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CEO PUBLICATION
G 94-10 (253)

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February, 1994

Submission for the Technology and Innovation Management Division of the
Academy of Management Meetings, Dallas, 1994

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EXAMINING COGNITIVE PROCESSES IN R&D: COGNITIVE SIMPLIFICATION ACTIVITY AS A MEASURE OF THE QUALITY OF THINKING IN NEW PRODUCT DEVELOPMENT TEAMS

A cognitive framework of R&D is extended. It is proposed that cognitive simplification processes can be a useful measure of the quality of cognitive activity in R&D. New product development teams reporting a higher incidence of cognitive simplification processes in their deliberations were rated lower on project performance.

Parts of this research have been supported by National Science Foundation Grant # IRI-9015526 and a grant from the TRW foundation

INTRODUCTION

Despite the obvious importance of thinking and reflection in a knowledge intensive function such as Research and Development (R&D), it is only recently that a cognitive/interpretive focus is gaining some, albeit, limited recognition in the organizational literature on new product development and innovation (Dougherty, 1992; Nonaka & Kenney, 1991; Purser & Pasmore, 1992). Science is a function of human cognition and thus a fuller understanding of R&D should necessarily include the investigation of human cognition; at least those cognitive processes that underlie scientific inquiry (Rubinstein, McManus & Laughlin, 1984). I posit that one approach towards studying the effectiveness of the quality of cognitive processes in R&D efforts is an examination of cognitive simplification activity in new product development environments. Accordingly, in this paper, I extend a cognitively based understanding of R&D, explore empirically cognitive simplification processes in scientific work, and assess their impact on the effectiveness of new product development outcomes.

BACKGROUND AND LITERATURE REVIEW

Writers on the philosophy of science were the earliest to recognize that cognitive and interpretive processes play a significant role in research and innovation. 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 (Whitley, 1972; Rubinstein et al., 1984, Giere, 1992; Nersessian, 1992). "Theories do not simply develop; they are developed through the cognitive activities of particular scientists" (Giere, 1992: xviii). "Scientific practice is marked by cognitive concerns, and we cannot hope to understand it without giving them due consideration" (Knorr-Cetina, 1981: 22). Examining merely the social aspects of scientific organization and communication patterns is insufficient.

Despite these repeated calls for inquiry into the cognitive components of R&D, there appears to be limited concerted effort in this direction. For example, Purser and Pasmore (1992) note that there is almost nothing in the management literature that relates directly to the processes of creation and application of knowledge in R&D efforts. As they elucidate; "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" (1992: 2). A similar view is reflected in the philosophy of science domain. For example, Whitley (1972) has stated that, "the production of scientific facts is still a black box to the social studies of science", and more recently Nersessian (1992:7) has asserted that; "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"

A brief review of the traditional approaches in the organizational literature towards understanding R&D and product innovation will clarify the point. At one level we have studies that deal with structural aspects of innovation and knowledge development (Burns & Stalker, 1961; Galbraith, 1982). Another set of studies emphasize the overall cultural conditions required for innovation (Pelz & Andrews, 1976; Kanter, 1983). A third and popular set of studies conceptualize R&D as an information processing system. While this approach is closer to a cognitive notion of R&D it still falls short. Most research under this framework has an "information input" focus, that is the way information enters an organization, and an "information exchange" focus which investigates the channels of communication through which information then flows. Representative areas of inquiry include technical information acquisition patterns of scientists (Allen, 1977; Chakrabarthi et al., 1983) sources of information used in different stages of the innovation process (Utterback, 1971; Rothwell et al., 1974) and communication patterns and networks internal to the R&D laboratory (Allen & Cohen, 1969; Allen, Tushman & Lee, 1980).

