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From Embedded Knowledge to Embodied Knowledge: New Product Development as Knowledge Management

Because new product development (NPD) teams are engaged in knowledge creation, NPD management should emphasize cognitive team processes rather than purely social processes. Using the notions of tacit knowledge and distributed cognition as a basis, the authors propose that the T-shaped skills, shared mental models, and NPD routines of team members, as well as the A-shaped skills of the team leader, are key design variables when creating NPD teams. The authors propose that trust in team orientation, trust in technical competence, information redundancy, and rich personal interaction are important process variables for the effective and efficient creation of new knowledge.

The extant literature on new product development (NPD) teams is based predominantly on fundamental work performed by social psychologists on the effectiveness of small work groups. As Bereiter and Scardamalia (1993, p. 118) point out, teams traditionally were perceived as "consisting of discrete individuals, each performing a specified function." In this perspective, the team outcome depends on the skill and reliability with which the individual functions are performed; the team is primarily a vehicle for coordinating the separate cognitive activities of individuals. Therefore, the majority of team studies have focused on the influence of social team processes on the team's key function of coordination. New product development teams, however, are engaged in knowledge-producing activity, which implies that an understanding of team social processes should be complemented by a cognitive perspective. Cognitive psychologists recently have proposed that cognition is more than the property of the solitary individual; what is emerging is a perception of cognition as distributed across the members of the team (Patel, Kaufman, and Arocha 1995; Perkins 1993). The individual brings to the situation his or her repertoire of skills, knowledge, and strategies, which affect and are affected by the situation. This dynamic interaction of individual and context results in the cognitive performance of the group (Patel, Kaufman, and Madger 1996, p. 140). The distributed cognition notion implies that teams should function more as a single unit engaged in a single process of expertise, rather than purely as a well-coordinated group of discrete, individual contributors.

The objective of this article is to develop, using the distributed cognition framework, some propositions on how teams should be created and managed to efficiently and effectively create knowledge by combining disparate bodies of knowledge. The rest of the article is organized as follows: In the next section, we present the knowledge-creation aspect of NPD. We emphasize the difference between tacit and explicit knowledge as a basis for developing the construct of embedded knowledge and establishing the importance of embedded knowledge in the NPD team context. In the subsequent section, we briefly describe the methodology for selecting and interviewing team members of five different NPD teams. Thereafter, on the basis of extant research findings and interviews, we develop propositions. We conclude with some implications for researchers and managers.

NPD as Knowledge Management: Distributed Knowledge and Cognition

From the idea-generation phase to the launch phase, the creation of new knowledge can be viewed as the central theme of the NPD process. One factor that increasingly is being considered in many of the treatments of knowledge is the role of *tacit knowledge*—knowledge that cannot be explicated fully even by an expert and can be transferred from one person to another only through a long process of apprenticeship (Polanyi 1967). Polanyi's (1967) famous dictum, "We know more than we can tell," points to the phenomenon in which much that constitutes human skill remains unarticulated and known only to the person who has that skill. In contrast, *explicit knowledge* is relatively easy to articulate and communicate and, thus, transfer between individuals and organizations. Explicit knowledge

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resides in formulae, textbooks, or technical documents. Analogous to the tacit and explicit dichotomy, Zuboff (1988) makes a distinction between embodied, or action-centered, skills and intellective skills. Action-centered skills are developed through actual performance (learning by doing). In contrast, intellective skills combine abstraction, explicit reference, and procedural reasoning, which makes them easily representable as symbols and, therefore, easily transferable.

Although initially conceived of at the individual level, tacit knowledge has been recognized as existing in the organization as well. For example, Nelson and Winter (1982) point out that much organizational knowledge remains tacit because it is impossible to describe all the aspects necessary for successful performance. They argue that creating an effective organization is not a matter of implementing a set of "blueprints," because much of the crucial know-how required resides only in the minds of the organization's members. In a similar vein, Kogut and Zander (1992) differentiate between information (e.g., facts) and know-how (e.g., how to organize factories). The listing of ingredients in a recipe consists of information, but the description of action steps is, at best, an imperfect representation of the know-how required. The conceptual distinction between tacit and explicit knowledge also appears in Reed and DeFillippi's (1990) discussion of causally ambiguous competencies. They describe tacitness as residing in the inability of even a skilled individual to spell out explicitly the decision rules and protocols that form the basis of performance. Badaracco (1991) conceives of tacit knowledge as existing in individuals or groups of individuals. He refers to such knowledge in individuals and social groups as *embedded knowledge*. Similar distinctions between explicit and largely tacit knowledge in organizations have been made by Scribner (1986), Nonaka (1991), Hedlund and Nonaka (1993), and Bohn (1994).

The prior discussion highlights the theoretical and empirical validity of a tacit component of organizational knowledge. For our treatment of NPD, we borrow the term "embedded knowledge" from Badaracco (1991) but define it more precisely. As soon as members of a team get together, there is potential for the team to create new knowledge. This new knowledge is a result of a combination of explicit and tacit knowledge. Combining explicit knowledge is rather easy; however, the degree to which the potential new knowledge, due to the integration of tacit knowledge, is realized depends on several variables. It is this domain of integration of tacit knowledge that is of interest; therefore, we conceive of *embedded knowledge* as the potential knowledge resulting from the combination of the individual team members' stores of tacit knowledge.

