinthal (1990) as a requirement for optimal complexity. The Vita project in its latter phase, namely the stage which was characterized by high quality and sufficiently complex deductive and inductive action, showed attributes of good knowledge linkages. Some quotes from the interviews suggesting such strong linkages are reproduced;
*External*

"brought in needed expertise in pharmacology; hired experts in the field"

"Specialists hired/on-boarded to fill in deficient knowledge"

"brought in independent [external] voice on toxicity"

"effective use of outside contractors to generate key data"

"willingness to use expertise outside of the company in an optimum manner, e.g., SAGs (Scientific Advisory Groups) and consultants"

"Information from SAG was critical to moving ahead with the regional program"

*Internal*

"there was informal scientific discussions among team members"

"the project team shared the data"

"the presence of collaboration between the scientists on the project"

"good collaborative efforts among the project and resource section members"
In conclusion, based on a grounded theory exercise we were able to develop some preliminary understandings of the potential relationship between cognitive simplification processes in scientific deductive and inductive action and unfavorable scientific outcomes and product development delays. Further, observations on the interaction of features of the context with cognitive simplification processes were extended.

In the next chapter we will expand our investigation by a more conventional statistical examination of the impact of cognitive simplification processes on the effectiveness of scientific outcomes. We will also explore relationships between the context and frequency of cognitive simplification activity.

This next step is a logical extension of a grounded theory building approach. As Martin and Turner (1986) suggest, grounded theory building can be used as an initial strategy for developing preliminary understandings, followed by subsequent research for confirming findings and engaging in addition theoretical development. It can be a precursor to subsequent large scale survey inquiries.
Chapter 5
A Survey Based Inquiry

The second stage of this study was designed to statistically validate with concurrent and on-going drug development projects. the qualitative findings drawn from the retrospective analysis of the five past projects. Accordingly, this chapter is organized into the following sections. We will describe the overall research objectives and specific hypothesis examined, followed by an explanation of the data collection methods and the sample. Then we will expand upon the measures employed for examining the hypotheses. Our last section will elaborate on the analytical strategy employed.
Overall Research Objectives

The exploratory research objectives of the study were to examine some consequences and antecedents of cognitive simplification process. Specifically, the following research questions and hypotheses guided our investigation in the second phase of the study:

Consequences of Cognitive Simplification Processes

I. To examine if differences in the levels of cognitive simplification activity in scientific deductive and inductive action is related to indices of project effectiveness, particularly project performance and product development cycle time.

The specific hypothesis examined were:

1. Product development teams reporting higher incidences of cognitive simplification processes in their deliberations, will also report higher incidences of delays in the product development process.

2. Product development teams reporting higher incidences of cognitive simplification process in their deliberations will be rated lower on level of project team performance (effectiveness);
   a) by project team members, and
   b) by management.

While we have extended specific hypothesis under the broad research question, we would like to underscore that these hypotheses have been proposed keeping in mind the exploratory nature of the research. There is an
element of newness to the topic, and this to our knowledge is potentially one of the few attempts to empirically examine the existence and effects of cognitive simplification processes in field settings, and particularly in new product development situations.

Therefore our hypotheses are general, positing a relationship between unsuccessful scientific outcomes and product development delays, and cognitive simplification processes. In other words, while we have measured various types of simplification processes, we are unable to predict and propose hypotheses on whether a specific type of simplification process will explain unsuccessful scientific outcomes more than others. Similarly, we are not in a position to hypothesize on the relationship between specific simplification processes and specific types of delays.

Antecedents of Cognitive Simplification Processes

II. To examine if there is a relationship between select processes of the project team functioning, variations in cognitive structures (styles) in project teams, and features of the organizational work context, and the level of cognitive simplification processes in scientific deductive and inductive action.

As evident from the research question, the notion of context was operationalized at three different levels; the first level of context related specifically to processes of the project team functioning such as group norms, leadership, and availability of, and barriers to requisite expertise. The second level dealt with diversity versus homogeneity of the embedded cognitive
structures, styles, and strategies of project teams, while the third level examined the perceptions of the larger work context within which the project teams operated, such as knowledge linkages internal and external to the firm, pressures from top management, and systems and processes to accumulate prior related knowledge. We can expect that all three aspects of context - project team functioning, diversity of cognitive styles and strategies, and the larger work environment will be related to the (reported) incidences of cognitive simplification processes in the deliberations of a project team.

A. The hypothesis examining the relationship of project team functioning to reported incidences cognitive simplification processes were;

3. Lower the reported level of group deliberative norms favoring open debate, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

4a. Lower the reported level of requisite expertise available in product development teams, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

4b. Higher the perceived barriers towards availability of requisite expertise higher will be the reported cognitive simplification processes in the deliberations of product development teams.

5. Higher the reported level of language barriers (absence of shared language) higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

6. Lower the reported level of an integrative leadership style, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

B. The specific hypothesis examining the relationship of the embedded cognitive styles and strategies of product
development teams to the incidence of cognitive simplification processes was:

7. Higher the level of homogeneity (lack of requisite diversity) in 'mind sets' available in product development teams, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

C. The specific hypothesis examining the relationship of perceived features of the overall work environment to the reported incidence of cognitive simplification processes were;

8. Lower the reported level of adequacy of systems for accumulation of prior related knowledge in the work environment, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

9. Lower the reported level of external and internal knowledge linkages in the work environment, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

10. Higher the reported level of perceived pressure in the work environment, higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

In summary, the direction of relationship will be negative to positive between the following antecedentory variables and cognitive simplification processes, that is, as one decreases the other increases. Group norms, availability of requisite expertise, integrative leadership, systems and processes for accumulating prior knowledge, and external and internal knowledge linkages will show a reversed relationship with cognitive simplification processes. As one gets smaller, the other will get larger.
Barriers to inflow of requisite expertise, lack of shared language, perceived pressure, and homogeneity in 'mind sets' will show a direct positive relationship with cognitive simplification processes. That is, as one increases the other will also increase.

Sample and Data Collection Methods

The sample for this second phase of data collection was the scientists and technical personnel employed in the research and development center who were organized across 25 concurrent and on-going drug development projects. A survey was administered to all of the 197 research and development personnel through the internal mailing system. Of the 158 subjects who responded, 49 percent were M.Ds or Ph.Ds with varying specializations from chemistry, life sciences, toxicology, and biopharmaceutics. The total responses produced a return rate of 80 percent.

In addition to the variables measured as part of this research, the survey contained other items reflecting the interests of the various members of the research team of which this investigator was a member. The items were developed based on an integration of the literature as well as understandings developed from the qualitative investigations of the retrospective study.

The survey was comprehensively pre-tested on 15 individuals to assess clarity, readability, and face validity. Based on feedback received, changes were made to the survey especially in terms of reframing items in a language
that was most fitting to the pharmaceutical R&D population. Subjects were instructed to respond to survey items based upon real time project deliberations.

**Measures**

As indicated earlier, specific items were constructed based on an integration of extant literature and emergent learnings from the retrospective analysis of the five cases. In the succeeding sections we will discuss all major measures employed as part of this specific study. All scale items were rated on a seven point scale, unless otherwise mentioned. Some items used reverse scoring and have been identified as such. In the following three sections we will present the measures pertaining to cognitive simplification processes, its consequences, and antecedents.

*Developing a Measure of Cognitive Simplification Processes*

Given that cognitive simplification processes have been studied individually in laboratory settings (Steinbruner, 1974; Tversky and Kahneman, 1974), or whose existence in field settings have been argued only conceptually (Schwenk, 1984; 1986) a survey based measure of cognitive simplification processes that can be applied in field settings had to be developed.

While some may argue against the suitability of employing self-report measures to study such an implicit phenomenon as cognitive simplification
processes, since, they may frequently operate outside the bounds of day-to-day consciousness (Rubinstein et al., 1984; Schwenk, 1984), our observations and interviews with the scientists suggested that they had a strong reflective orientation and could recount instances from their work where they felt particular biases were in operation. Further, Janis (1989) attests to the possibility of using self-report measures to assess defective cognitive procedures. He suggest that his vigilant problem solving model can be used to analyze sources of errors in decision making processes, including group decisions. And, this diagnosis can be made by rating the frequency and severity of symptoms of defective decision making.

We relied on Schwenk's (1984) framework to develop a measure of cognitive simplification processes. Items corresponded to the our earlier approximate classification of simplifications in deductive and inductive action.

The simplifications pertaining to deductive action or cognitive model formulation were; Inappropriate analogical reasoning which entails application of analogies and images from simpler situations to complex problems (Knorr-Cetina, 1981; Nersessian, 1992); Prior hypothesis bias, where an erroneous hypothesis about the relationship between variables guides decision making even if abundant evidence over numerous trials suggests that the hypothesis was wrong (Levine, 1971; Pruitt, 1961); Problem set when there is a repeated use of one problem solving strategy (Anderson and Johnson, 1966; Newell and Simon, 1972); Single outcome calculation where the problem is oversimplified and the focus is limited to a single goal and a single
alternative course of action for achieving the goal (Cyert and March, 1963; Steinbruner, 1974); illusion of control which is an overestimation of the extent to which outcomes of a strategy are under one or another's personal control (Lefcourt, 1973; Langer, 1975; Langer and Roth, 1975; Larwood and Whittaker, 1977); representativeness bias which is a tendency to overgeneralize or overestimate the extent to which the sample is representative of the population from a small data base or a few vividly described cases (Tversky and Kahneman, 1982; Nisbet and Ross, 1980); illusion of prediction or overestimating the accuracy of predictions for some alternatives (Tversky and Kahneman, 1982; Einhorn and Hogarth, 1978) and escalating commitment which is a tendency to allocate more resources to projects that are failing in the hope of salvaging an already substantial investment (Fox and Staw, 1979; Staw, 1981; Duhaime, 1981).

The potential simplifications associated with inductive action or information and alternatives evaluations were: adjustment and anchoring where initial judgements (understandings) about values of variables are not revised as new information is reported and only information confirming to the initial values are listened to, consequently, final estimates of values are biased towards initial values (Tversky and Kahneman, 1974; Kozielecki, 1981); bolstering a preferred alternative is the tendency to promote a preferred alternative by developing arguments to magnify its attractiveness (Festinger, 1956; Steinbruner, 1974); inferences of impossibility involves identifying the negative aspects of non-preferred alternatives in order to convince oneself that they are not possible to implement (Steinbruner, 1974); denying value trade-
offs is a tendency to over-value a favored alternative by denying its cost trade-offs (Steinbruner, 1974); and, devaluation of partially described alternatives as the name suggests, is devaluing the alternative that is partially described (Yates, Jagacinski and Faber, 1978).

Termed 'common pitfalls in selecting and evaluating alternatives', the scale consisted of fourteen items. Subjects were asked to rate the extent to which each cognitive simplification process was experienced as impacting the deliberations of their project team ranging from "To no extent" to "To a great extent".

Product Development Delays

Based on a synthesis of the literature presented earlier, a delay scale was developed. This nine item scale describes different types of delays and is scored so that a high score (7) reflects a high frequency of the particular delay and (1) reflects a non-incidence or negligible occurrence of the delay.

Items one and two --having to do with theory development and drug testing--were constructed for measuring the frequency of comprehension cycle (Mintzberg et al., 1976; Gupta and Wilemon, 1990) and searching (Hickson et al., 1986) types of delays. Item three measures the incidence of delays in responding to frequent changes in product requirements (Mintzberg et al., 1976; Stalk and Hout, 1990). Delays in acquiring and coordinating the necessary resources were measured using items four and five. These items
correspond to the scheduling delays as noted by Mintzberg et al., (1976), coordinating and supplying resource delays as described by Hickson et al. (1986) and lack of resource delays cited by Gupta and Wilemon (1990). Delays in recognizing and responding to failures were measured using item seven. This item is based on Gupta and Wilemon's (1990) category of delay having to do with a manager's unwillingness to recognize that past solutions were sub-optimal. Item eight measures delays in getting management approvals which is directly related to the sequencing delays described by Hickson et al. (1986). Finally, item nine, delays in overcoming internal resistance and politics was derived from the internal and political resistance delays as reported by Hickson et al. (1986).

*Project Performance*

Measuring R&D project performance (or effectiveness) is a difficult task, especially with on-going projects and thus deserves some extended treatment. The non-routine nature of scientific tasks do not allow for linear developments. Rather, projects go through phases of progress and phases of stasis, and a stagnant phase can suddenly be transformed by a key insight or breakthrough.

However, it is possible to capture the flavor of the effectiveness of a research and development unit or a particular project by using multidimensional measures and by obtaining performance ratings from a

As de Hemptinne and Andrews (1979) elaborate on the multidimensionality of measures:

"...the performance-effectiveness of research units is a multidimensional concept, encompassing a variety of distinct aspects. Although it is tempting to think of research units as falling somewhere along a simple good-bad or effective-ineffective dimension, the data shows that this is a much too simplistic conception. On the contrary units that "look good" by some criteria may--or may not--rate highly on the other criteria. Furthermore, the factor that predict to high levels of certain kinds of effectiveness are frequently different from the factors that predict to high levels of other aspects of effectiveness....it, leads to the conclusion that if one wants to understand and/or enhance the performance of R&D units", one should rely on multidimensional measures" (p. 10).

Andrews (1979) emphasizes the importance of gathering performance ratings from multiple parties:

"...even those people who reported being well informed about a unit's work might disagree to some extent about its quality, and that hence, it was important to obtain performance ratings from a number of different individuals and from individuals who could be expected to view the work of the unit from a number of different perspectives" (p. 34).

Andrews (1979) in collaboration with an international team of social scientists, natural scientists, and managers of research and experimental development (R&D) conducted what they termed as "The International
Comparative Study on the Organization and Performance of Research Units'. The study was sponsored by UNESCO under its Program of Science and Technology Policies. Results from round 1 of the study involved data collected from over 11,000 participants in approximately 1,200 research units in six European nations (Austria, Belgium, Finland, Hungary, Poland and Sweden). The sample represented units in academic organizations (universities) pursuing research in the natural, medical, social and technological sciences, scientific academies, cooperative organizations, productive enterprises, and private firms.

The study had two broad purposes; to find ways to enhance the performance effectiveness of research units and of their members, and to develop and test methods for assessing the organization and performance of research units.

Accordingly, multiple measures were employed to assess the performance of R&D units. They included: published and written output; patents and prototypes; reports and algorithms; general contribution of the unit to science and technology; recognition accorded internationally to the unit; social value of the unit's work; training effectiveness of the unit; administrative effectiveness of the unit in terms of success in meeting schedules; R&D effectiveness of the unit which included productiveness and innovativeness; and application of research results.
One additional reason for the multiple measures was due to the diversity of the settings sampled. For example, training effectiveness as a criterion is more applicable to universities than R&D units of private firms. Similarly, published documents would be a primary criterion for academic settings, especially in the social sciences, while patents and prototypes would be more representative of research in the technological sciences.

Performance effectiveness was rated by three parties: the staff scientists and technical support persons of the research unit; the management which consisted primarily of the unit head and the unit's administrative person if such a position existed; and external evaluators who were members of the international research team - a group of investigators (scientists, engineers and senior policy makers) with considerable knowledge regarding the functioning of scientists and scientific organizations and who were familiar with the work of the specific unit.

While the international study had a larger emphasis on making comparisons across R&D units located in six nations, Ancona and Caldwell's (1992) study specifically compared the performance of 45 new product development teams across five high technology companies. Managers were asked to assess the teams on efficiency, quality of technical innovations, adherence to schedules and budgets, ability to resolve conflicts, and overall performance. Factor analysis identified two factors; efficiency in developing technical innovations and adherence to schedules and budgets. Team members were asked to rate performance on efficiency, quality, technical innovation,
adherence to schedules and budgets, and work excellence. Factor analysis suggested one factor labelled team performance.

Based on an integration of the literature and extensive discussions with the scientists and management, the following measures were constructed to measure project performance. The essentiality of taking into consideration local knowledge about scientific performance is underscored by Bonmariage, Legros, and Vessiere, (1979), "effectiveness is what people in the research units say it is" (p. 294), and should be accorded due consideration.

Both team members and management rated project performance on:

**Project Productiveness**, or the extent to which the project is making progress towards its goals, that is, producing a new drug candidate, new site of intervention, or new use of existing drug.

**Project Innovativeness**, or how innovative is the project in the sense of generating new ideas or knowledge that advanced theory/science in this field; or contributed to developing new methods, test procedures etc.

These two measures closely parallel the definition of productiveness and innovativeness as employed by Andrews (1979). The measures assume added importance, given that, in the Andrews (1979) study, factor analysis suggested that productiveness and innovativeness revealed a stable pattern of relationships even after controlling for characteristics of the research unit (size,
experience, activities, climate, leadership, resources etc.). In other words, these two measures were suggestive of R&D effectiveness reasonably independent of the environment in which the unit operated, and contributed to the maximum variance explained. Further, the responses of the staff scientists and the unit heads converged well on the two measures (Bonmariage, Legros, and Vessiere, 1979).

Two other measures which were constructed and to which only the team members responded were:

**Project Progress**, or the extent to which the project is progressing in accordance with plans and schedules.

This question was employed to measure progress with reference to internal standards, that is, schedules, plans etc. and parallels Andrews (1979) and Ancona and Caldwell's (1992) measures on adherence to schedules.

**Competitive Progress**, or the relative competitive position of the project in relation to other laboratories working in the same or similar area.

This question was employed to measure progress with reference to external standards and was primarily derived based on discussions with the scientists.
All four questions were responded to by the scientists and technical personnel on a seven point scale, keeping in mind the specific project they were part of in terms of spending the greatest amount of their time.

For management, however, a twenty point spread was used at their behest. Eleven members of management that included the director of the center, four associate directors, and six resource section heads rated each project individually on productiveness and innovativeness. The management ratings were averaged to come up with a mean score for the two measures for each of the twenty-five projects rated.

*Group Deliberative Norms*

Based mainly on the observations of Janis (1989) and Walsh et al. (1988), two items measured the openness of group norms: 1) extent to which conflicting interpretations or alternatives are openly explored and discussed before making key decisions; and 2) extent to which members feel comfortable expressing counteropinions or disagreements when issues are being discussed.