While these different streams of research have extended a general framework in getting our hands around an elusive phenomenon such as R&D, they restrict themselves to providing the context for innovation; a legacy that can be traced early philosophers of science such as Reichenbach (1938) who argued that 'scientific discovery is an inexplicable process' and inquiry into the nature of science should be confined to the context and not discovery itself. Findings such as organic structures facilitate more innovation (Burns & Stalker, 1961), or innovation flourishes under climates that stimulate contradictory conditions of challenge and security (Pelz & 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 new product development is one of producing ideas about products or processes. Thus, while the context can play a role in influencing scientific reasoning processes (Knorr-Cetina, 1981), cognitive processes are the 'engine of innovation' ; they are the transformative core that constitute the fundamental basis of knowledge production in scientific settings.

Therefore, one can conceive that the essence of R&D is 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.

Understanding R&D as a cognitive process

The quality of thinking processes as the critical guarantor of scientific success is reflected in the emergent writings in the cognitive philosophy of science. While many of these writings are restricted to conceptual arguments and propositions, and empirical evidence for the most part is forthcoming, there appears to be an uniform agreement that the creative heart of scientific reasoning is a cognitive modeling process of the new problem domain to be explained, discovered or invented (Bradshaw, 1992; Nersessian, 1992; Rubinstein et al., 1984; Simon, 1966;1973a;1973b).

Though the nature of specific representations (pictorial vs. linguistic vs. symbolic) is still undergoing formulation (Nersessian, 1992; Eysenck & Keane, 1990), in reasoning and understanding people construct mental models of real and imaginary phenomena, events, situations, problems, and processes (Bartlett, 1932; Weick, 1979). For example, Simon's (1966; 1973a; 1973b) model of scientific discovery/invention entails the construction of a problem solving model of a wider problem space. To illustrate, confronted with anomalous data such as the behavior of liquids in nature, or a specific problem such as making possible 'manned flight' scientists engage in a search for hypotheses, data, and laws to construct a model to explain the data or the phenomenon to be realized (such as manned flight). The scientists then undertake a process of confirming (or disconfirming) the model by activities such as making new instruments, heating liquids, conducting experiments and so on (Bradshaw, 1992).

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 wider problem space) and the 'cognized environment' (which would be the problem model). The operational environment is the world that is objectively real and moldable while the cognized environment consists of all the information modeled in an individual's cognitive structure through the operation of which the individual recognizes, processes information about and responds to the operational environment. The cognitive modeling act is an attempt to understand the workings of nature; a process of constructing knowledge about the underlying laws of the scientific operational environment. For example in the case of 'manned flight' it would be attempts at modeling and understanding the workings of the aerodynamic laws of flight.

However, for successful scientific innovations the cognized model should progressively complexify itself so that it can become 'adaptively isomorphic' with the operational environment. "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., 1984: 37). Isomorphism refers to the correspondence between the elements and relations constituting a particular system, and the elements and relations constituting another system. Hence the cognitive model is adaptively isomorphic with the operational environment when there is a degree of optimal 'fit' between the cognized environmental model and the operational environment. That is, over a period of time the scientist should be able to progressively complexify his or her model of the new problem domain so that it mirrors the natural laws governing the operational universe or wider problem space.

Thinking in science as Deductive-Inductive alternation

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

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

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

Induction is the counterpart to deduction. It is that phase of the cycle of inquiry during which information pertaining to the operational environment is collected and evaluated as 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). It is frequently the outcome of an operative action of testing the cognitive model on the operational environment through experimentation. It is a processual notion, the manner in which information is evaluated and used by individuals (Price-Williams, 1969). Induction should be able to facilitate the incorporation of potential material from the environment enabling cognitive model confirmation or reformulation.

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

In summary, scientific success is dependent upon the quality of thinking processes as resident in deductive and inductive action. The quality of problem or model formulation (deduction) and the quality of information evaluation (induction) ultimately drive the success of scientific innovation.

An example will illustrate the point. 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 operational environment) than their competitors. He locates the crucial difference as resting in the quality of deductive and inductive activities demonstrated by the Wright brothers vis-a-vis their competitors.

For one there were two differing cognitive models of flight 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. The Airmen however, often sought to build gliders in advance of attempts to construct powered planes. Members of this tradition of whom the Wright brothers were the most representative recognized that flying was quite different from driving a car, and needed to be understood on its own terms. For example, the brothers built several kites to explore the natural laws of flight.