In the NPD context, a cross-functional team is brought together because its members have collective knowledge that cannot be held efficiently by any of its individual members. However, this collective knowledge is not present by definition when the team is assembled; it is only potentially present. We characterize the NPD team as a product development vehicle that brings to its task knowledge that is embedded in its members and their interactions as a team. The theoretical foundation for this conception is provided by Salomon's (1993) description of the reciprocal relations between individuals' and distributed cognitions. Specifically, Salomon's (1993, p. 122) hypothesis is that the two elements "interact with one another in a spiral-like fashion, whereby individuals' inputs, through their collaborative activities, affect the nature of the joint, distributed system, which in turn affects their cognitions such that their subsequent participation is altered, resulting in subsequent altered joint performances and products." Therefore, we propose that the potential for new knowledge is embedded in the team and its interactions. The NPD team possesses *embedded* knowledge; the new product is *embodied* knowledge. Therefore, the NPD manager's task is to manage the transition from embedded to embodied knowledge.

Methodology

Because our goal is to develop a knowledge-based treatment of the NPD process, we adopt a theory development orientation. We use the literature on organizational knowledge and distributed cognition as a starting point for examining NPD as the transition from embedded to embodied knowledge. Concepts in these literature motivated our propositions about NPD team characteristics and processes.

Parallel with the development of the propositions from the theory base, we conducted in-depth interviews with managers and team members involved in five separate NPD projects. The purpose of these interviews was twofold: First, we sought to get a firsthand feel for the relevance and face validity of our framework. Although the results are not being proffered as "proof" of our framework, the interviews helped us confirm that our theory-based assertions were in line with managerial experience and, thus, provided a sound basis for further theory development (Yin 1989). Second, we sought input from managers that could be used to guide the theory development process itself. In this aspect, we followed the spirit of grounded theory development (Glaser and Strauss 1967).

Sample. Following the systematic replication logic advocated by Yin (1993), we carefully chose five NPD teams from five different corporations to reflect a range of relevant characteristics. Five different industries were represented: traditional manufacturing, telecommunications, distribution, chemicals, and electronics. The corporations varied substantially in size as well. Four companies were large *Fortune* 500 companies, three of which had substantial global networks, and one was a regional firm. Finally, the projects were chosen to reflect a varying level of how innovative the new product was. One team was engaged in developing better processes for order management. Even though sophisticated robotics equipment was being incorporated, the innovativeness of the output was not high. The cross-functional diversity in this team was the lowest because most members were operational staff involved in the day-to-day functioning of the order fulfillment system. A second team was developing a software product. Compared with the previous team, this team was more cross-functional, in the sense that it brought together diverse knowledge

bases, including the Human Resources, Payroll, and Systems and Programming departments. The third team was from a research and development (R&D) unit but brought together members with different specialization in the chemical engineering, polymer, and chemistry disciplines. The fourth team was even more diversified than the previous three teams, in that it consisted of members with mechanical, electronics, and software engineering training. The fifth team, the most diverse in terms of knowledge domains, consisted of members from R&D, marketing, and manufacturing. This team had developed and commercialized a truly innovative product for which the company held several patents. Thus, the five cases together represent a wide variety of NPD contingencies. In all, approximately 30 in-depth interviews were conducted with individual team members.

Data collection and analysis. Following the guidelines available in literature (e.g., Eisenhardt 1989), we conducted semistructured interviews with team members. Although we guided the discussion to ensure that the interviewees covered the topics in which we were interested, we were careful to allow them to use their own words to describe the dynamics of their NPD teams. We also avoided leading questions, such as "Do you think rich personal interaction is helpful in creating embedded knowledge?" Each interview lasted approximately one hour. All interviews were tape-recorded and transcribed.

In analyzing the interview data, we looked for interviewee opinions that fell into three classes: (1) those that supported our current thinking, (2) those that conflicted with our current thinking, and (3) those that presented new thoughts. In the latter two cases, we went back to the literature to clarify the issues addressed. This process resulted in the theoretical framework presented subsequently. To conserve space, we do not present the quotes from the respondents in this version of the article.

Propositions: Embedded to Embodied Knowledge in Teams

The success of an NPD process can be assessed using two key indicators: effectiveness and efficiency. *Effectiveness* relates to the degree to which the product meets the targeted need of the customer (i.e., benefits and costs of the product). *Efficiency* is defined as a measure of resources (including time) used for a given output. Accordingly, we consider the effectiveness and efficiency with which embedded knowledge is converted to embodied knowledge (i.e., effectiveness and efficiency of the NPD process) as the two key dependent variables in our model.

We first present propositions regarding variables that are exogenous to the team process. Such variables are related to the selection of the team members. We then present other propositions that deal with variables endogenous to the team process. Many variables can affect the performance of an NPD team, including top management support, resources, organizational involvement, and so forth. We limit our discussion to the team as the unit of analysis. The team's relationship with the rest of the organization and factors external to the team are not analyzed here.