*Availability of Requisite Expertise*

This scale consisted totally of six items. All items were derived from Purser (1990) and Pasmore and Gurley (1991). Two items were scaled positively and measured the extent of availability of 1) required information, and 2) requisite expertise to make key decisions.
Four items which were reverse scored measured the extent to which the following barriers significantly impacted the inflow of requisite expertise in project deliberations, namely: 1) missing parties: people with relevant expertise who are missing from key discussions; 2) wrong parties: some people are involved in discussions or tasks who should not have been; 3) lack of internal consulting: important information from other areas within the center is not taken into account before major decisions are made; and 4) lack of external consulting: Important information from other divisions and the external environment is not taken into consideration before major technical decisions are made.

*Shared Language*

Drawing from Purser (1990) a one item, reversed score measure was used to determine the extent to which specialized language barriers prevent critical information from getting assimilated, with 1 being to a 'very little extent' and 7 being 'to a very great extent'.

*Integrative Leadership Style*

Relying on learnings from the retrospective analysis and supported by Streufert and Swezey’s (1986) observations, four positively scored items measured integrative leadership style: 1) extent to which the project leader has a good conceptual understanding of team member work; 2) is a sounding board
for new ideas; 3) is effective at providing fresh approaches; and 4) has the
ability to recognize and mediate conflicts.

*Diversity in Mind Sets*

To measure diversity in 'mind-sets' we used the inventory developed by
Pasmore (1990) called the 'Engagement Style Inventory' (included in the
appendix). Constructed primarily to understand preferred cognitive modes of
engagement in scientific and other non-routine work situations, this instrument
measures an individual's cognitive style on two distinct and bipolar
dimensions; intuitive-analytical and active-reflective. The theoretical premise
is that all modes are required for effective scientific work. There has to be an
adequate balance of the four cognitive modes, analytical, intuitive, active, and
reflective for scientific success.

The inventory was administered as part of the survey to all the
scientists, and we calculated the gap between the 'intuitive-analytical' and
'active-reflective' dimensions.

The premise was that the higher the gap between the two bipolar
dimensions, the less the diversity in mind-sets, indicating that one particular
style is predominant and the other regressive, so the higher the difference. On
the contrary, a lower gap or no gap, suggests a well balanced individual,
equally adept at both analysis and intuition, and action (induction) and
reflection (deduction).
We charted a cognitive mode profile for each product development team based on a summation of individual responses. For analysis purposes we used squared values of the 'intuitive-analytical' gap, and the 'active-reflective' gap as the diversity measure. The gap values were squared in order to compensate for the negative values of gap variables which would result if, for example, the analytical sum were higher than the intuitive sum, or the reflective sum were higher than the active sum. For our purposes, we were interested only in the 'gap value'. Moreover, the positive or negative sign of the gap was merely a reflection of the ordering of the 'intuitive-analytical' and 'active-reflective' dimensions in computation.

One can surmise that the higher the gap (value) in the intuitive-analytical and active-reflective dimension (an indication of homogeneity or lower diversity, in cognitive modes or mind-sets), the higher the level of cognitive simplification processes.

*Accumulation of Prior Related Knowledge*

Drawing from Cohen and Levinthal's (1990) ideas, and based on learnings from the retrospective analysis, this section included five positively scored items to evaluate the adequacy of processes and systems in place in the work environment for accumulating prior knowledge.
The questions were: 1) adequacy of technical documentation of past work (Purser, 1990; Pasmore and Gurley, 1991); 2) adequacy of systems in place for retrieving past learnings; 3) extent to which people's past experience and knowledge learned from previous projects are easy to tap into; 4) extent there is sufficient continuity in people and/or transfer of knowledge when projects are completed, and; 5) extent knowledge learned from failures is valued and incorporated into new hypotheses. All items were rated on a seven point scale.

Knowledge Linkages

All seven items were positively scored: 1) one item measured the links to external sources of information and expertise (the scientific community); 2) two items were employed to assess the interactions and sharing of knowledge across focus areas (different industry interest such as respiratory, gastro-intestinology or stomach related disorders); 3) three items for measuring information exchange between resource and project sections (such as chemists and life scientists); and 4) one item for interactions between the R&D center and receiving/operating divisions (such as manufacturing and marketing).

Perceived Pressure

Drawing on Janis (1989) three positively scored items measured perceived pressure: 1) an overall measure of time pressure; 2) pressure from management to show practical results; and 3) time and resource pressures on
discretionary research. The prediction is for a positive relationship, the higher the perceived pressure, the higher the cognitive simplification processes.

**Analytical Strategy**

Given the multiple hypotheses and the unexplored nature of the variables, we resorted to a comprehensive analytical strategy that included factor analyses, reliability analyses, and Multivariate (MANOVA) and Univariate analyses of variance (ANOVA), correlational and multiple regression analyses. For procedures which required consideration of individual project teams as the unit of analysis (for example variance techniques), only the responses of scientists who spent a majority of their total time on a project were included.

**Factor Analyses**

In order to assess the construct validity of the scales employed, 'exploratory factor analysis' of all scales was undertaken. Exploratory factor analysis as opposed to confirmatory factor analysis (which uses structural modeling methods such as LISREL), is a preferred approach when the nature of factor loadings is unknown and the investigation is exploratory (Byrne, 1989). To decide the number of factors to be extracted, the latent root criterion was used with a minimum eigen value specification of one. The eigen value criterion of one is a well accepted standard when component factor analysis is chosen as the basic model (Hair, Anderson, Tatham and Grablewsky, 1984).
Principal component factor solutions utilizing varimax rotation were obtained for all scales.

However, for factor analyzing the 'Engagement Style Inventory' we relied on a 'forced factor extraction procedure' which relies on a 'a priori' specification of the number of factors to be extracted before undertaking the factor analysis. This method is a useful approach for testing or confirming a theory or hypothesis about the factors present in a scale (Hair et al., 1984).

Reliability Analyses

Reliability analyses were undertaken for all scales. When factor analysis suggested that a scale had more than one factor (indicating a separate construct), individual reliability tests were carried out for all items representing each such factor. Cronbach alphas (the most commonly accepted measure of reliability, Hair et al., 1984; Nunally, 1978) were computed for the scales involved.

Multivariate (MANOVA) and Univariate (ANOVA) Analysis of Variance

In order to examine the consequences of cognitive simplification processes in relation to delays and project performance, we employed Univariate (ANOVA) and Multivariate (MANOVA) analysis of variance. Variance techniques are the appropriate analytical method when the
hypotheses are concerned with testing differences between groups (Hair et al., 1984).

Prior to conducting the variance analysis, the groups were classified into high and low simplification conditions (treatment) based on a median split, a well accepted method to classify groups into high and low treatment conditions. We used MANOVAs to confirm that the dichotomization into high and low simplification teams were statistically significant. The classification into high and low simplification conditions were carried out on median splits for an overall simplification score calculated based on averaging across all fourteen items of the cognitive simplification scale, as well as for the four factor scores which emerged from the factor analysis of the scale.

Finally, to test for significant differences between the high and low simplification teams on reported incidence of delays and project performance ratings, MANOVAs and ANOVAs were conducted.

*Correlational and Multiple Regression Analyses*

We used multiple regression analyses to examine the antecedents of cognitive simplification processes. Multiple regression is a preferred approach when examining the antecedents of a phenomena (Hill and Snell, 1989), since the underlying logic of this method is to predict the value of a dependent variable using the values of several independent variables (Hair et al., 1984).
For purposes of the multiple regressions, we grouped together as a class of predictors our three levels of operationalization of context since it made 'a priori' sense. In other words, all variables (or rather the various factors derived from the factor analyses of the relevant scales) relating to 'group functioning' such as group norms, requisite expertise and integrative leadership were fitted together in the regression equation to assess their relationship to the dependent variable, cognitive simplification processes. The regression procedures used assessed the individual effects of each independent variable, as well as determined the relative power of predictor variables vis-a-vis one another, in explaining the variance of the dependent variable.

The same procedure was adopted for examining the second level of context, namely homogeneity (diversity) of 'mind-sets' using the variables of 'intuitive-analytical' gap and 'active-reflective' gap. Similarly, the third level of context which related to functioning of the overall work environment in terms of systems and processes for accumulating prior related knowledge, knowledge linkages, and perceived pressure, were treated as a distinct class of predictors.

Five separate regression equations were constructed for each level of context, treating as the dependent variable for the first regression equation the overall cognitive simplification score. The other four equations had as their dependent variable factors one, two, three, and four derived from the factor analysis of the cognitive simplification scale.
Prior to running the regression equations, we computed a correlation matrix to examine the intercorrelations of the dependent variable(s) with the independent variables, and also among the independent variables. This step was carried out on account for two reasons.

For one, this would confirm the negative and positive directionality of our hypothesis and serve as an early test of the significance of the hypothesis. Based on our literature review, we had proposed that group norms, availability of requisite expertise, integrative leadership, systems and processes for accumulating prior knowledge, and external and internal knowledge linkages will show an inversely significant relationship with cognitive simplification processes. As one gets smaller, the other will get larger. We had posited that barriers to inflow of requisite expertise, lack of shared language, perceived pressure, and homogeneity in 'mind sets' will show a direct and significant positive relationship with cognitive simplification processes. That is, as one increases the other will also increase.

However, correlational analysis is not a robust test of relationships. Regression equations are more rigorous in explaining causal relationships since they take into consideration the intercorrelations of variables and determine the relative statistical power of predictor variables in explaining the criterion or dependent variable(s) (Hair et al., 1984). And the 'forced entry method' we followed in constructing our multiple (hierarchical) regression model requires that variables are entered one at a time in order of decreasing tolerance (that is, the variable most highly correlated with the dependent
variable is entered first). Computing a correlation matrix was necessary to determine the order of entry.

The 'forced entry' method was chosen because it allows one to isolate the predictor variable(s) which explain the most variance in the dependent variable, but at the same time, all variables are presented in the final equation with their relative contribution in explaining the variance of the criterion variable. The forced entry was complemented by a 'backward method' to confirm our findings.

Under the 'backward method' all predictor variables are entered simultaneously into the regression equation, and variables which do not meet a minimum tolerance criterion are forcibly removed. In addition the 'backward method' compensates for problems of multi-collinearity among variables. Multi-collinearity occurs when two or more independent variables are highly intercorrelated and thus can artificially inflate the $R^2$, or coefficient of determination value (the proportion of the variance of the dependent variable around its mean as explained by the independent variables). The SPSS-X regression 'backward method' procedure automatically computes the mutual tolerance of the independent variables fitted together in an equation. If the tolerance of any variable is less than 0.01, a warning is issued and the variable is not entered into the equation. Further, the procedure recomputes the tolerance of each variable at each step.
In the next chapter we will present and discuss the results of the analysis.
Chapter 6

Presentation and Discussion of Survey Results

In this chapter, we will examine the results of the predicted consequences of cognitive simplification processes (product development delays and project performance), and the antecedents of cognitive simplification processes (group related processes; diversity in cognitive modes, and select features of the overall work environment).

As noted in chapter 5, from the 197 surveys administered, 158 were returned (80% response rate). 49% of the respondents were M.Ds or Ph.Ds with specializations varying from chemistry, life sciences, toxicology, and biopharmaceutics. The subjects were organized across 25 concurrent and ongoing drug development projects teams and responded to survey items based on real time project deliberations. For analytical procedures where the project team was considered a unit of analysis, only scientists who spent a majority of time in the project were included.

In the subsequent sections we will discuss results pertaining to the consequences and antecedent of cognitive simplification processes.
Consequences of Cognitive Simplification Processes

In order to assess the construct validity and reliability of the scales employed we initially conducted 'exploratory factor analyses' and reliability analyses of the cognitive simplification scale, product development delay scale, and the project performance scales used with the team members and management.

Cognitive Simplification Scale Factor and Reliability Analysis

As indicated in Table 3, four factors emerged from the analysis of the cognitive simplification scale. The first factor included the following six items: prior (favored) hypothesis; single outcome calculation or oversimplification of the problem; problem set or overemphasizing a problem solving strategy; overconfidence in the illusion of prediction; illusion of one's personal control; and illusion of another's personal control. Interestingly, a majority of these factor items mirrored closely our 'a priori' classification of simplification processes in cognitive model formulation or deductive action, and thus we termed this factor 'Simplification in problem framing'.

The second factor also largely corresponded to our conceptual classification of simplification in inductive action or information and alternatives evaluation. The six items which showed high loadings on factor two were: favored information sources or adjustment and anchoring; magnifying preferred alternatives; denying risk-benefit (or value) trade-offs;
### TABLE 3
Factor and Reliability Analysis of Cognitive Simplification (Pitfalls) Scale

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1 Simplification in Problem Framing</th>
<th>Factor 2 Simplification in Information and Alternatives Evaluation</th>
<th>Factor 3 Poor Analogical Reasoning</th>
<th>Factor 4 Escalating Commitment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Favored hypothesis bias</td>
<td>.725</td>
<td>.178</td>
<td>.449</td>
<td>.140</td>
</tr>
<tr>
<td>2. Favored information sources</td>
<td>.185</td>
<td>.582</td>
<td>.532</td>
<td>.197</td>
</tr>
<tr>
<td>3. Allocating more resources</td>
<td>.199</td>
<td>.124</td>
<td>.141</td>
<td>.815</td>
</tr>
<tr>
<td>4. Inadequate analogical reasoning</td>
<td>.178</td>
<td>.107</td>
<td>.911</td>
<td>-.004</td>
</tr>
<tr>
<td>5. Oversimplification of the problem</td>
<td>.620</td>
<td>-.116</td>
<td>.370</td>
<td>.175</td>
</tr>
<tr>
<td>6. Magnifying preferred alternative</td>
<td>.282</td>
<td>.623</td>
<td>.411</td>
<td>.269</td>
</tr>
<tr>
<td>7. Depleting risk-benefit trade-offs</td>
<td>.453</td>
<td>.540</td>
<td>.357</td>
<td>-.250</td>
</tr>
<tr>
<td>8. Amplifying negative aspects of non-preferred alternative</td>
<td>.002</td>
<td>.849</td>
<td>.103</td>
<td>-.135</td>
</tr>
<tr>
<td>9. Devaluing partibility described alternatives</td>
<td>.349</td>
<td>.518</td>
<td>.196</td>
<td>-.325</td>
</tr>
<tr>
<td>10. Overemphasizing a problem solving strategy</td>
<td>.758</td>
<td>.230</td>
<td>.291</td>
<td>-.185</td>
</tr>
<tr>
<td>11. Limited generalization of theories, models, and findings</td>
<td>.303</td>
<td>.789</td>
<td>-.028</td>
<td>.126</td>
</tr>
<tr>
<td>12. Overconfidence in illusion of predication</td>
<td>.664</td>
<td>.556</td>
<td>-.081</td>
<td>.290</td>
</tr>
<tr>
<td>13. Illusion of one's personal control</td>
<td>.884</td>
<td>.235</td>
<td>.183</td>
<td>.089</td>
</tr>
<tr>
<td>14. Illusion of another's personal control</td>
<td>.844</td>
<td>.289</td>
<td>-.081</td>
<td>.032</td>
</tr>
</tbody>
</table>

| Eigen value                                      | 6.49                                      | 1.615                                                       | 1.23                              | 1.21                          |
| Pet. of variance explained                      | .465%                                     | .115%                                                       | .83%                              | .86%                          |
| Cronbach alpha                                  | .95                                       | .96                                                         | *                                 | *                             |

* Reliability coefficient for overall scale = .98
* Reliability not computed for single items

N=158
amplifying negative aspects of non-preferred alternatives, otherwise known as inferences of impossibility; devaluing partially described alternatives; and limited generalization of theories and findings or representativeness bias. We appropriately labelled this factor 'Simplification in information and alternatives evaluation'.

The third factor showed a very high loading of a single item - inadequate analogical reasoning. This was deemed appropriate given the significance attached to analogical reasoning as fundamental to scientific innovations (Nersessian, 1992). We identified this factor as 'Poor analogical reasoning'. The fourth factor also had a single item, which had to do with allocation of more resources to failing alternatives, termed as 'Escalating commitment'. Factor scores were computed by averaging across all items.

Reliability analysis on all fourteen items showed good internal consistency with a Cronbach alpha value of .98. For items comprising factor one (simplification in problem framing) the Cronbach alpha was .95, and for factor two (simplification in information and alternatives evaluation) it was .96. All Cronbach alphas well exceeded the .70 value recommended by Nunally (1978). Reliabilities were not computed for factors comprising one item.
Product Development Delays Scale Factor and Reliability Analysis

The factor analysis of the delay scale elicited three factors, as shown in Table 4. The first factor designated as **Timing and scheduling delays** included delays in responding to frequent changes in program activities, delays in getting resources, delays in responding to unrealistic schedules, and delays in recognizing that prior solutions were sub-optimal. The second factor was composed of delays in getting crucial people together, delays in getting management approvals and sanctions, and delays in overcoming internal resistance and politics was labelled 'Project management delays'. The third factor represented by delays in developing basic theory and models, and delays in synthesizing and testing new drug candidates was called **Comprehension cycle delays**. Factor scores were computed by averaging across items.

Reliability analysis for all items of the delay scale indicated a Cronbach alpha of .85. Items which fell under factor one (Timing and scheduling delays) indicated a reliability value of .78; for items under factor two (Project management delays) the coefficient was .79; and for factor three (Comprehension cycle delay) the Cronbach alpha was .71.