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

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

On the contrary, the Wright brothers explored solutions to problems using directed experiments. They built a kite to explore lateral control, and lift and thrust were solved through the use of wind tunnel experiments. Another characteristic of the brothers research was the extensive testing performed on each model and continually revising their understanding of aerodynamic laws; "By testing 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" (1992: 246-247)

Cognitive simplification processes as an index of quality of thinking in R&D

In the preceding sections I have extended a theoretic rationale suggesting a link between the quality of thinking and reasoning processes in R&D systems and the effectiveness of innovation outcomes. The quality of problem conceptualization/ model formulation (deduction) and the quality of information evaluation (induction) can play a key role in the success of scientific innovations.

I propose that one approach towards studying the effectiveness of the quality of thinking and reasoning processes in R&D efforts is an examination of cognitive simplification processes in new product development environments. 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.

Cognitive simplification processes are reliance on simple cognitive decision rules to make sense of and deal with complex and fuzzy problems. They have also been alternately called process biases and heuristics (Kahneman, Slovic & Tversky, 1982). Such simplification activity can manifest itself in, faulty framing of the problem, inadequate information search and evaluation of alternatives, and biased appraisal of consequences (Janis, 1989). They can be a major barrier in R&D efforts, since simplification can hamper the requisite complexification necessary for adaptive isomorphism.

Cognitive simplification processes frequently arise in response to the complexity of the task environment. They can operate outside the bounds of day-to-day consciousness, and can be open to but not manifest total awareness. When exposed to high environmental uncertainty and ambiguity, individuals can repress awareness of the uncertainty, modify their perceptions of the task environment so that it appears more certain, and act on a simplified model of reality they construct (Schwenk, 1984).

As Rubinstein et al. (1984) concur, the cognized environmental model can construct itself in terms of simplified cause and effect relations of the operational environment and constrain its functioning to those simplified elements and relations. A relevant example is documented in Tenkasi (1994) where the scientists in a pharmaceutical new product development team used a 'rat model' to understand the human digestive system in their efforts to come up with a cure for a certain digestion related affliction. While the drug worked with rats the results were far from impressive with humans. In retrospect they realized they should have used a primate model.

Further, the cognitive model can close down and cease to deal with anomalous input that suggests any revision of the cognitive model. This could happen in several ways such as actively seeking information that would support the model, distorting information from assimilation into the model, rejecting the information, and holding the information without assimilating it. An illustration of this process is evident in some members of another pharmaceutical new product development team refusing to acknowledge the toxicity side effects that were indicated in the tests of a drug they were developing (Tenkasi, 1994). The drug could not ultimately clear FDA standards and resulted in the scientists going back to the drawing board. .

Of particular relevance is an excellent review by Schwenk (1984) of simplification processes affecting problem conceptualization/ model formulation and information/alternatives evaluation in strategy formulation, a domain very close to R&D in terms of the level of uncertainty and complexity.

These simplification processes for which laboratory evidence exists and field examples can be identified are; *reasoning by analogy* that entails the application of analogies and images from simpler situations to complex problems; *prior (single) hypothesis bias*, where an erroneous hypothesis about the relationship between variables guides decision making even if abundant evidence over numerous trials suggested that the hypothesis was wrong; *problem set*, where there is a repeated use of one problem-solving strategy; *single outcome calculation*, which occurs when the focus is limited to a single goal and a single alternative course of action to achieve it; *illusion of control*, which is related to the strategy of choosing a single alternative course of action and where individuals overestimate the extent to which a strategy is under *one's own* or *other's* personal control; *representativeness bias* where there is a tendency to overestimate the extent to which a sample is representative of the population and can include *overgeneralization* of findings, models, and patterns from a small data base; a related bias is *overconfidence in the illusion of validity* where *predictions* are made from a few vividly described cases; *escalating commitment* is a tendency to allocate more resources to projects which are failing in the hope of salvaging an already substantial investment; *adjustment and anchoring* which is similar to prior hypothesis bias, but has to do with information evaluation, where initial judgments about values are not revised as new data is reported and consequently final estimates of values are biased towards initial values; *magnifying desirability of alternatives* is developing arguments to bolster the attractiveness of a preferred alternative; *inferences of impossibility* involves identifying the negative aspects of non-preferred alternatives in order to convince oneself that they are not possible to implement; *denying value trade-offs* is a tendency to over-value a preferred alternative by denying cost-benefit trade-offs; and *devaluation of partially described alternatives*, as the name suggests, is devaluing that alternative that is partially described.