Exogenous Variables[1]

T-shaped skills. The proposition that creativity and new ideas spring from the interaction of different knowledge sets has found acceptance in knowledge literature (e.g., Simon 1985), as well as in related fields such as social networks (e.g., Granovetter 1973) and the emerging scientific literature on complexity (e.g., Kaufman 1995). In the context of NPD teams, an implication has been that the deliberate conflict of ideas—what Leonard-Barton (1995) has termed "creative abrasion"—has a positive influence on performance. However, whether the abrasion is creative or destructive may depend on the capability of individual specialists to sustain a meaningful and synergistic conversation with one another. Such a capability goes beyond the mere social skills of "getting along with team members" (e.g., tolerance of different perspectives) to specific cognitive skills. Such skills have been termed "T-shaped skills" by Iansiti (1993). Persons with T-shaped skills are those who are

> not only experts in specific technical areas but also intimately acquainted with the potential systemic impact of their particular tasks. On the one hand, they have a deep knowledge of a discipline like ceramic materials engineering, represented by the vertical stroke of the T. On the other hand, these ceramic specialists also know how their discipline interacts with others, such as polymer processing—the T's horizontal top stroke (Iansiti 1993, p. 139).

The apparent market demand for persons with "hyphenated" skills (*Fast Company* 1996)—those able to integrate multiple knowledge bases in their own experience—is evidence of the perceived value of T-shaped skill sets.

Viewing a team as a distributed cognition system, we argue that the horizontal stroke of the T-shaped skill set enables team members to interact with one another meaningfully to allow for "creative abrasion" at a cognitive level. Without these skills, such interaction would be hampered, though tolerance of others' viewpoints might still be prevalent as a social norm. Therefore, we propose that the presence of T-shaped skill sets will have a positive influence on team performance:[2]

> P_1: The presence of team members with T-shaped skills will be related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

A-shaped skills. Also receiving considerable acceptance in the literature is the importance of the leader's role in motivating and managing knowledge creation. For a leader to be effective in this role, the cognitive structure of his or her knowledge should reflect A-shaped skills. Leonard-Barton (1995, p. 77) describes A-shaped skills thus: "[S]ome indi-

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[1]Exogenous variables might change during the NPD activity of the team; however, because these are characteristics that the team members bring to the team, we label them exogenous.

[2]It is possible to include skills such as manufacturing and marketing in the portfolio of skills of a team. However, it is not clear whether it is appropriate to include these functional skills at the inception of the team or later, in case of a "technology push" type of new product. Clearly, the ability to be responsive to the demands of the marketplace is a necessary skill that should be available in the team.

viduals embody technology fusion. Some people actually learn more than one discipline (although more than two is unlikely) and so have two disciplinary 'legs' on which to stand." Persons with A-shaped skills have the unique ability to integrate in their heads two different disciplines, in each of which they can claim some depth of expertise. Although rare, such persons provide another mechanism for managing creative abrasion within teams. Because developing A-shaped skill sets is an expensive task for both the person and the organization, it might not be feasible to ensure that all knowledge team members have them. However, we speculate that team leaders with A-shaped skills will be more effective at knowledge development tasks than will leaders without them. The underlying logic is that A-shaped skill sets provide team leaders with the cognitive resources to combine insights synergistically from multiple knowledge sets. In the NPD context, team leaders play the especially important role of maintaining a disciplining vision that integrates multiple perspectives and manages conflicting technical trade-offs (Brown and Eisenhardt 1995). We might argue that the cognitive skills to handle such integration and trade-offs, gained through the process of integrating two disparate areas, will help the team leader craft a unifying vision that does justice to all the disciplines represented. Thus, we propose the following:

P_2: The presence of a team leader with A-shaped skills will be related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

Shared mental models. In the distributed cognition literature, there is support for the idea that an outcome of team interaction is the construction of a shared understanding of the situation in which the team members find themselves (Hutchins and Klausen 1996, p. 23). In an effective team, the team members enter with a considerable amount of shared prior knowledge of how things are supposed to be. During their interaction, this shared prior knowledge becomes "a resource to negotiate or construct a shared understanding of their particular situation" (Hutchins and Klausen 1996, p. 23). In the marketing and management literature, such shared prior knowledge often has been referred to as "mental models" (Day and Nedungadi 1994; Johnson-Laird 1983; Senge 1990). Klimoski and Mohammed (1994) propose the construct of team mental models as a form of socially shared cognition that represents a "broad mental configuration of a given phenomenon" (Bacharach 1989, p. 500). Building on Klimoski and Mohammed's (1994) conception, we use the term *shared mental models* to represent often unconscious assumptions about the way the world works (Senge 1990), along with a shared common language, with its own vocabulary of nuances and taken-for-granted understandings (Nonaka 1991), and a shared organizational memory (Walsh and Ungson 1991).

Hedlund and Nonaka (1993) argue that the articulation, internalization, and reflection of tacit knowledge are facilitated by the availability of a common language that is rich in symbolic imagery and metaphor. This assertion is undergirded by the premise that the organization is a network of intersubjectively shared meanings, sustained by a common language and interpretive schema (Burrell and Morgan 1979; Daft and Weick 1984; Walsh and Ungson 1991). Furthermore, shared mental models also involve the acquisition of a common memory base of organizational experiences (Walsh and Ungson 1991). According to Walsh and Ungson (1991), organizational memory is the stored information from an organization's history that can be brought to bear on present decisions and that affects outcomes. The importance of organizational memory and shared language and vocabulary highlights the significance of shared mental models as a requirement for converting embedded into embodied knowledge. Thus,

P_{3a}: The extent of the shared mental models will be related positively to the efficiency with which embedded knowledge is converted to embodied knowledge.