Project Performance Scale Factor and Reliability Analysis

As mentioned previously, team members were asked to rate project performance on four items: project productiveness, project innovativeness, progress in relation to internal standards such as schedules, and competitive
### TABLE 4

Factor and Reliability Analysis of Delay Scale

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1 Timing and Scheduling Delays</th>
<th>Factor 2 Project Management Delays</th>
<th>Factor 3 Comprehension Cycle Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Delays in developing basic theory and models</td>
<td>.205</td>
<td>.034</td>
<td>.864</td>
</tr>
<tr>
<td>2. Delays in testing and synthesizing new drug candidates</td>
<td>.020</td>
<td>.162</td>
<td>.863</td>
</tr>
<tr>
<td>3. Delays in responding to frequent changes in product requirements</td>
<td>.745</td>
<td>.171</td>
<td>.003</td>
</tr>
<tr>
<td>4. Delays in assembling sufficient resources</td>
<td>.650</td>
<td>.242</td>
<td>.152</td>
</tr>
<tr>
<td>5. Delays in coordinating and accessing crucial people</td>
<td>.347</td>
<td>.689</td>
<td>.043</td>
</tr>
<tr>
<td>6. Delays in response to unrealistic schedules</td>
<td>.808</td>
<td>.141</td>
<td>.037</td>
</tr>
<tr>
<td>7. Delays in recognizing and accepting that prior solutions were sub-optimal</td>
<td>.722</td>
<td>.160</td>
<td>.165</td>
</tr>
<tr>
<td>8. Delays in getting management approvals and sanctions</td>
<td>.074</td>
<td>.849</td>
<td>.182</td>
</tr>
<tr>
<td>9. Delays in overcoming internal resistance and politics</td>
<td>.279</td>
<td>.876</td>
<td>.040</td>
</tr>
</tbody>
</table>

| Eigen Value                  | 3.57  | 1.35 | 1.17 |
| Pct. of Variance Explained  | 39.7% | 15.1%| 13.1%|
| Cronbach Alpha               | .78   | .79  | .71  |

Reliability coefficient for overall scale = .85
N=158
progress in relation to external standards or other competing laboratories working in the same or similar area. A factor analysis (Table 5) of these four items resulted in a single factor. The Cronbach alpha was .70.

Eleven members of management rated each project's performance on two items - project productiveness and project innovativeness. Factor analysis suggested a single factor (Table 6). The reliability coefficient was .70.

*Dichotomization of Project Teams into Low and High Simplification Conditions*

In order to examine the relationship of cognitive simplification processes to product development delays and project performance, we classified the product development teams into high and low simplification (treatment) conditions based on a median split of an overall simplification score and the four factor scores which emerged from factor analysis of the cognitive simplification scale.

The classification based on factor one (simplification in problem framing) resulted in 16 teams being grouped under the low simplification condition and 9 teams in the high simplification condition. For factor two (simplification in information and alternatives evaluation) there were 18 low and 7 high simplification teams. There were 17 low and 8 high for factor three (poor analogical reasoning), and 15 low and 10 high for factor four (escalating commitment). For a classification based on the median split of the overall
### TABLE 5

Factor and Reliability Analysis of Project Performance Scale
(Project Team Members)

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How productive is this project in relation to its goals, i.e. a new drug candidate, new site of intervention, or new use of an existing drug</td>
<td>.847</td>
</tr>
<tr>
<td>2. How innovative is this project in the sense of generating new ideas or knowledge that advanced theory/science in this field</td>
<td>.701</td>
</tr>
<tr>
<td>3. How is the progress of the project in relation to plans and schedules</td>
<td>.758</td>
</tr>
<tr>
<td>4. How is the competitive progress of the project in relation to other laboratories working in the same or similar area</td>
<td>.601</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigen value</td>
<td>2.10</td>
</tr>
<tr>
<td>Pct. of variance explained</td>
<td>52.4%</td>
</tr>
<tr>
<td>Cronbach alpha</td>
<td>.711</td>
</tr>
</tbody>
</table>

N=158
TABLE 6

Factor and Reliability Analysis of Project Performance Scale (Management)

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How <strong>productive</strong> is this project in relation to its goals, i.e. a new drug candidate, new site of intervention, or new use of an existing drug</td>
<td><strong>.897</strong></td>
</tr>
<tr>
<td>2. How <strong>innovative</strong> is this project in the sense of generating new ideas or knowledge that advanced theory/science in this field</td>
<td><strong>.897</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Eigen value</th>
<th>1.608</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pct. of variance explained</td>
<td>80.4%</td>
</tr>
<tr>
<td>Cronbach alpha</td>
<td>.71</td>
</tr>
</tbody>
</table>
cognitive simplification score we obtained 16 low and 9 high teams.

MANOVAs ensured that the dichotomization of the teams into low and high simplification conditions using the median splits on the overall simplification score as well as the four factors were significant and in the predicted direction.

Teams split on the median of the overall cognitive simplification score differed significantly on all fourteen items. The Manova indicated the following results; $F= 4.95$, $df= 14, 101$, $p < .000$ (Table 7).

For simplification in problem framing, a Manova suggested that the low and high simplification teams significantly differed on all items constituting this factor ($F= 4.01$, $df= 5, 112$, $p < .001$), with all items except one being significant at the .001 level (Table 8).

The Manova results for simplification in information and alternatives evaluation were as follows; $F= 5.23$, $df= 6, 91$, $p < .000$. All items under the factor were significantly different at either the .001 level or .01 level (Table 9).

The Anova runs for poor analogical reasoning ($F= 8.57$, $df= 1, 127$, $p < .004$) and escalating commitment ($F= 7.21$, $df= 1, 127$, $p < .008$) suggested that the low and high simplification teams were significantly different also (Tables 10 and 11).
### TABLE 7
Means, Standard Deviations, ANOVA and MANOVA for Dichotomization of Product Development Teams Based on Median Split of Overall Simplification Score

<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification Teams</th>
<th>High Simplification Teams</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=16 Mean</td>
<td>s.d.</td>
<td>N=9 Mean</td>
<td>s.d.</td>
</tr>
<tr>
<td>1.  Favored hypothesis bias</td>
<td>2.19</td>
<td>1.38</td>
<td>3.14</td>
<td>1.66</td>
</tr>
<tr>
<td>2.  Favored information sources</td>
<td>2.19</td>
<td>1.39</td>
<td>3.75</td>
<td>1.55</td>
</tr>
<tr>
<td>3.  Allocating more resources</td>
<td>1.72</td>
<td>1.34</td>
<td>1.83</td>
<td>1.47</td>
</tr>
<tr>
<td>4.  Inadequate analogical reasoning</td>
<td>1.76</td>
<td>1.19</td>
<td>2.53</td>
<td>1.55</td>
</tr>
<tr>
<td>5.  Oversimplification of problem</td>
<td>2.35</td>
<td>1.43</td>
<td>3.23</td>
<td>1.68</td>
</tr>
<tr>
<td>6.  Magnifying preferred alternative</td>
<td>2.30</td>
<td>1.36</td>
<td>3.30</td>
<td>1.64</td>
</tr>
<tr>
<td>7.  Denying risk-benefit trade-offs</td>
<td>1.81</td>
<td>1.00</td>
<td>3.20</td>
<td>1.63</td>
</tr>
<tr>
<td>8.  Amplifying negative aspects of non-preferred alternative</td>
<td>1.85</td>
<td>1.17</td>
<td>3.47</td>
<td>2.01</td>
</tr>
<tr>
<td>9.  Deviating partially described alternatives</td>
<td>2.17</td>
<td>1.41</td>
<td>3.33</td>
<td>1.79</td>
</tr>
<tr>
<td>10. Oversimplifying a problem solving strategy</td>
<td>2.04</td>
<td>1.24</td>
<td>3.00</td>
<td>1.78</td>
</tr>
<tr>
<td>11. Limited generalization of theories, models and findings</td>
<td>2.30</td>
<td>1.40</td>
<td>3.17</td>
<td>1.90</td>
</tr>
<tr>
<td>12. Overconfidence in illusion of prediction</td>
<td>2.45</td>
<td>1.59</td>
<td>3.53</td>
<td>1.63</td>
</tr>
<tr>
<td>13. Illusion of one's personal control</td>
<td>2.34</td>
<td>1.57</td>
<td>3.40</td>
<td>2.01</td>
</tr>
<tr>
<td>14. Illusion of another's personal control</td>
<td>2.42</td>
<td>1.44</td>
<td>3.37</td>
<td>1.85</td>
</tr>
</tbody>
</table>

**MANOVA Results**

F value=4.949
df=4,101
Significance of F=.000
TABLE 8

Means, Standard Deviations, ANOVA and MANOVA for Dichotomization of
Product Development Teams Based on Median Split of Simplification in "Problem Framing"

<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification Teams</th>
<th>High Simplification Teams</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>N=16</td>
<td>N=9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Devoted hypothesis bias</td>
<td>2.04 1.33</td>
<td>2.94 1.58</td>
<td>11.019</td>
<td>.001</td>
</tr>
<tr>
<td>2. Oversimplification of problem</td>
<td>2.08 1.37</td>
<td>3.24 1.61</td>
<td>18.401</td>
<td>.000</td>
</tr>
<tr>
<td>3. Oversimplifying a problem solving strategy</td>
<td>1.92 1.06</td>
<td>2.80 1.77</td>
<td>11.134</td>
<td>.001</td>
</tr>
<tr>
<td>4. Overconfidence in illusion of prediction</td>
<td>2.18 1.46</td>
<td>3.37 1.69</td>
<td>17.166</td>
<td>.000</td>
</tr>
<tr>
<td>5. Illusion of one's personal control</td>
<td>2.17 1.45</td>
<td>3.20 1.86</td>
<td>11.781</td>
<td>.001</td>
</tr>
<tr>
<td>6. Illusion of another's personal control</td>
<td>2.35 1.43</td>
<td>3.06 1.72</td>
<td>14.859</td>
<td>.015</td>
</tr>
</tbody>
</table>

MANOVA Results

F value=.004
df=5,112
Significance of F=.001

df=1,118
TABLE 9
Means, Standard Deviations, ANOVA and MANOVA for Dichotomization of Product Development Teams Based on Median Split of Simplification in Information and Alternatives Evaluation

<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification Teams N=18 Mean</th>
<th>s.d.</th>
<th>High Simplification Teams N=7 Mean</th>
<th>s.d.</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Favored information sources</td>
<td>2.13</td>
<td>1.24</td>
<td>3.53</td>
<td>.176</td>
<td>21.078</td>
<td>.000</td>
</tr>
<tr>
<td>2. Magnifying preferred alternative</td>
<td>2.34</td>
<td>1.36</td>
<td>3.15</td>
<td>1.74</td>
<td>6.348</td>
<td>.013</td>
</tr>
<tr>
<td>3. Denying risk-benefit trade-offs</td>
<td>1.84</td>
<td>1.01</td>
<td>3.03</td>
<td>1.66</td>
<td>19.282</td>
<td>.000</td>
</tr>
<tr>
<td>4. Amplifying negative aspects of non-preferred alternative</td>
<td>1.80</td>
<td>.98</td>
<td>3.15</td>
<td>2.02</td>
<td>19.966</td>
<td>.005</td>
</tr>
<tr>
<td>5. Devaluing partially described alternatives</td>
<td>2.19</td>
<td>1.41</td>
<td>3.12</td>
<td>1.70</td>
<td>8.334</td>
<td>.095</td>
</tr>
<tr>
<td>6. Limited generalization of theories, models and findings</td>
<td>2.29</td>
<td>1.28</td>
<td>3.18</td>
<td>1.88</td>
<td>7.769</td>
<td>.026</td>
</tr>
</tbody>
</table>

df=1,106

MANOVA Results
F value=5.224
df=5,98
Significance of F=.000
### TABLE 10

Means, Standard Deviations, and ANOVA for Dichotomization of Product Development Teams Based on Median Split of 'Poor Analogical Reasoning'

<table>
<thead>
<tr>
<th>Item</th>
<th>Low Simplification Teams N=17</th>
<th>High Simplification Teams N=8</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means</td>
<td>s.d.</td>
<td>Means</td>
<td>s.d.</td>
<td></td>
</tr>
<tr>
<td>Poor Analogical Reasoning</td>
<td>1.85</td>
<td>2.74</td>
<td>8.57</td>
<td>.004</td>
</tr>
</tbody>
</table>

\( df(e)=1,127 \)

### TABLE II

Means, Standard Deviations, and ANOVA for Dichotomization of Product Development Teams Based on Median Split of Escalating Commitment

<table>
<thead>
<tr>
<th>Item</th>
<th>Low Simplification Teams N=15</th>
<th>High Simplification Teams N=10</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means</td>
<td>s.d.</td>
<td>Means</td>
<td>s.d.</td>
<td></td>
</tr>
<tr>
<td>Escalating Commitment</td>
<td>1.57</td>
<td>2.30</td>
<td>7.21</td>
<td>.008</td>
</tr>
</tbody>
</table>

\( df(e)=1,127 \)
Relationship of Cognitive Simplification Processes to Product Development Delays

In order to test our hypothesis that product development teams reporting higher incidences of cognitive simplification processes in their deliberations will also report higher incidences of delays in the product development process, we employed MANOVAs and ANOVAs.

Thus, high and low and simplification groups (treatment) resulting from the median splits of all four factors of the cognitive simplification scale were compared on all nine delay items, as well as items constituting each factor of the delay scale (dependent variables).

Relationship of Simplification in Problem Framing to Delays

For teams split on the basis of low and high simplification in problem framing, the Manova procedure suggested a significant difference between the groups for delay factor two, namely project management delays ($F = 2.72; \text{df} = 3.115, p < .04$). The Anovas indicated that the nine product development teams, out of the twenty five reporting a high incidence of simplifications in problem framing, also reported a higher incidence of delays in getting crucial people together ($F = 2.61, \text{df} = 1.119, p < .014$), and a higher incidence of delays in getting management approvals and sanctions ($F = 3.75, \text{df} = 1, 119, p < .05$). No significant difference was found on the third delay item constituting this factor, namely delays in overcoming internal resistance and politics.
Table 12 presents the means, standard deviations, and results of the Anova and Manova.

A Manova run to determine the overall impact of 'simplifications in problem framing' on delays confirmed that there were no significant differences between the teams on the nine items of the delay scale. Also, no significant differences were found for the remaining two delay factors (Timing and scheduling delays, and Comprehension cycle delays), although the mean values in all three instances were in the predicted direction.

For the total delay score, the means of the low teams were 3.9 and the high teams were 4.1. For Timing and Scheduling delays it was as follows; low teams= 4.0 and high teams= 4.2. In the case of Comprehension cycle delays the low teams mean was 3.81 and the high teams mean was 4.29.

Relationship of Simplification in Information and Alternatives Evaluation to Delays

For teams classified into low (N= 18) and high (N=7) conditions based on Simplification in 'information and alternatives evaluation', the second factor, a Manova using all nine items of the delay scale as dependent variables, indicated significant differences between the two groups (F= 2.32, df= 9, 64, p < .025). Anovas revealed significant differences for four out of the nine items (see Table 13). The teams displaying higher 'simplifications in information and alternatives evaluation' also reported a higher incidence of delays in
### TABLE 12
Means, Standard Deviations, ANOVA and MANOVA for Project Management Delay Items for Low and High Simplification Conditions in Problem Framing

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teams N=16 Means</td>
<td>s.d.</td>
<td>Teams N=9 Means</td>
<td>s.d.</td>
</tr>
<tr>
<td>1. Delays in coordinating and accessing crucial people</td>
<td>3.38</td>
<td>1.63</td>
<td>4.20</td>
<td>1.64</td>
</tr>
<tr>
<td>2. Delays in getting management approvals and sanctions</td>
<td>3.51</td>
<td>1.59</td>
<td>4.14</td>
<td>1.71</td>
</tr>
<tr>
<td>3. Delays in overcoming internal resistance and politics</td>
<td>4.13</td>
<td>1.76</td>
<td>4.57</td>
<td>2.04</td>
</tr>
</tbody>
</table>

**MANOVA Results**

F value = 2.722  
df = 3, 115  
Significance of F = .041
TABLE 13

Means, Standard Deviations, ANOVA* and MANOVA for Overall Delay Items for Low and High Simplification Conditions in Information/Alternative Evaluation

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teams N=18</td>
<td>Mean</td>
<td>Mean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Delays in developing basic theory and models</td>
<td>3.82</td>
<td>3.97</td>
<td>1.83</td>
<td>0.107</td>
</tr>
<tr>
<td>2. Delays in testing and synthesizing new design candidates</td>
<td>3.40</td>
<td>4.03</td>
<td>1.90</td>
<td>1.95</td>
</tr>
<tr>
<td>3. Delays in responding to frequent changes in product requirements</td>
<td>3.18</td>
<td>3.93</td>
<td>1.81</td>
<td>3.37</td>
</tr>
<tr>
<td>4. Delays in assembling sufficient resources</td>
<td>4.27</td>
<td>4.63</td>
<td>1.47</td>
<td>.826</td>
</tr>
<tr>
<td>5. Delays in coordinating and accessing crucial people</td>
<td>2.91</td>
<td>4.07</td>
<td>1.64</td>
<td>10.73</td>
</tr>
<tr>
<td>6. Delays in response to unrealistic schedules</td>
<td>4.64</td>
<td>4.57</td>
<td>1.78</td>
<td>.356</td>
</tr>
<tr>
<td>7. Delays in recognizing and accepting that prior solutions were sub-optimal</td>
<td>3.09</td>
<td>4.00</td>
<td>1.91</td>
<td>4.62*</td>
</tr>
<tr>
<td>8. Delays in getting management approvals and sanctions</td>
<td>3.22</td>
<td>4.17</td>
<td>1.80</td>
<td>5.98</td>
</tr>
<tr>
<td>9. Delays in overcoming internal resistance and politics</td>
<td>3.56</td>
<td>4.47</td>
<td>2.00</td>
<td>4.35*</td>
</tr>
</tbody>
</table>

* df=1,73

MANOVA Results:

F value=2.323
df=8,64
Significance of F=.025
recognizing that prior solutions were sub-optimal (F = 4.63, df = 1.73, p < .035); delays in getting crucial people together (F = 10.73, df = 1.73, p < .002); delays in getting management approvals and sanctions (F = 5.98, df = 1.73, p < .017); and delays in overcoming internal resistance and politics (F = 4.32, df = 1.73, p < .04).

A separate Anova procedure using the total delay score as the dependent variable was used to examine the overall effect of simplifications in information and alternatives on delays. The test confirmed the earlier findings that simplifications in information and alternatives evaluation impacts most types of delays in product development teams. The low and high simplification teams differed significantly on the frequency of overall delays experienced (F = 8.72, df = 1.120, p < .004). The total mean delay score of the low simplification teams was 3.60 (N = 68) and the total mean delay score of the high simplification teams was 4.30 (N = 54).