RESEARCH FOCUS

The study was exploratory in nature. It was based on the premise that the quality of thinking and reasoning processes can influence R&D project outcomes, and one approach towards investigating their effectiveness is an examination of cognitive simplification processes in new product development efforts. Also, an added interest was in responding to Schwenk's (1984) call for documenting the effects of cognitive simplification processes in field settings. The larger study, of which this report is a part, also investigated qualitatively the incidence and impact of cognitive simplification processes in new product development activity, and examined qualitatively and quantitatively some of their contextual antecedents. However, in this paper I report the tests of the relationship between cognitive simplification processes and project outcomes.

The principal hypotheses examined were;

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

METHODS

Subjects

The subjects for the study were scientists and technical personnel employed in the R&D center of a pharmaceutical company. A survey was administered to all of the 197 personnel. The scientists were organized across 25 concurrent and on-going drug development projects. Of the 158 subjects who responded (80 percent return rate), 49 percent were M.Ds or Ph.Ds with varying specializations from chemistry, life sciences, toxicology, and biopharmaceutics. The survey was comprehensively pre-tested on 15 individuals. Subjects were asked to respond to items based upon real time project deliberations. Only scientists who spent a majority of their time on a single project were included in the analysis.

Cognitive simplification scale

Drawing from Schwenk (1984) a scale comprising of fourteen items was constructed to measure cognitive simplification processes. The items were reframed in a language that was most fitting of the pharmaceutical R&D population. Subjects were asked to rate the extent to which each simplification process was experienced as impacting the deliberations of their project team on a seven point response format ranging from "To no extent" to "To a great extent".

Project Performance scale

Measuring R&D project performance (or effectiveness) is a difficult task, especially with on-going projects. However, it is possible to capture the flavor of the effectiveness of R&D work by using multidimensional measures, obtaining performance ratings from a number of involved parties, and taking into consideration local knowledge about scientific performance (Andrews, 1979; Ancona & Caldwell, 1992). Therefore, based on discussions with scientists and management, and an integration of literature the following measures were constructed to measure project performance. 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 an 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 employed by Andrews (1979). In this international comparative study of 1,200 research units in six nations, factor analysis suggested that productiveness and innovativeness revealed a stable pattern of relationships (i.e., contributed to the maximum variance explained) even after controlling for characteristics of the research unit (size, experience, activities, leadership, resources etc.).

Two other measures that were constructed and to which only the team members responded (since it was felt that only they had the relevant knowledge) were;

Project progress, or the extent to which the project is progressing in accordance with plans and schedules (Ancona & Caldwell, 1992; Andrews, 1979), and

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

Scientists and technical personnel responded to all the four questions on a seven point scale. 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 section heads rated each project individually on productiveness and innovativeness. The managers ratings were averaged (Ancona & Caldwell, 1992) to come up with a mean score for each of the two measures for every one of the twenty-five projects rated.

Analyses

Three factor analyses were undertaken to assess the construct validity of the scales employed. The latent root criterion with a minimum eigen value specification of 1 was used to decide the number of factors to be extracted (Hair, Anderson, Tatham, & Grablowsky, 1984). Principal component factor solutions utilizing varimax rotation were obtained for all three scales and reliability analyses were conducted. Subsequently the 25 teams were classified into high and low simplification (treatment) conditions based on a median split of an overall simplification score obtained by averaging all simplification items, as well as on the basis of the four factor scores that emerged from the factor analysis of the cognitive simplification scale. Manovas and Anovas were used to establish that the dichotomization of the teams into high and low simplification conditions were in fact statistically significant. Further, to test for significant differences between the high and low simplification teams on project performance (effectiveness), Anovas were conducted.