However, an excessive degree of shared mental models also might have a negative side. Research in psychology and related fields has shown consistently that similarity of experience beyond a limit begins to have deleterious effects on team effectiveness; that is, the value of familiarity is time dependent (Guzzo and Dickson 1996). Teams with a high degree of shared mental models may be susceptible to "groupthink" (Janis 1982) and a sharp reduction in cognitive "requisite variety." If shared experience implies that the team's behavioral repertoire is not being renewed, its ability to innovate will suffer (Gersick and Hackman 1990). Furthermore, the level of shared mental models should not militate against the dissent and creative abrasion (Leonard-Barton 1995) necessary for a productive outcome. Thus,

P_{3b}: Shared mental models will have a curvilinear (inverted-U) relationship with the effectiveness with which embedded knowledge is converted to embodied knowledge.

NPD routines. The previous discussion of shared mental models suggests the possibility of engaging the same group of professionals in more than one NPD venture so that organizations can minimize the cost of increasing shared mental models among many persons. There is evidence in another conceptualization of organizational knowledge that suggests the same. Organizational knowledge can be judged from a "routines" perspective (Cyert and March 1963; March and Simon 1958; Nelson and Winter 1982; Simon 1947; Stene 1940), within which the concept of *routine* refers to the set of regular and predictable patterns of organizational behavior (Nelson and Winter 1982). According to this perspective, firms are repositories of productive knowledge (Winter 1991) that reside in the routines that underlie the behavior of organizational participants working together. Nelson and Winter (1982) suggest that routines are the organizational counterpart of individual skills.

In the context of NPD teams, the knowledge (routine) of how to combine the individual stocks of tacit knowledge is largely tacit. Team members who have worked in NPD teams previously would have developed their own routines for the combination of individual stores of tacit knowledge and, hence, would be more effective NPD team members. In addition, if team members previously have worked with other current team members, the routines of how to combine individual stocks of tacit knowledge are more specific to the personalities of the team members. Such a combination of

team members would be more effective than a group that has not worked as a team before. It is also important for team members to have the right type of routines. For example, Eisenhardt and Tabrizi (1995) study two types of NPD strategies: experiential and compressed. We expect the team routines for experiential and compressed strategies to be different. Furthermore, the former strategy might be more useful in uncertain contexts, whereas the latter might be more appropriate in predictable contexts, which suggests the importance of invoking the right set of routines. Thus, we propose the following:

P_{4a}: The level of appropriate NPD routines will be related positively to the efficiency with which embedded knowledge is converted into embodied knowledge.

Paralleling the shared mental models arguments, NPD routines also have negative sides to them. Again, studies of team performance in psychology are instructive. Katz (1982), for example, observes that group longevity and familiarity among team members eventually become detrimental to performance. Similarly, Guzzo and Dickson (1996, p. 332) note that a lack of change in membership contributes to stultification and entropy in teams. The very routines that facilitate smooth team functioning can become dysfunctional by inviting the miscoding of familiar situations and reducing innovation (Gersick and Hackman 1990). Thus, we argue that past experience also will have a curvilinear (inverted-U) relationship with the team's performance outcome.

P_{4b}: New product development routines will have a curvilinear (inverted-U) relationship with the effectiveness with which embedded knowledge is converted into embodied knowledge.

The four factors discussed so far—T-shaped skills, A-shaped skills, shared mental models, and NPD routines—are design variables. All could be used in putting together a team, by selecting team members who demonstrate these factors in the required degree. However, not all four variables are equally important in all contexts. A key moderating variable in this context is the inherent innovativeness of the product being developed.

Moderating role of inherent product innovativeness. In the NPD context, a team might set out to develop a really new product or make marginal improvements. Heany (1983) proposes that new products can have varying degrees of innovativeness. The most innovative level is the one that competes across categories. At the least innovative level, the new product could have one or more new attributes, tangible or symbolic. *Inherent innovativeness* is defined as the degree of innovativeness of the product the team sets out to achieve. The qualities required in team members would depend on the inherent innovativeness of the new product being developed. Findings in the group intelligence literature suggest that groups perform better than individuals in tasks that require creativity (Williams and Sternberg 1988). By definition, the more innovative the product is, the more is the creativity that goes into its development. Also, the more innovative the product is, the greater the need for different kinds of expertise (Chi, Glazer, and Farr 1988) and, thus, the need for T- and A-shaped skills. This suggests that inherent innovativeness moderates the influence of T- and A-shaped skills in the hypothesized relationships (i.e., P_1 and P_2) (Griffin and Hauser 1996; Olson, Walker, and Ruekert 1995).

However, we argue that the impact of shared mental models and NPD routines on the efficiency and effectiveness of conversion of embedded to embodied knowledge will remain the same, regardless of whether the new product being developed is innovative or falls in the "continuous improvement" category. The benefits stemming from shared mental models and NPD routines work by facilitating the interaction of individual cognitions within the team; such interaction is necessary in all NPD teams, regardless of the level of innovation associated with it. Thus,

P_5: The impact of the T- and A-shaped skill variables on the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge will be moderated by the degree of inherent innovativeness of the product. The more innovative the product is, the greater the impact of T- and A-shaped skills.

As was mentioned previously, the dynamic interaction between members influences the cognitive performance of the group (Patel, Kaufman, and Madger 1996, p. 140). The variables that determine interaction in this context are trust, information redundancy, and rich personal interaction. Because their value depends on the processes of the team, these variables are termed *endogenous variables*. The remaining propositions have to do with the aspects of managing the team process.