Significant differences between the teams were observed for project Management delays based on a Manova run (F = 6.13, df = 3.93, p < .001). Anovas verified that teams displaying higher levels of simplifications in information and alternatives evaluation also reported higher incidence of delays in getting crucial people together (F = 1.61, df = 1.95, p < .000); delays in getting management approvals and sanctions (F = 9.92, df = 1.95, p < .002); and delays in overcoming internal resistance and politics (F = 8.77, df = 1.95, p < .004). All results are displayed in Table 14.
TABLE 14

Means, Standard Deviations, ANOVA and MANOVA for Project Management Delay Items for Low and High Simplification Conditions in Information and Alternatives Evaluation

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Low Simplification Teams N=18</th>
<th>High Simplification Teams N=7</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Delays in coordinating and accessing crucial people</td>
<td>3.02 ± 1.54</td>
<td>4.34 ± 1.67</td>
<td>16.10</td>
<td>.000</td>
</tr>
<tr>
<td>2. Delays in getting management approvals and sanctions</td>
<td>3.17 ± 1.49</td>
<td>4.19 ± 1.64</td>
<td>9.96</td>
<td>.002</td>
</tr>
<tr>
<td>3. Delays in overcoming internal resistance and politics</td>
<td>3.64 ± 1.67</td>
<td>4.74 ± 1.93</td>
<td>8.77</td>
<td>.024</td>
</tr>
</tbody>
</table>

* df=1,95

MANOVA Results
F value = 6.122
df = 3,92
Significance of F = .001
Manovas suggested that differences on comprehension cycle delays were not significant though the mean values were in the predicted direction (Low team Mean = 3.9; High team Mean = 4.5).

Timing and scheduling delays, however, were close to significance ($F = 2.27, df = 3.91, p < .06$). The averaged mean values on this delay factor for the low teams was 3.7 and the high teams was 4.27.

Relationship of Poor Analogical Reasoning and Escalating Commitment to Delays

Comparison of the low and high teams dichotomized on poor analogical reasoning and escalating commitment did not show significant differences for any of the delay factors or delay items.

However, the means were in the predicted direction. For high and low classifications based on 'poor analogical reasoning', means for the total delay score were: low teams = 3.9; high teams = 4.2. For timing and scheduling delays, the low teams had a mean of 4.0 and for the high teams it was 4.15. For project management delays the low teams showed a mean of 3.70 and the high teams a mean of 3.95. In the case of comprehension cycle delays it was; low teams = 4.0, and high teams = 4.2.

A similar pattern was observed for dichotomization of teams based on 'escalating commitment'. The overall delay scores were low teams, 3.90 and
high teams, 4.02; For timing and scheduling delays it was, low teams, 4.06 and high teams, 4.15. Project management delays showed the following difference in means, low=3.7 and high 3.92. For comprehension cycle delays it was low, 4.05 and high 4.08.

In summary, the results suggested that 'simplifications in information and alternatives evaluation' showed a strong relationship to the incidences of delays as a whole. A similarly robust relationship was found with reference to project management delays and a near statistically significant relationship with Timing and scheduling delays.

Simplifications in problem framing showed a significant relationship to project management delays.

*Relationship of Cognitive Simplification Processes to Project Performance*

We used similar procedures of analysis of variance to examine the relationship of cognitive simplification processes to project performance. High and low simplification conditions (treatment) resulting from the median splits of all four factors of the cognitive simplification scale as well as the overall cognitive simplification score were compared on elements of project performance. The procedure was undertaken to investigate the hypotheses that product development teams reporting higher incidences of cognitive simplification process in their deliberations will be rated lower on level of
project team performance (effectiveness); a) by project team members, and b) by management.

*Relationship of Cognitive Simplification Processes to Project Performance*

*Ratings by Team Members*

Results showed strong confirmatory support for the relationship between cognitive simplification processes and project performance (as rated by team members). Anovas suggested significant differences for most items constituting the factor of project performance as well the total project performance index. Such differences were obtained for dichotomizations based on the overall cognitive simplification score and also the factors of simplification in problem framing, simplification in information and alternatives evaluation, and poor analogical reasoning.

For high and low teams based on the **overall simplification** score, Anovas suggested that teams rated high in overall simplification were rated lower on project **productiveness** \( (F= 6.223, \text{ df} = 1,136, \ p < .014) \), project **innovativeness** \( (F= 4.757, \text{ df} = 1,136, \ p < .031) \); project **competitive progress** in relation to other laboratories \( (F= 7.444, \text{ df} = 1,136, \ p < .007) \) and a total project performance index derived from averaging across all four items of the factor \( (F= 9.503, \text{ df} = 1,136, \ p < .002) \). Significant differences were not found for project progress in relation to internal standards, although the means were in the predicted direction \( \text{Low teams}= 4.2; \text{ High teams}= 3.9 \). The results are displayed in Table 15.
### TABLE 15
Means, Standard Deviations, and ANOVAs for Project Performance (Team Member Ratings) for Teams Classified on Overall Simplification Score

<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Project productiveness</td>
<td>4.84 (1.36)</td>
<td>4.20 (1.40)</td>
<td>6.223</td>
<td>.014</td>
</tr>
<tr>
<td>2. Project innovativeness</td>
<td>4.70 (1.40)</td>
<td>4.10 (1.28)</td>
<td>4.757</td>
<td>.031</td>
</tr>
<tr>
<td>3. Project progress in relation to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>internal standards</td>
<td>4.20 (1.30)</td>
<td>3.91 (1.40)</td>
<td>1.429</td>
<td>.234</td>
</tr>
<tr>
<td>4. Project competitive progress</td>
<td>4.10 (1.50)</td>
<td>3.30 (1.50)</td>
<td>7.444</td>
<td>.007</td>
</tr>
<tr>
<td>5. Project total* performance index</td>
<td>4.44 (1.98)</td>
<td>3.88 (1.03)</td>
<td>9.501</td>
<td>.002</td>
</tr>
</tbody>
</table>

*Based on averages of items 1-4.*  

df=1,136
Similar results were obtained for high and low teams based on simplifications in problem framing, simplifications in information and alternatives evaluation, and poor analogical reasoning (Tables 16, 17, 18).

For simplifications in problem framing the Anova results for project productiveness was $F = 6.184$, df $= 1, 138$, $p < .05$. Project innovativeness ($F = 7.071$, df $= 1,138$, $p < .009$), Project competitive progress ($F = 8.398$, df $= 1,138$, $p < .004$), and total project performance index ($F = 10.306$, df $= 1,138$, $p < .002$) showed a similar pattern. No significant differences were obtained on project progress (Low team means= 4.2 ; High team means= 3.91).

Simplifications in information and alternatives evaluation showed the following results: Anovas for project productiveness ($F = 3.993$, df $= 1,138$, $p < .037$); project innovativeness ($F = 5.887$, df $= 1,138$, $p < .017$); project competitive progress ($F = 7.567$, df $= 1,138$, $p < .007$), and total project performance index ($F = 10.146$, df $= 1,138$, $p < .002$) were significant. Project progress was not related (Low team means= 4.3, High team means= 3.7).

Project teams scoring high in inadequate or poor analogical reasoning showed lower project performance on four measures. Their productiveness ($F = 7.063$, df $= 1,138$, $p < .034$), innovativeness ($F = 7.435$, df $= 1,138$, $p < .007$), competitive progress ($F = 5.578$, df $= 1,138$, $p < .01$), total project performance index ($F = 8.178$, df $= 1,138$, $p < .005$) were all lower. While project progress was also rated lower it was not statistically significant (Low team means= 4.2; High team means= 3.8).
<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification Teams</th>
<th>High Simplification Teams</th>
<th>( F ) Value</th>
<th>Significance of ( F )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N=16</td>
<td>Mean</td>
<td>s.d.</td>
<td>Mean</td>
</tr>
<tr>
<td>1.</td>
<td>Project productiveness</td>
<td>4.83</td>
<td>1.40</td>
<td>4.18</td>
</tr>
<tr>
<td>2.</td>
<td>Project innovativeness</td>
<td>4.70</td>
<td>1.45</td>
<td>4.00</td>
</tr>
<tr>
<td>3.</td>
<td>Project progress in relation to internal standards</td>
<td>4.20</td>
<td>1.20</td>
<td>3.90</td>
</tr>
<tr>
<td>4.</td>
<td>Project competitive progress</td>
<td>4.10</td>
<td>1.52</td>
<td>3.20</td>
</tr>
<tr>
<td>5.</td>
<td>Project total* performance index</td>
<td>4.49</td>
<td>.98</td>
<td>3.84</td>
</tr>
</tbody>
</table>

\*Based on averages of items 1-4.
<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teams N=18</td>
<td>Teams N=7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mean 1.35</td>
<td>Mean 1.50</td>
<td>4.993</td>
<td>.037</td>
</tr>
<tr>
<td>1. Project productivity</td>
<td>4.80</td>
<td>4.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Project innovativeness</td>
<td>4.70</td>
<td>4.00</td>
<td>5.887</td>
<td>.017</td>
</tr>
<tr>
<td>3. Project progress in relation to</td>
<td>4.30</td>
<td>3.70</td>
<td>2.973</td>
<td>.087</td>
</tr>
<tr>
<td>internal standard</td>
<td>1.24</td>
<td>1.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Project competitive progress</td>
<td>4.10</td>
<td>3.20</td>
<td>7.567</td>
<td>.007</td>
</tr>
<tr>
<td>5. Project total* performance index</td>
<td>4.42</td>
<td>3.81</td>
<td>10.146</td>
<td>.002</td>
</tr>
</tbody>
</table>

*Based on averages of items 1-4.
### TABLE 18

Means, Standard Deviations, and ANOVAs for Project Performance
(Team Member Ratings) for Teams Classified on (Poor) Analogical Reasoning

<table>
<thead>
<tr>
<th>Items</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>s.d.</td>
<td>Mean</td>
<td>s.d.</td>
</tr>
<tr>
<td>1. Project productiveness</td>
<td>4.80</td>
<td>1.30</td>
<td>4.00</td>
<td>1.50</td>
</tr>
<tr>
<td>2. Project innovativeness</td>
<td>4.70</td>
<td>1.30</td>
<td>3.90</td>
<td>1.40</td>
</tr>
<tr>
<td>3. Project progress in relation to</td>
<td>4.20</td>
<td>1.30</td>
<td>3.80</td>
<td>1.40</td>
</tr>
<tr>
<td>internal standards</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Project competitive progress</td>
<td>4.00</td>
<td>1.50</td>
<td>3.40</td>
<td>1.60</td>
</tr>
<tr>
<td>5. Project total* performance index</td>
<td>4.40</td>
<td>.97</td>
<td>3.80</td>
<td>1.10</td>
</tr>
<tr>
<td>df=1, 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Based on averages of items 1-4.
For teams split on escalating commitment, the differences were not significant for either the total performance index (Low team means = 4.3; High team means = 4.1), project productiveness (Low means = 4.5; High means = 4.1), project innovativeness (Low means = 4.5; High means = 4.4), project competitive progress (Low means = 3.8; High means = 3.7) or project internal progress (Low means = 4.2; High means = 4.0).

In summary, cognitive simplification processes in problem framing, information and alternatives evaluation, and analogical reasoning were strongly related to lower ratings of project performance (effectiveness) by team members, as was the overall simplification index.

*Relationship of Cognitive Simplification Processes to Project Performance Ratings by Management*

We used a single dependent measure called Project performance, derived from averaging the two items (productiveness and innovativeness) that constituted a single factor. All classifications of teams, except for the dichotomization based on escalating commitment, showed a significant relationship to project performance.

Teams evidencing high overall simplifications, high problem framing simplifications, high information and alternatives evaluation simplifications, and poor analogical reasoning were rated by management as significantly lower on project performance (Table 19).
TABLE 19

Relationship of Cognitive Simplification Processes to Project Performance (Management Ratings)
Means, Standard Deviations and ANOVAs

<table>
<thead>
<tr>
<th>Classification Basis</th>
<th>Low Simplification</th>
<th>High Simplification</th>
<th>F Value</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teams</td>
<td>Teams</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N=16 Mean s.d.</td>
<td>N=9 Mean s.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>N=16 Mean s.d.</td>
<td>N=9 Mean s.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.191 1.647</td>
<td>8.915 3.481</td>
<td>20.147</td>
<td>.000</td>
</tr>
<tr>
<td>3. Simplification in information and alternatives evaluation</td>
<td>N=18 Mean s.d.</td>
<td>N=7 Mean s.d.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11.000 2.041</td>
<td>9.414 3.31</td>
<td>6.746</td>
<td>.019</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>N=17 Mean s.d.</td>
<td>N=8 Mean s.d.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

df=1136
The results were as follows: overall simplification index (F= 9.457, df= 1,136, p< .003); simplifications in problem framing (F= 20.147, df= 1,136, p< .000); simplifications in information and alternatives evaluation (F= 6.746, df= 1,136, p< .010); poor analogical reasoning (F= 6.356, df= 1,136, p< .013).

Escalating commitment was not related to project performance management ratings (Low teams mean= 9.81; High teams mean= 9.703).

Discussion of Results on Consequences of Cognitive Simplification Processes

The results provide strong empirical evidence that cognitive simplification processes can significantly explain delays in the product development process as well as project performance effectiveness.

Product development teams that experience higher levels of simplifications in information and alternatives evaluations are likely to encounter more and different types of delays, which can adversely impact product development time.

Specifically, 'simplifications in information and alternatives evaluation' showed a strong relationship to the incidences of delays as a whole, as well as project management delays, and a near significant relationship with timing and scheduling delays.
This finding is also corroborated by learnings from the Vita project which experienced significant delays in the product development process. A large proportion of the delays can be attributed to simplifications in information and alternatives evaluations, such as denying cost-benefit trade-offs, relying on favored information sources, magnifying the attractiveness of preferred alternatives, amplifying negative aspects of non-preferred alternatives, and devaluing partially described alternatives, in the project leader's push for an orally based drug.

In essence, product development teams which do not take the time to consider all available information sources and forego the processes of 'thinking hard' and debating alternatives are likely to prematurely converge upon a preferred alternative which they might later regret. While such teams may appear more decisive and active, the results suggest that the same teams may also be expending energies in overcoming significant project management delays. Thus, teams which prematurely converge on a preferred alternative are less apt to have a viable fall back strategy if their efforts do not pan out. Consequently, these teams encounter major project management delays as they scramble to regroup crucial people, await new management sanctioning and approvals, and attempt to overcome internal resistance and politics. Once these delays occur and political interests become more salient, these teams also experience delays in recognizing and accepting prior sub-optimal solutions (Hickson et al., 1986) which was evident in the project leader of the Vita project's continued push for an oral drug even after the project failed at clinical tests.
The importance of considering all available information sources is also underscored by Eisenhardt's (1989) findings. Her case study analysis of decision making in high velocity environments suggests that faster and higher quality decision making occurs in teams that use more, and not less information, and consider more, not fewer alternatives.

Concerning the link between simplifications in problem framing and project management delays, the results emphasize the necessity for product development teams to invest in multiple problem solving strategies and debate competing hypotheses (Eisenhardt, 1989). These activities can obviate the possibility of oversimplification and premature decision closure (Imai et al., 1985) while making explicit the trade-offs involved. Examining and interpreting multiple problem frames can help team members and managers to make a more deliberate assessment of the risks associated with a particular choice situation.

Comprehension cycle delays were not significantly impacted by any of the four cognitive simplification factors, although the mean values were in the predicted direction. These results are surprising since from a logical angle it appears that simplifications in problem framing, information and alternatives evaluation, and inadequate analogical reasoning should be related to comprehension cycle delays, since these simplification types impinge upon comprehension processes. However, at this point we cannot comment on the nonsignificance of this relationship since the study was exploratory in nature.
We believe that empirical identification of these factors are themselves a worthwhile contribution. However, we do recognize the need for further examination and elaboration in the future.

The overall simplification index, as well as simplifications in problem framing, information and alternatives evaluation and analogical reasoning were all significantly related to project performance effectiveness ratings by team members and management. These results align well with our earlier theoretical conceptions of the requirements of complexification for scientific success and cognitive simplification processes as a principal barrier which can hamper the complexification process and result in (development delays and) unsuccessful scientific outcomes.

A point of interest here is, why simplifications in information and alternatives evaluation showed a stronger relationship to delays and project performance, than simplifications in problem framing and analogical reasoning, which were robustly related principally to project performance.

A plausible explanation for these findings are that an immediate manifestation of simplifications in information and alternatives evaluation would be delays. As we have observed earlier, once a problem is framed a certain way, information which (only) confirms this framing is actively sought (Knorr-Cetina, 1981; Janis, 1989). This was evident in the Vita project, where the issue was framed as an oral delivery drug by the project leader who selectively sought information to support this focus.
However, frequently this emphasis can become one of 'trying to force fit data into the existing frame'. Thus, as one set of selectively evaluated data does not produce the anticipated results, the process can extend itself into one of considering more selective data or more ways of cutting or analyzing the data in order to confirm this frame. In statistical parlance this can be equated with initially employing multivariate analysis and if that does not produce results in the expected direction, then trying and fitting the same data into a regression equation.

A quote from the Vita project is revealing. As the project leader emphasized;

"Let us consider more tests [to prove oral efficacy], cut the data in different ways, - spend more time".

The challenge turned into proving that an oral drug was indeed possible and tests [and time] were added to make it work. Thus this phase of the Vita project showed numerous delays.

The project was able to make a turn around, and progress smoothly only when the fundamental framing of the problem was questioned and modified from oral to topical. When the realization set in that the proposed relationship was not correct and attempts to confirm this fundamentally erroneous frame will only result in more delays (as a consultant remarked;
"you don't have a snowball's chance in hell of developing an oral drug"), project performance became more effective.

Therefore, while simplification in information and alternatives evaluation was related to both delays and project performance, fundamental framing of issues which in many ways determines overall project success is closely associated with simplifications in problem framing and analogical reasoning. This may explain why problem framing and analogical reasoning showed a robust relationship principally to project performance effectiveness.

Another issue worth some discussion is the non significance of 'Escalating commitment' in either explaining delays or project performance effectiveness. One potential explanation is that escalating commitment can be equated more with a broader cognitive orientation of investing more resources, than with specific forms of deductive and inductive action. In fact escalating commitment might be a 'root' simplification activity which may precipitate 'derivative' simplifications in problem framing, information and alternatives evaluation, and analogical reasoning. The Vita example is a case in point. In his escalating drive to force an oral drug candidate, the project leader listened to selective information that confirmed his framing of the issues, bolstered the attractiveness of the preferred alternative, downplayed the attractiveness of the non-preferred alternatives, devalued partially described alternatives, and was subject to an illusion of personal control. Therefore, it is conceivable that escalating commitment might be more directly related to other types of cognitive simplification processes and indirectly related to project performance
and product development delays. This relationship is worth investigation in the future.
Antecedents of Cognitive Simplification Processes

For assessing the impact of context (antecedents) on cognitive simplification processes, we operationalized context at three distinct levels; group functioning related processes, cognitive modes, and features of the overall work environment.