RESULTS

As indicated in Table 1, four factors emerged from the analysis of the cognitive simplification scale. The first factor included six items; prior (single) hypothesis bias, single outcome calculation or oversimplification of problem; problem set or overemphasizing a problem solving strategy; overconfidence in illusion of validity of prediction; and illusion of one's and other's personal control. Since many of these items mirrored closely our 'a priori' classification of simplifications in problem formulation or deductive action this factor was termed '**simplification in problem framing**'. The second factor also corresponded closely to the conceptual classification of simplifications in inductive action or information/alternatives evaluation. The six items were; adjustment and anchoring or relying on favored information and sources; magnifying preferred alternatives; denying value (cost-benefit) trade-offs; amplifying negative aspects of non-preferred alternatives or inferences of impossibility; devaluing partially described alternatives; and overgeneralization of theories and findings from a limited data base. This factor was appropriately labeled **'simplification in information and alternatives evaluation**'. The third factor showed a very high loading of a single item, inadequate analogical reasoning, which seemed apt given the significance attached to analogical reasoning as fundamental to scientific innovations (Nersessian, 1992). The factor was identified as **'poor analogical reasoning'** . The fourth factor had a single item, allocating more resources to failing alternatives, termed as '**escalating commitment'**. Reliability analysis on all fourteen items showed a Cronbach alpha of .98. For factor one it was .95 and for factor two it was .96. Reliabilities were not computed for single items.

Insert Table 1 about here

The factor analysis of the project performance scale used by team members resulted in all four items (productiveness, innovativeness, progress in relation to internal schedules, and progress in relation to competitors) collapsing into a single factor. Similar results were obtained for the project performance scale used by the managers. The two items (productiveness and innovativeness) factored together. A total project performance score was computed for each scale by averaging the individual items. Reliability coefficients for both scales were .71.

The dichotomization of the teams into high and low simplification groups based on a median split of the four factors as well as an overall simplification score were all statistically significant. A median split of simplification in problem framing resulted in 16 teams under low and 9 under high simplification conditions. The Manova indicated that the teams differed significantly on all items constituting factor one ($F=4.01$, $df = 6,112$, $p < .001$). A split based on factor two resulted in 18 low and 7 high simplification teams. The Manova results for simplification in information and alternatives evaluation were; $F= 5.23$, $df = 6, 112$, $p < .000$. There were 17 low and 8 high teams for factor three (poor analogical reasoning) and 15 low and 10 high teams for factor four (escalating commitment). 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 teams were significantly different also. A classification based on the overall simplification score resulted in 16 low and 9 high teams. A Manova indicated the following results; $F=4.95$, $df = 14, 101$, $p< .000$.

Results showed strong confirmatory support for the relationship between cognitive simplification processes and project performance as rated by team members as well as by management . Anovas suggested significant differences for the total project performance score in both cases and in the predicted direction (means and standard deviations are not reported due to space limitations). 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 dichotomized on the overall simplification score, an Anova indicated that the teams that were rated **higher** in overall simplification activity were rated

lower by **team members** on the total project performance index ($F= 9.503$, $df=1,136$, $p<.002$). Similar results were obtained for simplification in problem framing ($F= 10.31$, $df=1,138$, $p < .002$), and simplification in information and alternatives evaluation ($F= 10.15$, $df=1,138$, $p<.002$). Project teams rating higher in poor analogical reasoning also showed lower project performance ratings ($F= 8.12$, $df=1,138$, $p<.005$). For teams split on escalating commitment, the differences in project performance ratings were not significant .

A similar pattern was observed with reference to management ratings of team performance. The Anova results were as follows; overall simplification activity index ($F=9.46$, $df=1,136$, $p<.003$); simplifications in problem framing ($F=20.15$, $df=1,136$, $p<.000$); simplifications in information and alternatives evaluation ($F=6.75$, $df=1,136$, $p<.01$); poor analogical reasoning ($F= 6.36$, $df=1,136$, $p<.013$). Escalating commitment was not related to project performance.