Endogenous Variables

Trust. The extant literature on the social psychology of teams suggests that trust among team members has a significant influence on team performance (e.g., Zand 1972, 1981). *Trust*, defined as reciprocal faith in others' intentions and behavior (Kreitner and Kinicki 1992), has been identified as integral not only to the performance of small teams but also to many current organizational arrangements, such as strategic alliances and just-in-time delivery systems (e.g., *BusinessWeek* 1986). However, we suggest that the extant usage of "trust" as an interpersonal construct in the social sense is only one form of trust; we label this type of trust "trust in team orientation" here. Both distributed cognition literature and our interviews with managers suggest that there is another form of trust that is important in NPD teams; we label this "new" type of trust "trust in team members' technical competence." We discuss both types of trust in detail subsequently.

Trust in team orientation. Trust in team orientation, as we use it here, is defined as team members having reciprocal faith in others' intentions and behavior to work toward team goals rather than toward narrow, individual, or functional goals or agendas. An atmosphere lacking in such trust leads to the withholding of information and attempts to influence decision making toward narrow interests and divert resources away from team goals (Zand 1981). Trust is critical in a cross-functional and/or interorganizational team, be-

cause the withholding of information due to a lack of trust can be especially harmful to the processes of knowledge articulation, internalization, and reflection (Hedlund and Nonaka 1993). Thus,

P_{6a}: The aggregate level of trust in team orientation of team members will be related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

Trust in team members' technical competence. Quite apart from the traditional use of trust as an interpersonal construct in the social sense, the distributed cognition view of NPD teams establishes the need to consider a cognitive variant of trust. Consider the construct of technical competence, as it is identified in marketing literature (Moorman, Deshpandé, and Zaltman 1993; Sako 1992). According to Moorman, Deshpandé, and Zaltman (1993, p. 83), technical competence "can be observed and assessed much more readily," a conceptualization that emphasizes explicit rather than tacit knowledge. We argue that, though prior technical accomplishments may provide a proxy for technical competence, what is more crucial is the extent to which team members are trusted to be competent to handle the complex and as-yet-undetermined challenges that might appear. Furthermore, such competence may reside in the capacity to solve a problem on their own or get others to solve it for them (i.e., to syndicate a solution). Prior technical record can be assessed using "objective" measures, such as publications or track record with successful projects; trust requires a subjective projection of that perceived competence into an uncertain future. The construct of trust in team members' technical competence brings clarity to a context marked by inherent unreliability in the measurement of such a projection. Thus, *trust in team members' competence* is defined as the reciprocal faith team members have in one another to complete the tasks in their areas of expertise successfully, either by themselves or by involving other suitable persons. Thus, we posit that

P_{6b}: The aggregate level of trust in team members' technical competence will be related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

Although prior track record often is used as a proxy for competence in the early days of the team, it is reasonable to propose that a team member's ongoing contributions to team performance are crucial in maintaining, enhancing, or reducing others' trust in his or her competence. As far as trust in team orientation is concerned, we argue that it is enhanced, reduced, or kept level, depending on the team member's observable behavior and input; that is, the team is likely to use process indicators to assess trust in team orientation. For example, team members might deduce a person's commitment to team goals from his or her everyday behavior in within-team and team–outsider interactions. Given the tacit nature of technical competence, however, team members may be unable to use direct observation as an indicator of how much trust to continue to place in one another. As Thompson and Tuden (1959) point out, instrumental tests that focus on outcomes are used when knowledge about cause/effect relations is low. We propose, therefore, that the team's efficiency and effectiveness in converting embedded to embodied knowledge will have a feedback effect on trust in technical competence. Thus, our model includes a feedback loop from the dependent variable to trust in technical competence. We propose that

P_{6c}: There is positive feedback from the dependent variable to trust in team members' technical competence. As a team member contributes to the technical progress of the project, the trust in the member's competence increases. If a team member does not make adequate contributions to the project, the trust in his or her technical competence decreases.

Richness of personal interaction. Richness of personal interaction (RPI) consists of direct (i.e., face-to-face), frequent, and informal communication among team members. Such open and extensive communication among team members is a factor that also is emphasized by traditional treatments of teams (e.g., Bavelas and Barrett 1951). In the traditional literature, RPI would be viewed as influencing the outcomes by increasing the group cohesiveness, especially trust in the team orientation of other members. For example, Moorman, Deshpandé, and Zaltman (1993) find that trust is influenced by the interaction quality (called "nonresearch abilities" by them) between the provider and the recipient of information. As we show in Figure 1,