In the subsequent sections, we will elaborate on the results obtained on the interaction of each level of context with cognitive simplification processes.

Relationship of 'Group Functioning' to Cognitive Simplification Processes

Factor and Reliability Analyses

The results of the exploratory factor and reliability analyses of the scales employed to operationalize select features of group functioning were as follows:

Group Norms: A single factor emerged from the two item scale that measured the extent to which conflicting interpretations are openly explored; and the extent to which members felt comfortable expressing disagreements. The reliability for the scale was .76 (Table 20).

Requisite expertise: The six item scale had two items measuring
### TABLE 20

**Factor and Reliability Analysis of Group Norms Scale**

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extent to which conflicting interpretation or alternatives are openly explored and discussed before making key discussions</td>
<td>.838</td>
</tr>
<tr>
<td>2. Extent to which member(s) feel comfortable expressing counter opinions or disagreements when important technical issues are being discussed</td>
<td>.838</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigen value</td>
<td>1.406</td>
</tr>
<tr>
<td>Pct. of variance explained</td>
<td>70.3%</td>
</tr>
<tr>
<td>Cronbach alpha</td>
<td>.76</td>
</tr>
</tbody>
</table>

N=158
requisite expertise in terms of availability of critical information and relevant expertise and four items measuring barriers to requisite expertise; missing parties, wrong parties, and lack of internal and external consulting.

The rotated solution suggested two factors (Table 21). Factor one, which included the four impediments to requisite expertise, was labeled 'Barriers to requisite information and expertise' and showed a reliability coefficient of .90. Factor two with a Cronbach alpha of .68 was termed 'Availability of requisite information and expertise'.

**Integrative leadership:** The four items constituting this scale (extent to which project leader has good conceptual understanding of member work; is a sounding board for ideas; provides fresh approaches; and recognizes and mediates conflicts) loaded onto a single factor (Table 22). The reliability coefficient was .90.

**Absence of shared language,** another measure pertaining to group functioning, was represented by a single item. Thus, factor and reliability analysis was not undertaken.

**Correlational Analyses**

Correlational analysis was performed between the dependent variables (overall simplification index and the four factors), and the independent variables (group norms, availability of, and barriers to requisite
TABLE 21

Factor and Reliability Analysis of Requisite Expertise Scale

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extent to which critical information has been available prior to making key</td>
<td></td>
<td></td>
</tr>
<tr>
<td>decisions</td>
<td>-0.064</td>
<td>0.742</td>
</tr>
<tr>
<td>Extent to which relevant expertise has been available to make key decisions</td>
<td>-0.275</td>
<td>0.844</td>
</tr>
<tr>
<td>Extent of impact of missing parties from key discussions</td>
<td>0.673</td>
<td>-0.117</td>
</tr>
<tr>
<td>Extent of impact of wrong parties in key discussions</td>
<td>0.631</td>
<td>-0.223</td>
</tr>
<tr>
<td>Extent of impact of lack of internal consulting</td>
<td>0.848</td>
<td>-0.163</td>
</tr>
<tr>
<td>Extent of impact of lack of external consulting</td>
<td>0.765</td>
<td>-0.154</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Eigen value</th>
<th>Pct. of variance explained</th>
<th>Cronbach alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.384</td>
<td>39.7%</td>
<td>0.90</td>
</tr>
<tr>
<td></td>
<td>1.1228</td>
<td>20.5%</td>
<td>0.68</td>
</tr>
</tbody>
</table>

N=158
### TABLE 22

Factor and Reliability Analysis of Integrative Leadership Scale

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extent to which project leader has an excellent conceptual understanding of member work</td>
<td>.800</td>
</tr>
<tr>
<td>2. Extent to which project leader is an excellent sounding board for new ideas</td>
<td>.920</td>
</tr>
<tr>
<td>3. Extent to which project leader is effective at providing fresh approaches</td>
<td>.832</td>
</tr>
<tr>
<td>4. Extent to which project leader recognizes and mediates conflicts between groups or individuals</td>
<td>.910</td>
</tr>
</tbody>
</table>

Eigen value 3.00

Pct. of variance explained 75.0%

Cronbach alpha .92

N=158
expertise, absence of shared language, and integrative leadership).

This exercise was undertaken to confirm the directionality of the proposed relationships and to conduct an early test of significance of the following hypotheses:

The lower the reported level of group deliberative norms favoring open debate, the higher the reported level of cognitive simplification processes in the deliberations of product development teams.

The lower the reported level of requisite expertise available in product development teams, the higher the reported level of cognitive simplification processes in the deliberations of product development teams.

The higher the perceived barriers towards availability of requisite expertise, the higher the reported cognitive simplification processes in the deliberations of product development teams.

The higher the reported level of language barriers (absence of shared language), the higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

The lower the reported level of an integrative leadership style, the higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

Further, the correlational patterns would help determine the order of variable entry into the regression equation.

As predicted (Table 23), group norms (r= -.21, p < .05), availability of requisite expertise and information (r= -.21, p < .05), and integrative leadership (r= -.36, p < .01) showed a significant inverse relationship to the overall index
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Group Norms</th>
<th>Availability of Information and Expertise</th>
<th>Integrative Leadership</th>
<th>Barriers to Information and Expertise</th>
<th>Absence of Shared Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Overall simplification index</td>
<td>-.21*</td>
<td>-.21*</td>
<td>-.36**</td>
<td>+.54**</td>
<td>+.17*</td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>-.14</td>
<td>-.16</td>
<td>-.35**</td>
<td>+.49**</td>
<td>+.15</td>
</tr>
<tr>
<td>3. Simplification in information and alternative evaluation</td>
<td>-.22*</td>
<td>-.17*</td>
<td>-.34**</td>
<td>+.56**</td>
<td>+.17*</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>-.30**</td>
<td>-.28**</td>
<td>-.27**</td>
<td>+.44**</td>
<td>+.05</td>
</tr>
<tr>
<td>5. Escalating commitment</td>
<td>-.11</td>
<td>-.13</td>
<td>-.27**</td>
<td>+.34**</td>
<td>+.26**</td>
</tr>
</tbody>
</table>

* p < .05  
** p < .01

+ indicates a positive relationship  
- indicates a negative relationship
of cognitive simplification processes. Likewise, barriers to inflow of requisite expertise and information ($r = +.54, p < .01$) and lack of shared language ($r = +.17, p < .05$) showed a significant positive relationship to the overall cognitive simplification index.

For simplification in problem framing as the dependent variable, the following correlations were observed: group norms ($r = -.14, n.s.$), availability of requisite expertise and information ($r = -.16, p < .05$), integrative leadership ($r = -.35, p < .01$), barriers to inflow of requisite expertise and information ($r = +.49, p < .01$), and lack of shared language ($r = +.15, n.s.$).

For simplification in information and alternatives evaluation, the correlation coefficients were: group norms ($r = -.22, p < .05$), availability of requisite expertise and information ($r = -.17, p < .05$), integrative leadership ($r = -.34, p < .01$), barriers to inflow of requisite expertise and information ($r = +.56, p < .01$), and lack of shared language ($r = +.17, p < .05$).

For poor analogical reasoning as the dependent variable, the following correlations were observed: group norms ($r = -.30, p < .01$), availability of requisite expertise ($r = -.28, p < .01$), integrative leadership ($r = -.27, p < .01$), barriers to inflow of requisite expertise and information ($r = +.44, p < .01$), and lack of shared language ($r = +.05, n.s.$).

Escalating commitment as the dependent variable showed the following correlation coefficients: group norms ($r = -.11, n.s.$),
availability of requisite expertise and information ($r = -.13, \text{n.s}$), integrative leadership ($r = -.27, p < .01$), barriers to inflow of requisite expertise and information ($r = +.34, p < .01$), and lack of shared language ($r = +.26, p < .01$).

Regression Analyses

Multiple regression analysis is a more robust test of causal relationships than simple correlational analysis. The regression procedure takes into consideration the intercorrelations of variables and determines the relative statistical power of predictor variables in explaining the criterion or dependent variable(s).

As we had mentioned earlier, all the variables pertaining to 'group functioning' were treated as a class of predictors and fitted together in the regression equation to assess their relationship to the dependent variable. Five different regression equations were constructed treating as the dependent variable for the first equation, the overall cognitive simplification index. The other four equations had as their dependent variable, factors one, two, three, and four derived from the cognitive simplification scale.

A sample equation is presented below:
Overall cognitive simplification score =

Function of [Group norms (-)*, Availability of requisite expertise and information (-)*, Integrative leadership (-)*, Barriers to requisite expertise and information (+)*, Lack of shared language (+)*]

* Indicates the predicted direction of relationships

We used two methods in our regression procedure, 'forced entry' and 'backward method'. The 'backward method' was particularly useful in dealing with issues of multi-collinearity among independent variables. The two methods converged on the findings.

The results are presented in Table 24. While the correlational analysis suggested significant relationships between almost all the independent variables and the dependent variables, especially in the case of the overall cognitive simplification index, the results were more parsimonious in the regression procedure. The earlier significant relationships could have been the result of multi-collinearity or significant inter-correlations among the independent variables which the 'backward method' regression procedure compensated for.

For the overall simplification index as the dependent variable, Barriers to inflow of requisite expertise and information (unstandardized regression coefficient= .572, beta coefficient= +.56, p < .000) and Integrative leadership (unstandardized regression coefficient = - .142, beta coefficient= - .17, p < .03) were the most predictive. For the overall equation the $R^2$ was .36.
<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Group Norms</th>
<th>Barriers to Info. and Expertise</th>
<th>Availability of Info. and Expertise</th>
<th>Lack of Shared Language</th>
<th>Integrative Leadership</th>
<th>R²</th>
<th>F</th>
<th>Sig of F</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Overall simplification index</td>
<td>-1.03 (.07)</td>
<td>.555 (.096)</td>
<td>- .007 (.08)</td>
<td>.14 (.09)</td>
<td>-.17 (.06)</td>
<td>.36</td>
<td>12.56</td>
<td>.0000</td>
<td>5,114</td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>-.03 (.08)</td>
<td>.52 (.11)</td>
<td>-.04 (.09)</td>
<td>.16 (.10)</td>
<td>-.16 (.07)</td>
<td>.29</td>
<td>9.36</td>
<td>.0000</td>
<td>5,113</td>
</tr>
<tr>
<td>3. Simplification in information and alternative evaluation</td>
<td>-.16 (.07)</td>
<td>.58 (.10)</td>
<td>.045 (.08)</td>
<td>.11 (.10)</td>
<td>-.11 (.07)</td>
<td>.37</td>
<td>13.02</td>
<td>.0000</td>
<td>5,112</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>-.25 (.09)</td>
<td>.49 (.12)</td>
<td>-.10 (.10)</td>
<td>.21 (.12)</td>
<td>-.02 (.09)</td>
<td>.32</td>
<td>10.4</td>
<td>.0000</td>
<td>5,110</td>
</tr>
<tr>
<td>5. Escalating commitment</td>
<td>-.06 (.10)</td>
<td>.37 (.10)</td>
<td>-.002 (.10)</td>
<td>.15 (.12)</td>
<td>-.13 (.09)</td>
<td>.18</td>
<td>4.64</td>
<td>.0007</td>
<td>5,109</td>
</tr>
</tbody>
</table>

( ) parenthesized values indicate standard error estimates

+ indicates a positive relationship
- indicates a negative relationship
The F value was 12.56, (p < .000, df= 5,114) which along with the statistically significant value of the beta coefficient indicates that the population $R^2$ (coefficient of determination) is not equal to zero, or in other words, a linear relationship exists between the independent and dependent variables, and the proposed regression model fits the data well.

For the dependent variable, simplifications in problem framing, the only significant predictor variable was Barriers to inflow of requisite expertise and information (unstandardized regression coefficient= .59, beta coefficient= .52, p < .000).

However, near significant relationships were obtained for Language barriers or lack of shared language (unstandardized regression coefficient= + .184, beta coefficient= .16. p < .08) and Integrative leadership (unstandardized regression coefficient= - .14, beta coefficient = -.17, p < .06). $R^2$ was .29 with an F value of 9.36, and an associated probability of p < .0000 (df = 5,113).

For simplifications in information and alternatives evaluation the following independent variables were most predictive: Openness of Group Norms (unstandardized regression coefficient= -.15, beta coefficient= -.16, p < .04), and Barriers to inflow of requisite expertise and information (unstandardized regression coefficient= + .63, beta coefficient= + .58, p < .0000). $R^2$ was .37, and the F value was 13.02 (p < .0000, df= 5,112).
Poor analogical reasoning as the dependent variable showed the following significant relationships. **Group Norms** (unstandardized regression coefficient$= -.30$, beta coefficient$= -.25$, $p < .002$), **Barriers to inflow of expertise and information** (unstandardized regression coefficient$= +.64$, beta coefficient$= +.49$, $p < .0000$) and Language barriers or absence of shared language (unstandardized regression coefficient$= +.28$, beta coefficient$= +.21$, $p < .02$) were the best predictors of analogical reasoning. The $F$ value was $10.4$, with an associated probability of $p < .0000$ (df$= 5, 110$). The $R^2$ was $0.32$.

For escalating commitment, the independent variable most predictive was **Barriers to inflow of requisite expertise and information** (unstandardized regression coefficient$= +.44$, beta coefficient$= +.37$, $p < .0000$). The $F$ value was $4.63$ ($p < .0007$, df$= 5, 109$) and $R^2$ was $0.18$.

In summary, the following significant relationships were obtained between the predictor and the criterion variables:

The higher the barriers to inflow of requisite information and expertise, and the lower an integrative leadership style on the part of the project leader, the higher the overall cognitive simplification index.

The higher the barriers to inflow of requisite information and expertise (and the higher the absence of shared language, and lower the integrative leadership style), the higher the level of simplifications in problem framing activities.

The lower the level of openness of group norms and the higher the barriers to inflow of requisite information and expertise, the higher the level of simplifications in information and alternatives evaluation activities.
The lower the level of openness of group norms and the higher the barriers to inflow of requisite information and expertise and the absence of shared language, the higher the level of simplifications in analogical reasoning.

The higher the barriers to inflow of requisite information and expertise, the higher the potential level of escalating commitment.

Discussion of Results

The results substantially prove that all antecedent variables, except for the availability of information and expertise, were significantly related to either the overall cognitive simplification index or one of the four factors.

One plausible explanation for the non significance of 'availability of requisite information and expertise' lies in the fact that existence of 'barriers' would preclude their availability -- as was confirmed by the predominance of 'barriers to inflow of information and expertise' as a predictor of cognitive simplification processes. This relationship was further attested by the significant negative intercorrelation among barriers to, and availability of information and expertise (r = -.26, p < .01). Thus the higher the level of barriers, the lower the availability of requisite expertise and information.

Barriers to inflow of information and expertise was a powerful explanatory variable. It was predictive of the overall simplification index, as well as simplifications in problem framing, information and alternatives evaluation, analogical reasoning, and escalating commitment. This relationship is attested by Janis (1989) who suggests that constraints that affect the inflow
of essential information and expertise to the decision making situation can result in defective cognitive procedures. Thus, teams that ensure inflow of requisite information and expertise, by ensuring that there are no missing parties or wrong parties, and engage in consulting internal and external to the firm have a lower probability of defective cognitive procedures in scientific problem solving.

An integrative leadership style on part of project leadership was significantly related to the overall simplification index and related to simplifications in problem framing. The need for integrative leadership is underscored by Streufert and Swezey (1986) who suggest that in complex decision situations it is necessary to have a leadership function with multidisciplinary understanding and is able to provide an integrative overview of events at hand. Janis (1989), in a similar vein, argues that in uncertain situations leadership is the key integrative mechanism. As we discussed in the Vita case, the project leader's lack of conceptual understanding of toxicity issues pushed the project on the wrong path contributing to delays and failure at clinical trials.

Openness of group norms was related to simplifications in information and alternatives evaluations and poor analogical reasoning. The necessity for airing all alternatives and interpretations is an obvious requirement for undertaking an objective and complete evaluation of all available information at hand (Janis, 1989; Walsh et al., 1988). Norms which stifled scientists from openly expressing their views reinforced the selective evaluation of
information in the Vita case. The relationship of norms to analogical reasoning was evident in the Mita case, where the use of a 'rat model' was never questioned even though some people were skeptical about its appropriateness, since the norm of 'each one an expert' was operative.

Absence of shared language was predictive of poor analogical reasoning and errors in problem framing. The Mita case affirms this relationship. Team members did not understand each other's points of view. New project members were not really brought on board and there was no common point of reference around the product concept or project hypothesis.

*Relationship of Diversity in 'Mind Sets' to Cognitive Simplification Processes*

*Factor Analysis*

To factor analyze the 'Engagement Style Inventory' we used a 'forced factor extraction procedure'. This procedure relies on an 'a priori' criterion where the number of factors to be extracted is specified before hand. It is a useful approach to test a theory or hypothesis on the number of factors present in an instrument or to replicate findings. We specified a factor count of 4 in line with Pasmore's (1990) premise that the instrument attempts to measure four distinct cognitive modes: analytical, intuitive, active and reflective.

Our factor analysis confirmed the 'a priori' identification of four factors. As displayed in Table 25, the first factor was represented by the
TABLE 25

Factor Analysis* of Intuitive, Analytical Active and Reflective Dimensions

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1 Active</th>
<th>Factor 2 Analytical</th>
<th>Factor 3 Reflective</th>
<th>Factor 4 Intuitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Intuitive Scale</td>
<td>-.09</td>
<td>-.08</td>
<td>-.11</td>
<td>.98</td>
</tr>
<tr>
<td>2. Analytical Scale</td>
<td>.04</td>
<td>.99</td>
<td>-.05</td>
<td>-.08</td>
</tr>
<tr>
<td>3. Active Scale</td>
<td>.96</td>
<td>-.04</td>
<td>.04</td>
<td>-.09</td>
</tr>
<tr>
<td>4. Reflective Scale</td>
<td>.03</td>
<td>-.05</td>
<td>.99</td>
<td>-.11</td>
</tr>
<tr>
<td>Eigen Value</td>
<td>1.32</td>
<td>1.11</td>
<td>1.0</td>
<td>.70</td>
</tr>
<tr>
<td>Pct. of variance explained</td>
<td>32.9</td>
<td>27.6</td>
<td>23.1</td>
<td>16.5</td>
</tr>
</tbody>
</table>

* Forced factor extraction procedure
'active' dimension (loading .96), the second factor by the 'analytical' dimension (loading .99), the third factor by the 'reflective' dimension (loading .99) and the fourth factor by the 'intuitive' dimension (.98). The first three factors had an Eigen value of 1 or above making them significant. However, the last factor (intuitive) showed an Eigen value of only .70.