In summary, teams evidencing higher overall simplification activity, higher problem framing simplifications, higher information and alternatives evaluation simplifications, and poorer analogical reasonings were rated by both team members and management as significantly lower on project performance.

DISCUSSION

The results provide strong empirical evidence that cognitive simplification processes in scientific deductive-inductive action can significantly hamper project performance effectiveness. These results align well with our earlier theoretical conceptions of the requirement of complexification for scientific success and cognitive simplification activity as a principal barrier that can hamper the process. From a broader perspective the study confirms an obvious, though widely ignored relationship, that the quality of cognitive activity in R&D efforts is related to the success of scientific outcomes. The study also contributes by extending cognitive simplification processes as a potential approach for examining the quality of thought processes in R&D. This fits in with Manz and Neck's recent (1991) call for ways to approach the 'Management of thought' in organizations, "perhaps the ultimate frontier to be explored in the pursuit of employee and organizational effectiveness" (1991: 94).

One issue worth some discussion is the non significance of 'escalating commitment' in explaining project performance effectiveness. A potential explanation is that escalating commitment can be equated with a broader cognitive orientation of investing more resources than with specific forms of deductive and inductive action. It might be a 'root' simplification that can precipitate 'derivative' simplifications in problem framing and information evaluation. For example, a project team that has invested considerable resources in a project might not be willing to let go and might selectively seek/evaluate information, or frame issues in such a way that they reinforce member beliefs that the project will succeed. This relationship is worth investigation in the future.

The findings of the study have a number of implications for enhancing the effectiveness of new product development processes. One obvious implication is exploring ways to obviate cognitive simplification activity in R&D. As observed previously these processes can frequently operate outside the bounds of day-to-day consciousness (Rubinstein et al., 1984). A major requirement then is consciously raising, and bringing into awareness, scientific deductive-inductive action in process. In Schutz's (1964) terms, it is the ability to periodically suspend our natural attitude so that interpretations given in a matter-of-course, taken for granted 'natural' way are noticed. Through this one can understand the ways in which one's scientific world is constructed and interpreted, and one may change them appropriately (Collins, 1983).

There appear 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 the *process* of cognition. 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, & Peterson, 1979). In summary, content is a description of "How do I see the world?", and processes are mechanisms through which the content is made possible, or rather, "how did I come to see the world as I do?". A study of, and intervention into both these complementary aspects of 'thought' are required to minimize simplification and facilitate complexification.

Inquiry into the processes of cognition, or the reasoning patterns and procedures that people engage in to construct their understandings of a situation, is best facilitated by asking questions (Janis, 1989) on the types and adequacy of processes individuals employ to come to know what they know (or the content of cognition). This would implicate processes such as analogical reasoning, reliance on various information sources, and rules used in evaluating alternatives. Examining the processes of cognition is the primary focus behind Janis's (1989) vigilant problem solving model. Along similar lines could be an examination of the interventional potential of the survey of cognitive simplification processes. Can extended feedback and discussion of the results improve the performance of product development teams?- a worthwhile topic for investigation in the future.

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

Cognitive mapping is essentially a device for displaying through the use of a map like diagram, the 'elements of thought' (Eden, 1992). 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 (Weick, 1979).

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 that can be used to provide closely documented descriptions of scientists' recurrent interpretative practices that are essentially embodied in their discourse. Further, such analysis can show how these interpretative procedures vary in accordance with variations in social context.

A third implication in dealing with cognitive simplification processes would be to attend to the contextual environments of new product development teams. How does the social context influence the quality of reasoning processes ? (Knorr-Cetina, 1981). Exploring the relationship between context and cognition can help product development teams make more informed design choices in the way they organize themselves. In sum, all the aforementioned issues are potential areas for future research.

One limitation from a methodological perspective is that the findings are based on the study of a single R&D organization engaged in pharmaceutical development work which limits the generalizability. A second limitation is that we used self-report measures to assess cognitive simplification processes. Although the original study used in-depth interviews to complement the survey approach, understanding an elusive and implicit phenomena such as cognitive simplification processes may require more sensitive methodologies such as 'cognitive mapping' or 'thought listing'.

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