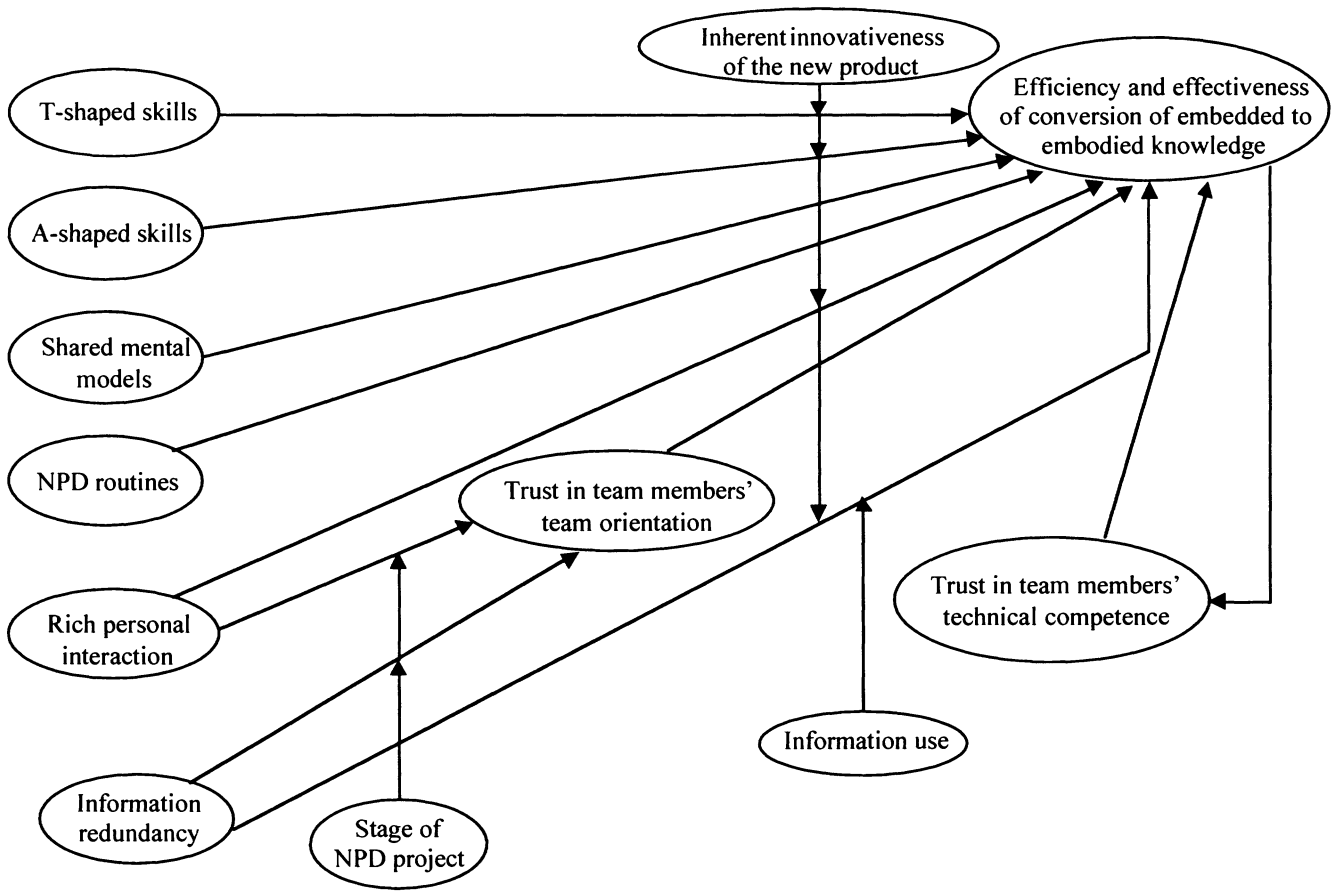
P_7: Rich personal interaction, consisting of direct, frequent, and informal interaction among team members, will influence the trust in the team orientation of other members positively, which, in turn, is related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

However, the distributed cognition perspective suggests that, quite apart from the trust-mediated effect, RPI directly affects the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge. This appears as the direct path from RPI to the dependent variable in Figure 1. Our reasoning is as follows:

The cognitive effect of RPI can be understood best in terms of what Clark and Marshall (1981) have referred to as "the linguistic copresence heuristic." During a conversation, anything said at time t is assumed to be known mutually at time t + 1. Therefore, what was individual knowledge prior to t becomes part of the shared knowledge base at t + 1. Although this progression is feasible with all types of interaction (e.g., by e-mail, in person), the first aspect of rich interaction, direct personal interaction, has a dynamism and flexibility that make it much more effective than less direct forms of communication. Interactive conversations enable participants to "formulate messages that are tightly linked to the immediate knowledge and perspectives of the individual participants, because it affords the participants moment-to-moment information on each other's understanding" (Krauss and Fussell 1991, p. 175). The primary benefit from direct interaction is what Yngve (1970) has called "messages transmitted in the back channel." As Krauss and Fussell (1991, p. 175) put it,

> The brief vocalizations, head nods and shakes, and facial expressions produced by the participant who at that

FIGURE 1
Determinants of the Efficiency and Effectiveness of Conversion of Embedded to Embodied Knowledge in NPD



moment is nominally in the role of listener are a rich source of information about the state of the common ground. Such information permits the formulation of messages that are extremely efficient because they are based on a reasonably precise assessment of the hearer's current knowledge and understanding.

This argument leads to the expectation that team members who are able to interact directly (i.e., face-to-face) will be more effective and efficient at creating new knowledge.

The second aspect of rich interaction is the frequency with which team members are able to interact. If interaction is direct but occasional, it is unlikely that team members will get sufficient opportunity for articulation and internalization and, therefore, for the conversion of embedded to embodied knowledge (Hedlund and Nonaka 1993). The finding that physical proximity alone may not be sufficient to ensure interaction underscores this point (Pinto, Pinto, and Prescott 1993). Given the nature of communication required for the combination of tacit knowledge stores, team members would need to interact on an almost continuous basis. In addition, frequent interaction among team members can contribute to the building of strong ties between them (Krackhardt 1992), which further facilitates the use and creation of knowledge within the team.