**Correlational Analysis**

The correlational results are displayed in Table 26. As noted earlier, lower values of the intuitive-analytical gap and active-reflective gap represent diversity in 'mind sets', while higher gap values indicate homogeneity in 'mind-sets'.

Specifically, the hypothesis being examined was:

The higher the level of homogeneity in 'mind sets' (as represented by a higher intuitive-analytical and active-reflective gap) in product development teams, the higher the reported level of cognitive simplification processes in the deliberations of product development teams.

However, only the active-reflective gap (squared) values showed a significant positive linear relationship to the overall simplification index and the first three simplification factors, suggesting that the higher the homogeneity (or lack of diversity) in action and reflection, the higher the level of cognitive simplification processes. Intuitive-analytical gap displayed a negative relationship to the overall simplification index and the four
TABLE 26

Correlation Matrix Between Cognitive Simplification and 'Intuitive-Analytical' and 'Active Reflective' Gaps

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>'Intuitive-Analytical' Gap</th>
<th>'Active-Reflective' Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Overall simplification index</td>
<td>-.06</td>
<td>+.26**</td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>-.05</td>
<td>+.25**</td>
</tr>
<tr>
<td>3. Simplification in information and alternatives evaluation</td>
<td>-.03</td>
<td>+.16</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>-.07</td>
<td>+.19**</td>
</tr>
<tr>
<td>5. Escalating commitment</td>
<td>-.18*</td>
<td>+.15</td>
</tr>
</tbody>
</table>

* p < .05

** p < .01

+ indicates a positive relationship

- indicates a negative relationship
factors, with a significant relationship with escalating commitment.

The correlation values were as follows:

For overall simplification index as the dependent variable, the correlation coefficients with the independent variables were: intuitive-analytical gap ($r = -.06; n.s$) and active-reflective gap ($+ .26, p < .01$).

For simplifications in problem framing the values were: intuitive-analytical gap ($-.05, n.s$) and active-reflective gap ($+.25, p < .01$).

For simplifications in information and alternatives evaluation the following results were obtained: intuitive-analytical gap ($-.04, n.s$) and active-reflective gap ($+.16, n.s$).

Poor analogical reasoning as the dependent variable displayed the following correlation coefficients: intuitive-analytical gap ($r = -.07, n.s$) and active-reflective gap ($+.19, p < .01$).

For escalating commitment, the intuitive-analytical gap showed a significant negative relationship ($r = -.18, p < .05$) suggesting that the higher the homogeneity (or lack of adequate balance in intuition and analysis), the lower the level of cognitive simplification processes. An examination of the overall sample means for intuition (23.0) and analysis (26.0) suggested that a predominant analytical mind set can be inferred to be related to lower levels of escalating commitment. The correlation for active-reflective gap was $r = +.15, n.s$.

Regression Analysis

The regression results closely paralleled the correlation analysis (Table 27).


**TABLE 27**

**Regression Results Between Cognitive Simplification and 'Intuitive-Analytical' and 'Active-Reflective' Gaps**

<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Intuitive-Analytical Gap</th>
<th>Active-Reflective Gap</th>
<th>( r^2 )</th>
<th>F Value</th>
<th>Sig of F</th>
<th>df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall simplification index</td>
<td>-0.07 (.001)</td>
<td>.27 (.001)</td>
<td>.07</td>
<td>8.84</td>
<td>.003</td>
<td>2,117</td>
</tr>
<tr>
<td>Simplification in problem framing</td>
<td>-0.06 (.001)</td>
<td>.25 (.001)</td>
<td>.06</td>
<td>3.88</td>
<td>.02</td>
<td>2,116</td>
</tr>
<tr>
<td>Simplification in information and alternatives evaluation</td>
<td>-0.04 (.001)</td>
<td>.15 (.002)</td>
<td>.03</td>
<td>1.46</td>
<td>.24</td>
<td>2,115</td>
</tr>
<tr>
<td>Poor analogical reasoning</td>
<td>-0.07 (.001)</td>
<td>.20 (.002)</td>
<td>.04</td>
<td>4.33</td>
<td>.04</td>
<td>2,112</td>
</tr>
<tr>
<td>Escalating commitment</td>
<td>-0.18 (.001)</td>
<td>.15 (.002)</td>
<td>.06</td>
<td>3.33</td>
<td>.04</td>
<td>2,112</td>
</tr>
</tbody>
</table>

( ) parenthesized values indicate standard error estimates

+ indicates a positive relationship

- indicates a negative relationship
The active-reflective gap was a significant predictor of:

the overall simplification index (unstandardized regression coefficient = + .003, beta coefficient = + .27, p < .003; F = 8.84, p < .003, df = 2, 117; R² = .07).

simplification in problem framing (unstandardized regression coefficient = + .004, beta coefficient = + .25, p < .007; F = 3.88, p < .02, df = 2, 116; R² = .06), and,

poor analogical reasoning (unstandardized regression coefficient = + .006, beta coefficient = + .20, p < .03; F = 4.33, p < .04, df = 2, 112; R² = .04).

Significant relationships were not obtained between the independent variables and simplification in information and alternatives evaluation.

The intuitive-analytical gap was a negative predictor of escalating commitment: (unstandardized regression coefficient = -.002, beta coefficient = -.18, p < .04; F = 3.33, p < .04, df = 2, 112; R² = .06).

In summary, the higher the active-reflective gap, or predominance of action (induction) at the expense of reflection (deduction), or reflection at the cost of action (induction), the higher the overall level of cognitive simplifications, simplifications in problem framing, and simplifications in analogical reasoning.

The other major finding was that the higher the intuitive-analytical gap (or primacy of the analytical mode), the lower the potential for escalating commitment processes.
Discussion of Results

The 'active-reflective' gap was significantly predictive of overall simplification, problem framing, and analogical reasoning. These findings resonate well with the notion of Rubinstein et al. (1984) that operative action (induction) and problem formulation (deduction) are mutually interdependent activities. Both are needed for equilibration and complexification, and thus successful scientific outcomes.

In fact, polarizing deduction and induction, or in other words, paying undue attention to one at the expense of the other, has been termed 'monophasis' as opposed to 'diaphasis' which entails a balance. Preference for abstract conceptualizations which does not attempt to take into account, or rejects information from the operational environment is an overemphasis on reflection (or deduction) in scientific inquiry. On the other hand, stressing data generation (or action) as the primary mode of scientific problem solving with minimal levels of problem conceptualization is one pattern which tilts the balance towards induction.

The 'intuitive-analytical' gap was negatively related to escalating commitment, which is an interesting finding. A paired T-test between the sample means for 'analytical' (26.0, s.d=5.38) and 'intuitive' (23.0, s.d=5.30) showed that they were significantly different (t value= -3.78, p < .000, df= 142). This suggests that a predominant analytical mind set may be related to
lower levels of escalating commitment. This relationship appears plausible. As Janis (1989) posits, frequently escalating commitment results from egocentric behavior, which can be justified on the basis of an intuitive 'over-optimism' that a particular project will succeed, or a failing course of action will somehow turn around. On the contrary, an analytical, rational approach will be able to detect diminishing returns in an investment and obviate the chances of escalation of commitment towards a failing course of action.

But more broadly, diversity in 'mind-sets' as an antidote to simplification is supported in the literature. More work examining this relationship can be carried out in the future.

*Relationship of Features of the Overall 'Work Context' to Cognitive Simplification Processes*

*Factor and Reliability Analyses*

The exploratory factor and reliability analyses of the three scales employed to measure select features of the larger work environment are presented below.

**Accumulation of Prior related knowledge**: The rotated factor solution indicated two distinct factors (Table 28). The first factor named 'processes of accumulating prior related knowledge' included three items: extent people's experience and knowledge from past projects are easy to
<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1 Processes of Accumulating Prior Knowledge</th>
<th>Factor 2 Systems for Accumulating Prior Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extent of technical documentation of past work</td>
<td>.135</td>
<td>.887</td>
</tr>
<tr>
<td>2. Extent of systems in place for retrieving past learning</td>
<td>.200</td>
<td>.844</td>
</tr>
<tr>
<td>3. Extent peoples experience and knowledge learned from previous projects are easy to tap into</td>
<td>.767</td>
<td>.033</td>
</tr>
<tr>
<td>4. Extent there is sufficient continuity in people and/or transfer of knowledge when projects are completed</td>
<td>.737</td>
<td>.274</td>
</tr>
<tr>
<td>5. Extent knowledge from failures is incorporated into new hypotheses</td>
<td>.723</td>
<td>.178</td>
</tr>
</tbody>
</table>

| Eigen value | 2.30 | 1.01 |
| Pet. of variance explained | 46.0% | 20.2% |
| Cronbach alpha | .84 | .80 |

N=158
tap into; extent there is sufficient continuity in people and transfer of knowledge when projects are completed, and extent knowledge from failures is incorporated into new hypotheses. The reliability coefficient of this scale was .84.

The second factor, 'systems for accumulating prior knowledge', was constituted by two items: extent of technical documentation of past work, and extent of systems in place for retrieving past learning. The Cronbach alpha was .80.

**Knowledge linkages**: Two factors resulted from this scale (Table 29). Factor one designated as 'Internal knowledge linkages' measured frequency of informal interaction and extent of knowledge sharing among the different focus areas. The remaining two items measured the frequency of information exchange and extent of joint efforts among the project and resource groups in charting research designs and test methods.

Factor two was appropriately distinguished as 'external knowledge linkages' and included two items; extent of links to external sources of information and expertise, and frequency of communication with receiving/operating divisions.

**Perceived Pressure**: This three item scale loaded on to a single factor (Table 30). One item which was a general question on the extent of time pressures, schedules, and deadlines had a low loading of .40 and was dropped.
### TABLE 29

**Factor and Reliability Analysis of Knowledge Linkages Scale**

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor 1 (Internal Knowledge Linkages)</th>
<th>Factor 2 (External Knowledge Linkages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extent of links to external sources of information and expertise</td>
<td>-.150</td>
<td>.760</td>
</tr>
<tr>
<td>2. Frequency of informal interactions between people in different focus areas</td>
<td>.892</td>
<td>-.005</td>
</tr>
<tr>
<td>3. Extent of sharing of knowledge across focus areas</td>
<td>.886</td>
<td>-.009</td>
</tr>
<tr>
<td>4. Frequency of exchange of information between members of resource sections and project sections</td>
<td>.718</td>
<td>-.087</td>
</tr>
<tr>
<td>5. Extent of interactions between resource and project groups related to developing research designs and test methods</td>
<td>.764</td>
<td>-.063</td>
</tr>
<tr>
<td>6. Frequency of communications between center members and receiving division</td>
<td>.062</td>
<td>.806</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigen value</td>
<td>2.73</td>
<td>1.22</td>
</tr>
<tr>
<td>% of variance explained</td>
<td>45.5%</td>
<td>20.2%</td>
</tr>
<tr>
<td>Cronbach alpha</td>
<td>.81</td>
<td>.63</td>
</tr>
</tbody>
</table>

N=158
TABLE 30

Factor and Reliability Analysis of Scale to Measure Perceived Pressure

<table>
<thead>
<tr>
<th>Scale Items</th>
<th>Factor Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Extent of time pressures, schedules and deadlines</td>
<td>.409*</td>
</tr>
<tr>
<td>2. Extent pressure to show practical results causes high project goals to be sacrificed prematurely</td>
<td>.830</td>
</tr>
<tr>
<td>3. Extent increasing demands on time and resources has reduced the discretionary research necessary for novel or breakthrough ideas</td>
<td>.841</td>
</tr>
</tbody>
</table>

Eigen value 1.563

Pct. of variance explained 52.1%

Cronbach alpha .75

N=158

Note: * Dropped from scale due to poor factor loading
The two remaining items which were retained were: extent pressure to show practical results causes high project goals to be sacrificed, and extent increasing demands on time and resources reduces discretionary research. The reliability coefficient for this scale was .75.

Correlational Analysis

The correlational analysis provided an early indication of the directionality and significance of relationships between the dependent and independent variables. The three hypothesis tested were:

The lower the reported levels of adequacy of systems for accumulation of prior related knowledge, and external and internal knowledge linkages in the work environment, the higher the reported level of cognitive simplification processes in the deliberations of product development teams.

The higher the reported level of perceived pressure in the work environment, the higher will be the reported level of cognitive simplification processes in the deliberations of product development teams.

The directionality of the predicted relationships were confirmed (Table 31). For the overall cognitive simplification index as the dependent variable, the correlation coefficients were: processes of accumulating prior knowledge ($r = -0.24, p < .01$), systems for accumulating prior knowledge ($r = -0.11$, n.s), internal knowledge linkages ($r = -0.06$, n.s), external knowledge linkages ($r = -0.19$, $p < .05$), and perceived pressure ($r = +0.18, p < .05$).
### TABLE 31
Correlational Matrix Between Cognitive Simplification and Features of the 'Work Environment'

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Processes of Accumulating Prior Knowledge</th>
<th>Systems for Accumulating Prior Knowledge</th>
<th>Internal Knowledge Linkages</th>
<th>External Knowledge Linkages</th>
<th>Perceived Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Overall simplification index</td>
<td>-.24**</td>
<td>-.11</td>
<td>-.06</td>
<td>-.19*</td>
<td>+.18*</td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>-.24**</td>
<td>-.16</td>
<td>-.02</td>
<td>-.22**</td>
<td>+.18*</td>
</tr>
<tr>
<td>3. Simplification in information and alternatives evaluation</td>
<td>-.25**</td>
<td>-.05</td>
<td>-.06</td>
<td>-.11</td>
<td>+.14</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>-.09</td>
<td>-.13</td>
<td>-.14</td>
<td>-.17</td>
<td>+.14</td>
</tr>
<tr>
<td>5. Escalating commitment</td>
<td>-.08</td>
<td>-.05</td>
<td>-.11</td>
<td>-.05</td>
<td>+.18*</td>
</tr>
</tbody>
</table>

* p < .05  
** p < .01

+ indicates a positive relationship  
- indicates a negative relationship
For simplification in problem framing the following correlations were observed: processes of accumulating prior knowledge ($r = - .24, p < .01$), systems for accumulating prior knowledge ($r = - .16, n.s$), internal knowledge linkages ($r = -.02, n.s$), external knowledge linkages ($-.22, p < .01$), and perceived pressure ($r = + .18, p < .05$).

For simplifications in information and alternatives evaluation the correlation coefficients were: processes of accumulating prior knowledge ($r = - .25, p < .01$), systems for accumulating prior knowledge ($r = - .05, n.s$), internal knowledge linkages ($r = -.06, n.s$), external knowledge linkages ($-.11, n.s$), and perceived pressure ($r = + .14, n.s$).

For poor analogical reasoning the coefficients obtained were: processes of accumulating prior knowledge ($r = - .09, n.s$), systems for accumulating prior knowledge ($r = - .13, n.s$), internal knowledge linkages ($r = -.14, n.s$), external knowledge linkages ($-.17, p < .05$), and perceived pressure ($r = + .14, n.s$).

Escalating commitment showed the following correlations: processes of accumulating prior knowledge ($r = - .08, n.s$), systems for accumulating prior knowledge ($r = - .05, n.s$), internal knowledge linkages ($r = -.11, n.s$), external knowledge linkages ($-.05, n.s$), and perceived pressure ($r = + .18, p < .05$).
Regression Analysis

The results confirmed some of the significant correlations obtained (Table 32).

Processes of accumulating prior knowledge (unstandardized regression coefficient = -.23, beta coefficient = -.23, p < .01), and external knowledge linkages (unstandardized regression coefficient = -.21, beta coefficient = -.20, p < .03) were significant predictors of the overall simplification index. The overall equation indicated a good fit with an F value of 2.75, p < .02, df = 5, 111. The R^2 was .11.

For simplification in problem framing as the criterion variable, the significant predictor was processes of accumulating prior knowledge (unstandardized regression coefficient = -.23, beta coefficient = -.22, p < .02). External knowledge linkages were close to significance as a predictor (unstandardized regression coefficient = -.18, beta coefficient = -.16, p < .08). For the overall equation, the F value was 2.70 (p < .02, df = 5,110), with an R^2 value of .11.

Simplification in information and alternatives evaluation was significantly related to only processes of accumulating prior knowledge (unstandardized regression coefficient = -.27, beta coefficient = -.25, p < .006). The R^2 was .10 and the F statistic was 2.41 (p < .04, df = 5,109).
<table>
<thead>
<tr>
<th>Dependent Variables</th>
<th>Processes of accumulating prior knowledge</th>
<th>Systems for accumulating prior knowledge</th>
<th>Internal Knowledge Links</th>
<th>External Knowledge Links</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beta coeff</td>
<td>Sig of T</td>
<td>Beta coeff</td>
<td>Sig of T</td>
<td>Beta coeff</td>
</tr>
<tr>
<td>1. Overall simplification index</td>
<td>-.23 (.09)</td>
<td>.01</td>
<td>-.02 (.10)</td>
<td>.87</td>
<td>-.09 (.10)</td>
</tr>
<tr>
<td>2. Simplification in problem framing</td>
<td>-.22 (.09)</td>
<td>.02</td>
<td>-.05 (.11)</td>
<td>.65</td>
<td>-.13 (.12)</td>
</tr>
<tr>
<td>3. Simplification in information and alternative evaluation</td>
<td>-.25 (.09)</td>
<td>.006</td>
<td>-.08 (.11)</td>
<td>.47</td>
<td>-.12 (.12)</td>
</tr>
<tr>
<td>4. Poor analogical reasoning</td>
<td>.07 (.13)</td>
<td>.50</td>
<td>-.02 (.14)</td>
<td>.87</td>
<td>-.03 (.15)</td>
</tr>
<tr>
<td>5. Escalating commitment</td>
<td>-.14 (.11)</td>
<td>.18</td>
<td>-.18 (.12)</td>
<td>.11</td>
<td>-.12 (.13)</td>
</tr>
</tbody>
</table>

( ) parenthesized values indicate standard error estimates

+ indicates a positive relationship
- indicates a negative relationship

TABLE 32

Regression Results Between Cognitive Simplification and 'Work Context' Variables
The overall regression equation fits were not significant for analogical reasoning \( (F = 1.51, p < .19, \text{df} = 5, 107, R^2 = .07) \) and escalating commitment \( (F = 1.83, p < .11, \text{df} = 5, 106, R^2 = .08) \) and therefore have to be interpreted with some caution.