A third aspect of rich interaction is the informality of interaction within the cross-functional team. Warren Bennis has noted that "informality inevitably increases" in networks (*Fortune* 1994a). The need for direct observation and figurative communication (Nonaka 1991) implies that informal interactions are required in NPD teams. In contrast to traditional models of information processing in organizations, which imply that formal procedures and designated roles determine information flows, current research confirms the intuition that social ties among persons affect information flows. For example, Stevenson and Gilly (1991) find that managers often avoid dealing with formally designated problem solvers and use personal ties to pass on information. Because patterns of information flow can determine who gets what kind of information when, and because such information is the basis for managerial decisions, we can argue that the set of social arrangements has a major influence on the effectiveness of the organization. Meyers and Wilemon (1989) find that informal networks (informal discussions, knowledge transferred with team members to other projects, and friendship ties) were much more significant than formal channels in transferring learning. In addition, recent research indicates that formal, planned approaches may be less than optimal in inducing innovation (Mezias and Glynn 1993). The role of chance and serendipity in creative problem solving increasingly is being recognized. Some authors have described innovation as arising from the "interaction between necessity and chance, order and disorder, continuity and discontinuity" (Nonaka 1990, p. 27). Simulation studies demonstrate the need to introduce

variance into routine processes that are designed to generate innovation (Mezias and Glynn 1993). Informal interaction, which can take place in an unplanned, spontaneous manner, is necessary from this viewpoint. Building on these arguments, we propose that

P_8: The more the team members interact directly, frequently, and informally with one another, the greater the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

Information redundancy. Information redundancy (IR)—the sharing of information over and above the minimal amount required by each person to do the job—is another endogenous variable that is significant in influencing knowledge creation. Information redundancy both directly and indirectly (through trust in team orientation) influences the dependent variable (Figure 1). The argument for its indirect influence through trust in team orientation is not unlike that for RPI. As Zand (1981) points out, information sharing is associated closely with trust. Nonaka (1990) also argues that IR increases the possibility of trust among organization members.

P_9: Information redundancy will influence the trust in the team orientation of other members positively.

The direct path by which IR influences the dependent variable is justified by reference to the absorptive capacity notion of organizational knowledge. Cohen and Levinthal (1990) conceptualize *absorptive capacity* as the capability to recognize the value of new and external information, absorb it, and apply it productively. Analogously, Kogut and Zander (1992, p. 384) propose the notion of a *combinative capability*, which they define as the capability to "synthesize and apply current and acquired knowledge." Research in developmental psychology suggests that a person's ability to make sense of new information depends on the breadth of categories into which prior knowledge is organized, the differentiation of those categories, and the linkages across them (Bower and Hilgard 1981). Because the categorization of prior knowledge is highly specific to a person, this provides the rationale for why different NPD team members draw different meanings from an identical piece of information. A potentially important piece of information might go unnoticed if viewed with the wrong lens. A policy of actively promoting IR is a good way to encourage the serendipitous interaction of ideas and people that is often the source of innovation (Mezias and Glynn 1993; Nonaka 1990). If the design of the team incorporates traditional gatekeeper roles (Rogers and Rogers 1976), either in the interest of reducing information overload or out of political motives, there is a danger of losing these advantages. Thus, we argue that the relationship between the level of IR and the effectiveness of knowledge conversion is linear in the new NPD context. As such,

P_{10}: The extent of IR will be related positively to the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge.

Moderating Variables

Inherent innovativeness of the product. The concept of the inherent innovativeness of the product being developed was discussed previously. This variable also moderates the relationships between three of the endogenous variables and the efficiency and effectiveness of the conversion of embedded to embodied knowledge. The three endogenous variables are trust in technical competence of team members, RPI, and IR. The logic is straightforward. If the product being developed has a low level of innovativeness, a high degree of trust in the technical competence of other team members is not required. Similarly, RPI and IR do not need to be as high as in a situation in which an innovative product is being developed (Riggs et al. 1992). However, the influence of trust in team orientation will not be moderated by inherent innovativeness. The argument here is that trust in team orientation is primarily a social construct that is unaffected by the extent of cognitive complexity in the task. Rather, trust in team orientation provides the necessary social-psychological lubricant that makes it possible for all members to function together.

P_{11}: The direct impact of the RPI, IR, and trust in technical competence variables on the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge will be moderated by the degree of inherent innovativeness of the product. The more innovative the product, the greater the variables' positive impact will be.

Stage of NPD. Griffin and Hauser (1996) suggest that the phase of the project is one of the situational dimension variables that influence the degree of integration needed between R&D and marketing. We postulate that this variable is an important moderator of the relationship between RPI and trust in team orientation, as well as between IR and trust in team orientation. The argument is as follows: In the initial stages of the project, team members might not know one another well enough in the context of the task on hand. Therefore, RPI and IR are necessary to form trust in team orientation. A change in RPI and IR would have a greater impact on trust in team orientation in the earlier stages than would the same change in RPI and IR in the later stages, thus the moderating role of stage of NPD.

P_{12}: The impact of RPI and IR on trust in team orientation will be moderated by the stage of NPD. In the early stages of the project, RPI and IR will influence trust in team orientation more positively than in the later stages.