External knowledge linkages were significantly related to analogical reasoning (unstandardized regression coefficient= - .32, beta coefficient= - .23, \( p < .01 \)), and perceived pressure (unstandardized regression coefficient= + .25, beta coefficient= + .27, \( p < .01 \)) was predictive of escalating commitment.

In summary, the following significant relationships were obtained between the predictor and the criterion variables:

- The lower the level of processes of accumulating prior knowledge, the higher the overall cognitive simplification index and the higher the level of simplifications in problem framing and information and alternatives evaluation.

- The lower the level of external knowledge linkages, the higher the overall cognitive simplification index and the level of simplifications in problem framing (close to significance) and analogical reasoning.

- The higher the level of perceived pressure, the higher the potential for escalating commitment processes.

*Discussion of Results*

Processes of accumulating prior knowledge was a significant explanatory variable of overall simplification, problem framing, and
information and alternatives evaluation. Thus, teams that actively seek to tap into people's past experience and knowledge, incorporate knowledge from past failures into a new hypothesis, and ensure that there is transfer of knowledge when projects are completed, have a lower probability of employing defective cognitive procedures in their scientific activities. This notion of accumulating prior related knowledge is critical to building absorptive capacity, an imperative prerequisite for scientific innovation (Cohen and Levinthal, 1990).

An issue to be considered is the non significance of 'systems for accumulating prior related knowledge'. One potential explanation is that systems are constituted in processes. While there may exist systems in the organization such as technical documentation of past work, or systems for retrieving past learnings, it is through active processes of utilizing such systems that inflow of past learnings into current projects is made possible. The high positive intercorrelation ($r = .38$, $p < .01$) between processes and systems for accumulating prior knowledge appears to confirm this rationale.

'External knowledge linkages' showed a strong relationship to the overall simplification index, problem framing, and analogical reasoning. The results are not surprising given that scientific research is such a knowledge intensive process and linkages to universities and professional associations are a requirement to keep current on recent developments. External knowledge linkages are a constant source of new ideas. Knorr-Cetina (1981) has documented a case where a critical turn in the project came as a result of one of the scientists visiting a laboratory in Italy. And, the exposure to the work
being conducted there gave him new insights and ideas on a current problem he was working on.

It is puzzling that 'internal knowledge linkages' was not significant. One conceivable argument is that internal knowledge linkages contribute to accumulating knowledge. Interactions across focus areas and between resource and project groups might ensure tapping into past learnings from successful and failed efforts. Significant positive intercorrelations were obtained with processes for accumulating prior knowledge \( (r = .49, p < .01) \) and systems for accumulating prior knowledge \( (r = .30, p < .01) \).

Perceived pressure showed a significant positive relationship to escalating commitment. These results align well with the observations of Janis (1989) and Schwenk (1984) that the higher the level of obstacles experienced, the more acute is the tendency to escalate commitment. The sociology of conflict literature (Coser, 1964) also offers a similar view; the higher the level of threat, the more passionate is the tendency to persist with the current course of action. The Vita example is a case in point. The more the project leader wanted to prove that an 'oral drug' was the right focus and imposed pressure on the toxicologist to make it happen, the more intent the toxicologist was on proving that an oral drug was an infeasible application.

Figure 4 is an overall summary of the significant contextual antecedents of cognitive simplification processes.
Figure 4
Significant Contextual Antecedents of Cognitive Simplification Processes

- Barriers to inflow of requisite information and expertise
- Active-reflective gap

Overall simplification index

- Integrative leadership
- Processes of accumulating prior knowledge
- External knowledge linkages

(-)

- Barriers to inflow of requisite information and expertise
- Absence of shared language
- Active-reflective gap

Simplification in problem framing

(+)

- Integrative leadership
- Process of accumulating prior knowledge
- External knowledge linkages

(-)

- Barriers to inflow of requisite information and expertise

Simplification in information and alternatives evaluation

(+)
Figure 4 (continued)
Significant Contextual Antecedents of Cognitive Simplification Processes

- * Barriers to inflow of requisite information and expertise
- * Absence of shared language
- * Active-reflective gap

(+)  Inadequate analogical reasoning

(+)  Openness of group norms
(-)  External knowledge linkages

(+)  Barriers to inflow of requisite information and expertise
(+)  Perceived pressure

(-)  Intuitive-analytical gap

(+)  Escalating commitment

* indicates a significant positive relationship
- indicates a significant negative relationship
Chapter 7
Conclusions, Implications and Suggestions for Future Research

Conclusions

This dissertation had three exploratory objectives. Presented below are the objectives and brief concluding statements on how each one was addressed in the study.

1. To propose a theoretic framework of Research and Development as a cognitive process with a particular emphasis on understanding and explaining simplifications in scientific work.

A preliminary framework of research and development as a cognitive process was extended. The creative heart of scientific reasoning was posited as a cognitive modeling process of the new problem domain to be explained, discovered or invented. Scientific success was viewed as a process of the cognitive model progressively complexifying itself through deductive and inductive action, and attaining adaptive isomorphism with the operational environment.

Cognitive simplification processes in deductive and inductive action were located as a principal barrier that can hamper the effectiveness of scientific work and prevent the conceptual system from attaining the state of optimal complexity required for success. Two predicted consequences of simplifications were delays in the product development process and
unsuccessful performance outcomes. Potential contextual antecedents that can stimulate simplifications in scientific enterprise were also proposed.

2. To examine if differences in the levels of cognitive simplification activity evidenced is related to indices of project effectiveness, particularly project performance and incidence of delays in the product development process.

Through qualitative and quantitative methods, the relationship of cognitive simplification processes to delays and project performance was significantly established. Product development teams that evidenced higher levels of cognitive simplification activity (including different types of simplification activity) also reported experiencing more and different types of delays in the product development process. Project performance ratings of teams experiencing higher levels of simplifications were lower than teams reporting a lesser incidence of simplification activity.

3. To examine if there is a relationship between socio-structural factors of the project team context and the level of cognitive simplification activity evidenced.

The retrospective analysis of two case studies indicated several contextual influences on cognitive simplification processes. Statistical results substantiated many of these observations. Barriers to inflow of information and expertise, integrative leadership style, openness of group norms, absence of shared language, balancing cognitive modes of action and reflection, analytical mind-set, processes for accumulating prior knowledge, external knowledge
linkages, and perceived pressure were all significantly related to various types of cognitive simplification processes.

Interestingly, many of the above contextual factors that promote simplification form part of the 'organizing schema' of traditional organizations. A primary objective of organization design is to reduce uncertainty and complexity, minimize variability, and promote sameness of response to situations. Sameness of response and traditionality result from practices such as division of labor, chain of command, specialization, formalization, departmentalization, and establishment of routines (Weick, 1991; Huber, 1991). In fact, our findings suggest that these traditional assumptions about organizing can drive out the requisite complexity necessary for scientific innovations.

Barriers to inflow of information and expertise as manifest in lack of consultation with parties internal or external to the firm, or missing parties in deliberations, can very well be a consequence of the segmentation of the project unit resulting from formalization practices. External knowledge linkages and processes for accumulating prior knowledge can also be adversely impacted by formalization and departmentalization which can hinder communication across and external to the organization.

Lack of an integrative leadership can be viewed as representing a hierarchical leadership style rooted in a traditional chain of command. Similarly, lack of openness in group norms can be an outcome of strict
division of labor or specialization. We found that in the Mita case the notion of each one an expert in his or her domain (a division of labor or specialization concept) came in the way of asking critical questions about the appropriateness of the rat model.

In summary, the practices of traditionality that organizations support to reduce variability and avoid surprises may very well contribute to cognitive simplification processes and restrain the development of optimal complexity.

Implications

The findings of this study have numerous implications for enhancing the effectiveness of new product development processes.

Given 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 reduced, if not totally eliminated.

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 environments of product development teams - choices that derive
principally from the findings of this study on the relationships between contextual influences and cognitive simplification processes.

*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.

While at one level our survey based assessment of cognitive simplification processes was intended as a measure of simplification activity, it can also be construed as an intervention into the processes of cognition. By asking respondents to identify occurrences of simplification activity in their scientific deliberations, we forced the scientists to suspend their natural attitude and reflect on their actions, thereby raising into their awareness the ways in which their scientific worlds were being constructed and interpreted, thus opening the potential for change.

*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). In more technical terms, a cognitive map can be viewed as a directed graph whose nodes represent concepts or factors in the actor's decision domain, and whose arcs represent cause and effect relationships between source and destination nodes (Boland, Schwartz, Tenkasi, Maheshwari, and Te'eni, 1992). In a less profound way, Eden (1992) argues, 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.

Tenkasi and Boland (1993), in a similar vein, argue that the organizing principle of cognition is principally narrative. Sense making is founded on an innate human narrative capacity, which is the engine of our cognitive activity. What frames or schemas we do have (which includes schematic representational structures such as cognitive maps) are constructed through narrative. Schemas are secondary, derived or residual to the primary cognitive activity of making sense of our experience by narrating it.

From an interventional perspective, they propose that locating of narratives and making them available for discussion among organizational members can aid in breaking cycles of routine reproduction. It is in narratives that one can locate organizational defensive routines and simplifications. Stories and narratives are embodied forms of cognition and constitute the basics of lived day to day human experience. They are more amenable to inquiry than abstracted notions such as cognitive maps, which as derivatives of narratives, are once removed.

Rubinstein et al. (1984) adopt a similar tone in expressing the removed quality of cognitive maps. They posit that the cognized environment can model
itself. It may construct models of its own models. However, just as the
cognized environment models are typically partially isomorphic with aspects
of the environment they model, the secondary model [cognitive maps] will
only be partially isomorphic with the primary model. With each remove from
the initial modeling, the more abstract the model becomes and loses some
closeness of fit with the system being modeled.

However, as we asserted earlier, an intervention into both these
interdependent aspects of cognition appears essential to promote cognitive
model learning and development and thus overcoming cognitive
simplification. This would implicate the importance of the various approaches
available for intervening into the content and processes of cognition.

*Attending to the Contextual Environments of Product Development Teams*

Many significant relationships were obtained between contextual
variables and cognitive simplification processes. Attending to these influences
can contribute to reducing simplifications, fostering requisite complexity and
thereby improving the quality of cognitive activity in product development
efforts.

For example, barriers to inflow of requisite expertise and information
can be identified by employing the deliberation analysis methodology
(Pasmore, 1988). The deliberation analysis process identifies critical
informational uncertainties, maps knowledge needs and sources, and explores ways to fill informational and knowledge gaps through methods such as consultations with internal and external parties. Likewise, for each set of deliberations, key parties are distinguished in the process making sure that wrong parties are not part of the deliberations.

Our findings indicate that traditionally based hierarchical leadership practices can be a major stimulant of cognitive simplification processes. A leadership function which can view issues from an integrated perspective drawing from a multi-disciplinary conceptual base seems to be a critical requirement for managing complex new product development processes. Other essential skills such as recognizing and mediating conflicts and being able to act as a sounding board for various member ideas also constitute the integrative role in complex decision situations.

Frequently, a single individual may not be able to perform such a role adequately, since new product development entails highly specialized expertise on part of the various team members. A distributed approach to the leadership function, where various team members take leadership for the different initiatives which fall under their domain of expertise can be a viable option. Measures such as job rotation can help members develop the required familiarity in disciplines other than their own and can aid in building a multi-disciplinary perspective. Further, a distributed approach towards the leadership function can be facilitated by training the team members in self-designing, self-managing concepts.
In contrast to a lack of shared language which can promote simplification, the emphasis should be on building a fluid learning community based in practice (Brown and Duguid, 1991)—evolving, interpenetrative, 'communities-of-practice', whose shape emerges in the process of activity and collaboration with one other, and who through this process are able to develop shared as well as unique views of phenomena.

In addition to such 'practice' based learning, education and training activities, job rotation, and joint presentations can help team members develop a shared language and understand each other's disciplines in an optimal manner, while retaining their unique perspectives.

Lack of openness in group norms can stifle the much required learning from each other necessary to develop optimal complexity. The requirement is for an inquiry based, dialogical learning systems that stresses the sharing, surfacing, and examining of divergent perspectives. Training members in decision making methods such as devil's advocacy and dialectical inquiry (Schweiger, Sandberg, and Rechner, 1989) that help generate divergent assumptions and perspectives, can improve the openness of group norms around debate and dialogue.

Heterogeneity in cognitive styles or balancing cognitive modes of action and reflection can be facilitated through training. A good example is the Bausch-Lomb case presented earlier where a refresher course in experimental
design helped bring down the incidences of rework. While the experimental design course was an exercise in reflection or deduction, a similar program emphasizing inductive operations can be equally helpful. Further, attention can be paid to the composition of teams by ensuring there is an adequate representation of both cognitive modes in member make up.

While research supports that generally diversity in cognitive modes can be an effective antidote against cognitive simplification, our results indicate that a predominant analytical mind set was related to lower levels of escalating commitment. This finding suggests that in addition to carrying individuals with a strong analytical bent as part of the team, and giving them primary responsibility to review the project for signs of escalating commitment, impartial external parties such as scientific advisory groups can be employed to determine whether there is indeed a tendency towards investing more resources in a failing course of action. The key is conducting a rational analysis of projects to detect signs of escalating investment.

Actively encouraging and institutionalizing processes and practices of accumulating prior knowledge as part of the research and development culture can ensure that product development teams avoid the 'forever young and stupid syndrome'.

Huber (1991) endorses the critical role of organizational memory in organizational learning, and suggests computer based memory retrieval systems to facilitate the learning process. This would include systems to
automatically capture and retrieve critical information from transaction
artifacts such as electronic mail and electronic bulletin board or blackboard
systems, and creating computer-based expert systems by tapping into the
knowledge of resident experts.

Facilitating external knowledge linkages through university
partnerships, professional meetings, sabbaticals, and visiting professorships
can help scientists keep current on recent developments in their field.

Perceived pressure from management was related to escalating
commitment behavior. While research suggests that all pressure is not bad,
consistent and repeated pressure may drive individuals to persist with their
current course of action. Management can learn to establish the appropriate
balance between a directive and an accommodative style in dealing with team
members. Further, open dialogue can help both parties develop an appreciation
for each other's perspectives.

Table 33 is a summary depiction of contextual design factors that can
help obviate cognitive simplification processes.
<table>
<thead>
<tr>
<th>Contextual factors that contribute to cognitive simplification processes</th>
<th>Contextual design factors that can obviate cognitive simplification processes</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Barriers to inflow of requisite information and expertise</td>
<td>• Mapping critical informational uncertainties, knowledge needs and sources</td>
<td>• Deliberation analysis</td>
</tr>
<tr>
<td>• Lack of integrative leadership (or hierarchical leadership)</td>
<td>• Developing integrative leadership skills for project management • Promoting distributed leadership function</td>
<td>• Job rotation • Training for self-designing teams</td>
</tr>
<tr>
<td>• Lack of shared language</td>
<td>• Building learning communities of practice</td>
<td>• Education and training • Job rotation • Joint presentations</td>
</tr>
<tr>
<td>• Lack of openness of group norms</td>
<td>• Developing an inquiry based dialogical learning system</td>
<td>• Training in decision making methods such as devil's advocacy and dialectical inquiry</td>
</tr>
<tr>
<td>• Homogeneity in cognitive styles (predominance of action over reflection or vice versa)</td>
<td>• Developing diversity in cognitive styles (adequate balance between cognitive modes)</td>
<td>• Education • Balanced team composition</td>
</tr>
<tr>
<td>• Lack of analytical mode to identify escalating commitment</td>
<td>• Rational analysis of escalating investment</td>
<td>• Team composition • Impartial external parties</td>
</tr>
<tr>
<td>• Lack of processes for accumulating prior knowledge</td>
<td>• Institutionalized processes and practices of accumulating prior knowledge</td>
<td>• Computer based systems to capture and retrieve critical information</td>
</tr>
<tr>
<td>• Lack of external knowledge linkages</td>
<td>• Facilitate external knowledge linkages</td>
<td>• University partnerships • Professional meetings • Sabbaticals</td>
</tr>
<tr>
<td>• Undue pressure from management</td>
<td>• Optimal pressure from management</td>
<td>• Appropriate balance between accommodative and directive style • Open dialogue</td>
</tr>
</tbody>
</table>
Future Research Directions

It is important to note that this study has some limitations to be dealt with in the future. From a conceptual perspective we argued that scientific innovation requires optimal complexity and proposed that cognitive simplification processes can hamper a conceptual system from attaining the requisite level of complexity. However, this study did not measure complexity, nor did it address the question whether overcoming cognitive simplification processes in itself can contribute to the level of complexity required. In other words, it is a Herzbergian kind of enigma. Does non-preservation of simplification denote complexification or just merely its absence. Complexification could be a result of a totally different set of factors such as play, passion, excitement, and enthusiasm. These issues warrant further investigation.

There are a few limitations from a methodological perspective. First, the findings are based on the study of a single Research and Development organization, engaged in pharmaceutical development work. While this study is potentially one of the few attempts to examine cognitive simplification processes in a new product development setting through qualitative and quantitative methods, its generalizability is limited to the organization investigated. The results have to be validated by collecting data from a larger sample of R&D organizations both pharmaceutical and non-pharmaceutical.

A second limitation of the study to be rectified is that it used self-report measures to assess an elusive and implicit phenomena such as cognitive
simplification processes. While our observations as well as interviews with the scientists suggested that they had a strong reflective orientation, and could recount instances from their work when particular simplifications were in operation, other sensitive field based methodologies such as cognitive maps and discourse analysis could have been used to complement our survey based approach. In addition, subjects' detailed descriptions of their own problem solving efforts (Mintzberg et al., 1976) and cognitive assessment strategies such as 'thought listing' (Cacioppo and Petty, 1981) could have been employed.

Likewise, we employed self-report measures to assess product development delays. More stringent external measures would have enhanced the rigor of the study.

In similar lines, the use of self-report measures could have had a confounding effect on the results, especially the findings based on the correlational and regression procedures. An overall negative mood among the respondents could have contributed to low ratings on all the survey questions resulting in responses and significant co-relationships among factors such as higher level of barriers to inflow of information and expertise, and higher levels of simplifications in information and alternatives evaluation. Appropriate controls to check for and weed out such influences could be incorporated into future studies.
In terms of substantive content, we observed some interesting interrelations among the contextual variables. For example, 'barriers to inflow of requisite expertise and information' was negatively correlated to 'availability of information and expertise'. Similarly, internal knowledge linkages positively correlated with processes of accumulating prior knowledge. A next stage of the study can develop finer understandings of the interrelationships among the independent variables and their relationship to cognitive simplification processes.

Another area of inquiry would be to understand the interventional potential of a survey of cognitive simplification processes. Can extended feedback and discussion of the results reduce the incidence of delays and improve the performance of product development teams—a worthwhile topic for investigation in the future.

Finally, while this study examined the relationship between select socio-structural features of the project team context and cognitive activity, an extension of this exploration can cover how different types of structures and cultures associated with the management of innovation interact with the quality of deductive-inductive action.
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Boland, R. J., Tenkasi, R. V., & Te'eni, D. (forthcoming) Designing information technology to support distributed cognition. *Organization Science*.


APPENDIX

Retrospective Analysis Interview Form

Project: ___________________________________________

Deliberation: _________________________________________

Interviewer: __________________________________________

Interviewee Demographics:

Focus Area: __________________________________________

Job/Position: __________________________________________
(Director/AD, Section Head,
Staff, A&T)

Project Section or Resource Section (Circle One)

Functional Area (Check One):

____ Life Scientist ______ Analytical Chemist

____ Synthetic Chemist ______ Biopharmaceutics

____ Toxicologist ______ Regulatory

____ Research Computer Scientist ______ Statistician

____ Medical (M.D.)
INTRODUCTION

1. **Explain Purpose of Interview**
   (XXXX) has identified 15 work processes and selected 6 of these processes for initial evaluation and improvement as phase 2 of Total Quality. I'm part of the team working on the process DEVELOP TECHNOLOGY TO MEET THE NEEDS OF THE BUSINESS. This process includes the major decisions on-site of intervention and selection of drug candidates for clinical testing. We are interviewing members of project teams to assess how we conduct the deliberations that form the basis of the key decisions of the project.

   (The projects were selected to provide broad representation of the Division and were limited to projects that had completed the early stages of selecting sites for therapeutic intervention and identifying drug candidates.)

2. **Clearly Describe the Deliberation Which is the Focus of the Interview**
   A process of information exchange, planning, or decision-making related to a topic that requires ongoing attention during the life of a project. Deliberations are a key element in the organizations' knowledge generation and utilization processes.

3. **Explain How the Interviewee was Chosen**
   You have been selected for the interview because you were a participant in one of the key deliberations associated with the project.

4. **Give an Overview Format of the Interview**

5. **Explain How interview Data Will Be Used**
   The interview data will first be shared and analyzed within our satellite team. Our findings and recommendations will be integrated with the results of a similar study of four other projects. A summary of the key learnings will be prepared and distributed to all members of the project teams which were part of the study. And a recommendation for improvements to the way we identify pathways for intervention and drugs for clinical testing will be sent to the (XXXX) for approval. This report will not be available until early (XXXX).

6. **Expected Benefits or Outcomes**
   First, to gain a clear understanding of the processes we use to produce and utilize knowledge especially when faced with incomplete or uncertain information.

   Second, to improve these processes and the organizational context so that we successfully nurture both scientifically sound ideas and discontinuities which enable us to maintain a technology pipeline of marketable innovations.

   Third, to maintain and build our people's innovative drive and appreciation for our organization's key strengths and values.

   Don't forget to listen, record interviewee comments, ask questions for clarity, and thank interviewee for their time.
INFORMATION EXCHANGE - Node 1

The following questions should be answered relative to the first node identified in the deliberation.

1. What information did you bring or contribute to this phase of the deliberation?

2. What was your interpretation of the data or information you brought? What did you think it meant?

3. What was the impact of your information on the deliberation process or outcomes?

4. What information was relied on and used in this node of the deliberation?

5. How certain (complete, not open to multiple interpretations, accurate) was the information or knowledge that was used?

6. What information or new learning did you take away with you from this node of the deliberation?
OUTCOMES OF THE DELIBERATION

7. In your opinion, what information was missing in making the key decisions associated with this deliberation? Could this information have been available?

8. What risks are associated with the outcomes of this deliberation?

9. What are the benefits of taking this risk?

10. Are the benefits appropriate for the given level of risk?

11. Were there major influences outside of the project team that affected the outcome(s) of this deliberation? (Influences could include people, organizational structure or processes, competitive/business factors, etc.) What or who were they? How did they impact the deliberation?
ORIENTATION

1. What were your objectives or point of view on the issue? What did you want to see happen as an outcome of this deliberation? Why?

Why was this outcome(s) important to you?

2. Were there other interests or points of view related to the outcome(s) of the deliberation? What were they?

Node 1:

Node 2:

Node 3:

Node 4:

3. Were there important perspectives/parties missing or ignored from this deliberation? What/who were they? How could they have impacted the deliberation?

Node 1:

Node 2:

Node 3:

Node 4:
SURVEY OF KNOWLEDGE GENERATION AND UTILIZATION*

I. DEMOGRAPHIC INFORMATION
A. JOB/POSITION: (Check One)
   ______ Director/AD
   ______ Section Head
   ______ Project Leader (if not Section Head)
   ______ Group Leader
   ______ Staff
   ______ A&T

B. PROJECT SECTION or RESOURCE SECTION (Circle One)

C. SERVICE YEARS WITH (XXXX) (Check One)
   ______ <5 Years
   ______ 5-10 Years
   ______ 10-20 Years
   ______ 20-30 Years
   ______ >30 Years

D. NUMBER OF YEARS IN CURRENT ASSIGNMENT (Check One)
   ______ <1 Year
   ______ 1-3 Years
   ______ 3-5 Years
   ______ >5 Years

E. TECHNICAL FUNCTION: (Check One If Applicable)
   Please indicate the technical discipline in which you are currently working.
   ______ Organic Chemistry
   ______ Analytical Chemistry
   ______ Life Science
   ______ Toxicology
   ______ Market Analysis
   ______ Medical (M.D.)
   ______ Biopharmaceutics
   ______ Regulatory
   ______ Statistics
   ______ Other

F. PROJECT WORK:
   What percentage of your total work time do you currently devote to the project which
demands the greatest amount of your time?

   ______ a. Less than 25%
   ______ b. 25%-49%
   ______ c. 50%-99%
   ______ d. 100%

    Please indicate the project which demands the greatest amount of your time
currently? Check one from the list below:

* Note: Only those sections of the survey pertaining to this study have been included.
II. COGNITIVE PITFALLS (Simplification) IN SELECTING AND EVALUATING ALTERNATIVES

Indicate the extent to which any of the conditions listed below impacted the selection and evaluation of alternatives in the project on which you spend the greatest amount of your time.

To no extent: this pitfall did not occur in deliberations

To some extent: this pitfall had a moderately negative impact

To a great extent: this pitfall had a significantly negative impact

1 2 3 4 5 6 7

Favored Hypothesis Bias: One dominant hypothesis dictated most decisions, and evidence or information contrary to this hypothesis was discounted or not considered.

Favored Information Sources: Information from some preferred sources were relied on for making decisions, and information from other sources were considered if they conformed to information from these preferred sources.

Allocating More Resources: There was a tendency to persist in allocating more resources to alternatives that were failing, in the hopes of salvaging the already substantial investment in these alternatives.

Inadequate Reasoning: Without any objective evaluation of how representative it was, a framework/model from a past project/problem was used to understand and make sense of a current project/problem.

Oversimplification: In some complex decision situations, there was a tendency to oversimplify the problem and prematurely focus on a single alternative rather than attempting to generate a number of alternative courses of action.

Overvaluing Preferred Alternatives: In some decision making situations, there was a tendency to overvalue preferred alternatives by:

- Magnifying the attractiveness of the preferred alternative.
- Denying risk/benefit trade-offs.
- Identifying/amplifying the negative aspects of non-preferred alternatives.

Devaluation of Partially Described Alternatives: Among a group of alternatives, there was a tendency to devalue alternatives that were not completely described without allowing a further examination of such alternatives.
<table>
<thead>
<tr>
<th>To no extent; this pitfall did not occur in deliberations</th>
<th>To some extent; this pitfall had a moderately negative impact</th>
<th>To a great extent; this pitfall had a significantly negative impact</th>
</tr>
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<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6/7</td>
</tr>
</tbody>
</table>

**Overvaluing Preferred Alternatives:** In some decision making situations, there was a tendency to overvalue preferred alternatives by:

**Overemphasizing a Problem-Solving Strategy:** In decision making situations, there was a tendency to repeatedly use one or few problem solving strategies.

**Ability to Generalize Theories, Models, and Findings:** In some decision situations, there was a tendency to generalize theories and models from a few vivid or successful cases.

**Overconfidence in the Illusion of Prediction:** In some decision situations, there was a tendency to overestimate accuracy of predictions for some alternatives.

**Illusion of Personal Control:**

In some situations there was a tendency to overestimate the extent to which the outcomes of a strategy was under one's personal control. There was an assumption that through additional effort, one can make the strategy succeed should problems arise.

In some situations, there was a tendency to overestimate the extent to which the outcomes of a strategy was under another's personal control. There was an assumption that this other will find ways to make the strategy succeed should problems arise.
**DELAY IDENTIFICATION**

This section contains statements which describe different types of delays. Please identify how frequently these delays impact your work.

<table>
<thead>
<tr>
<th>No or very little impact</th>
<th>A moderate impact</th>
<th>A significant impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
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<td>6</td>
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<td>7</td>
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</table>

___ a. Delays in developing basic theory, models and/or infrastructure required to test the hypothesis.

___ b. Delays in synthesizing and testing new drug candidates.

___ c. Delays in responding to changes in program activities.

___ d. Delays in assembling sufficient technical resources.

___ e. Delays in responding to over-optimistic schedules.

___ f. Delays in recognizing and accepting that prior solutions were technically unsuitable and sub-optimum.

___ g. Delays in getting crucial people together at the same time.

___ h. Delays in getting management approvals or sanctioning for various courses of action.

___ i. Delays in overcoming internal resistance and organized politics.
PROJECT PERFORMANCE SCALE

1. In your opinion, how productive is the project in relation to its goals, i.e., producing a new drug candidate, new site of intervention, new use of existing drug, etc. -- is this project? (Circle a number on the scale below.)

<table>
<thead>
<tr>
<th>Highly productive</th>
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<tbody>
<tr>
<td>6</td>
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<tr>
<th>Not at all productive</th>
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<td>3</td>
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</table>

2. In your opinion, how innovative -- in the sense of generating new ideas or knowledge that advanced theory/science in this field; or contributed to developing new methods, test procedures, etc. -- is this project? (Circle a number on the scale below.)

<table>
<thead>
<tr>
<th>Highly innovative</th>
</tr>
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<tr>
<td>6</td>
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<tr>
<th>Not at all innovative</th>
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<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

3. How would you describe the progress being made on this project?

<table>
<thead>
<tr>
<th>Progressing better than expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Not progressing as well as expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Progressing as expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

4. Indicate the current competitive position of the project by circling a number of the scale below.

<table>
<thead>
<tr>
<th>Labs ahead</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Non-lab(s) believed to be ahead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-lab(s) at same stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>
GROUP NORMS SCALE

Please answer the following questions based on your impression of how decisions have been made on this project. Write a number in the blank beside each statement based on the following scale.

<table>
<thead>
<tr>
<th>To a very small extent</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>To a very great extent</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

1. To what extent have conflicting interpretations or alternatives openly been explored and discussed before making key decisions.

2. To what extent have you felt comfortable expressing counter-opinions or disagreements when important technical issues were being discussed.
REQUISITE EXPERTISE SCALE

Please answer the following questions based on your impression of how decisions have been made on this project. Write a number in the blank beside each statement based on the following scale.

<table>
<thead>
<tr>
<th>To a very small extent</th>
<th>To a very great extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

1. To what extent has critical information been available prior to making key decisions.

2. To what extent has relevant expertise been available to make key decisions.

Please indicate the extent to which the following conditions impacted the deliberations of this project.

<table>
<thead>
<tr>
<th>No. or very little impact</th>
<th>A significant impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

3. Missing parties: People who have relevant information are missing from key discussions.

4. Wrong parties: Some people are involved in discussions of tasks who should not have been.

5. Lack of internal consulting: Important information from other areas within (XXXX) is not taken into account before major technical decisions are made.

6. Lack of external consulting: Important information from other divisions and the environment is not taken into account before major technical decisions are made.
PROJECT (INTEGRATIVE) LEADERSHIP SCALE

Please write in the space provided the number that reflects the degree to which each statement is an accurate description of the project leader.

<table>
<thead>
<tr>
<th>Not at all accurate</th>
<th>Very accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7</td>
<td></td>
</tr>
</tbody>
</table>

_____ 1. Has an excellent conceptual understanding of my work on the project.

_____ 2. Is an excellent sounding board for new ideas.

_____ 3. Is particularly effective at providing original ideas or fresh approaches.

_____ 4. Has the ability to recognize and mediate conflicts between groups or individuals.
**LANGUAGE BARRIERS SCALE**

Please indicate the extent to which the following conditions impacted the deliberations of this project.

<table>
<thead>
<tr>
<th>No. or very little impact</th>
<th>A significant impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

1. Language barriers: Different individuals or groups fail to assimilate critical information because of specialized language barriers (example: terminology of a technical discipline)
ENGAGEMENT STYLE INVENTORY

6. People differ widely in their preferred approach to their work. Please rank order each of the statements below from most representative of you (4) to least representative of you (1). Make certain that you rank order all of the alternatives: no ties are allowed.

Sample Response:

1a. I spend most of my time thinking about:

4 The future 1 The past 3 The present 2 No particular time

1. When confronted with an issue, the first thing I usually do is:

Think about the new opportunities it represents
Think about how I solved similar problems in the past
Think about what steps to take first
Think about what I might learn from it

2. My approach toward risk taking is:

Trust my instincts
Weigh the odds, then decide
If at first you don't succeed, try, try again
Don't go off half-cocked: think it through

3. My energy in conversations is highest when:

I'm engaged in creative thinking
I'm analyzing the facts to reach a decision
I'm developing a plan of action
I'm getting at the underlying issues

4. I would describe myself as:

Self-confident Reasonable High-energy Calm

5. Other people contribute most to my thinking when they:

Stimulate me to think of new ideas
Offer data to support my arguments
Propose action steps to move us ahead
Help me to see the logic in a situation
Please rank order each of the statements below from most representative of you (4) to least representative of you (1). Make certain that you rank order all of the alternatives: no ties are allowed.

6. I am attracted to situations that call for:
   - New approaches
   - Careful research
   - Immediate response
   - Long-term planning

7. In meetings I usually:
   - Challenge the status quo
   - Clarify the basis for decisions
   - Help set the agenda
   - Summarize key points

8. When I make decisions, they are usually based on:
   - Faith that things will work out
   - The facts in the situation
   - Doing whatever is called for to achieve results
   - What I have learned from experience

9. I would prefer to be evaluated based upon:
   - The quality of my ideas
   - The effort I have put forth
   - The outcomes of my efforts
   - My long-run contributions

10. When I meet with people from other departments or functions, I find their input valuable if:
    - It sparks new ideas
    - It is based upon facts, not just opinion
    - Helps us make progress
    - It offers a different perspective
ACCUMULATING PAST KNOWLEDGE

Please indicate how accurately each of the following statements reflect the mode of operating within (XXXX).

<table>
<thead>
<tr>
<th>Mostly inaccurate</th>
<th>Mostly accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

- 1. People's past experience and knowledge learned from previous projects are easy to tap into.

- 2. When projects are completed, there is sufficient continuity in people and/or transfer of knowledge so that the division continues to build a solid technical base in the project focus area.

- 3. Knowledge learned from failures is valued and incorporated into new hypotheses.

Indicate, based on your experience, the extent to which each of the following factors are currently present in the work environment.

<table>
<thead>
<tr>
<th>None</th>
<th>A great deal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

- 4. Technical documentation of past work.

- 5. Systems for retrieving past learnings.
## KNOWLEDGE LINKAGES SCALE

Please indicate, by circling the appropriate number, the phrase which most accurately completes each statement.

1. The informal interactions between people in different focus areas are:

<table>
<thead>
<tr>
<th>Infrequent</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Periodic</th>
<th>4</th>
<th>5</th>
<th>Frequent</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

2. The sharing of knowledge across focus areas is:

- Limited, mostly through technical reports
- Extensive, informal; emergent & new ideas are shared

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

3. The exchange of information between members of resource sections and project sections are:

- Infrequent, short duration
- Periodic, short duration
- Frequent, continuous

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

4. The interaction between resource and project groups related to developing research designs and test methods is:

- Limited, developed independently
- Cooperative; jointly developed

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

5. Communication between members of (XXXX) and the receiving division is:

- Very formal; at structured meetings only
- Somewhat informal; at unstructured meetings
- Extremely informal 1:1 communication predominates

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
Please indicate how accurately each of the following statements reflect the mode of operating within (XXXX)

6. Links to External sources of Information or Expertise

<table>
<thead>
<tr>
<th>None</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>A Great Deal</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

7. Time Pressure, Schedules and Deadlines - How much is there?

<table>
<thead>
<tr>
<th>None</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>A Great Deal</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

Please indicate how accurately each of the following statements reflect the mode of operating within (XXXX)

<table>
<thead>
<tr>
<th>Mostly inaccurate</th>
<th>Mostly Accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

8. Pressure to show practical results frequently causes high project goals to be sacrificed prematurely.

9. Increasing demands on time and resources has reduced discretionary research making it less likely that novel or breakthrough ideas will occur.