However, the stage variable will not moderate the other paths in Figure 1. In the relatively unstructured domain of knowledge creation, teams rarely progress in a monotonic fashion. Knowledge teams move through patterns of alternating "inertia" and "revolution;" long periods of equilibrium are punctuated by sudden breakthroughs and changes in direction (Gersick 1988). In addition, the cohesiveness of the groups might fluctuate widely over time. Therefore, the apparently random nature of knowledge-based innovation seems to suggest that RPI, IR, and trust (both types) can become important at any stage of the NPD process (Eisenhardt and Tabrizi 1995; Mezias and Glynn 1993).[3]

[3]Stage of NPD is not hypothesized to moderate the relationship of the exogenous and dependent variables. Because teams might progress in a punctuated equilibrium mode, the exogenous variables might become important at any stage.

Information use. The literature on information use suggests that availability of information does not guarantee its use (Deshpandé and Zaltman 1982, 1984, 1987; Menon and Varadarajan 1992). Thus, we propose a moderating role of use in the relationship between IR and knowledge creation. In our context, which is based on distributed cognition literature, two factors can significantly determine information use:[4]

1. Technological preparedness. The logic behind this variable is that the extent to which new information is used depends on how technologically prepared the potential user is. From a cognitive viewpoint, Bower and Hilgard (1981, p. 424) suggest that memory development is self-reinforcing; that is, a person will find it easier to assimilate new information if he or she already has a stock of objects, patterns, and concepts that are related directly to the new input. Similarly, Lindsay and Norman (1977) argue that preexisting mental structures play a crucial role in determining how easily new words are acquired by a learner. Thus, a team member's propensity to use any particular item of information that is available depends to a great extent on the technological schemas with which he or she already is equipped. This variable is similar to Menon and Varadarajan's (1992) prior disposition variable, but the disposition is constrained to technological preparedness.
2. Perceived relevance. There is continuing debate in the literature about whether managers' functional backgrounds lead to selective perception (Dearborn and Simon 1958; Waller, Huber, and Glick 1995). However, it generally is agreed that managerial perceptions affect their choices and actions (Thomas, Clark, and Gioia 1993). When new information is received, the receiver views it from a particular frame of reference, which relates to his or her existing cognitive structure and mental schemas. How relevant the new information is judged to be depends on the frame of reference used. This variable, therefore, implies that information will be used if it is perceived to be relevant for the task for which the member is responsible in the team. In the judgment of relevance, concepts such as whether the information confirms existing notions, political acceptability, and actionability (Deshpandé and Zaltman 1982) might be included.[5] The provider of the information can frame the information proactively to make it relevant. Therefore, the interaction (Deshpandé and Zaltman 1982) between the sender and receiver determines the actual framing of the information and its subsequent use.[6] Thus,

P_{13}: The impact of IR on the efficiency and effectiveness with which embedded knowledge is converted to embodied knowledge is moderated by the use of information. The greater the use of information, the more positive the influence of IR is on the dependent variable.

[4]In the NPD context, varied interpretation of the information might be the key indicator of information use. Learning occurs (i.e., information has been used) when the number of options increases (Huber 1991).

[5]The "relevance" notion, as it is used here, incorporates Deshpandé and Zaltman's (1982) surprise variable, as well as the confirmatory research variable.

[6]Another variable that potentially could influence use is task complexity (Menon and Varadarajan 1992). This concept is captured in our innovativeness variable, which directly moderates the said path.

Discussion and Conclusions

Our model has significant managerial and research implications. We discuss the managerial implications first in the form of seven specific prescriptions that flow from our model and then highlight a few directions for additional research.

Managerial Implications

Screen NPD team members for T-shaped skills. Some indications of a T-shaped skill set may be (1) a broad, rather than narrow, set of professional and personal interests; (2) a variety of professional and personal experiences; and (3) a richly diverse network of professional and personal contacts.

Screen NPD team managers for A-shaped skills. Persons with degrees in multiple fields or significant on-the-job experience in multiple fields may be especially valuable as NPD team managers, even if the expense of such skill sets precludes every team member possessing them. Variants of the idea should be considered as well. For example, it may be possible to develop A-shaped skill sets across subteams of two people. Perhaps a "two-in-a-box" style of leadership—as Intel is reported to practice, in which two people working closely together act as a "virtual" leader with A-shaped skills—could be implemented. Some reported stories of successful job-sharing at the top, such as Schacht and McGinn at Lucent Technologies (*The Wall Street Journal* 1996a), suggest that such innovative mechanisms are both feasible and gaining ground in practice.

Screen NPD team members for extent of shared mental models. In the traditional context of NPD, when the bulk of NPD was undertaken within the corporation, shared mental models in this sense largely could be taken for granted. In the NPD context characterized by the dispersion of knowledge across organizations (e.g., suppliers) as well as domains of knowledge, however, it might not be realistic to assume a common language and memory for all team members involved. Therefore, it is important to assess and increase the level of shared mental models among team members to ensure efficient development of new products. For example, we find some organizations now sending their developers to spend time in their customer or supplier organizations to learn about their practices and cultures. Another illustration is provided by the Japanese manufacturers of power generation and transmission equipment and their major customers, the electricity utilities, that hire their engineers from the same engineering schools. This practice makes it likely that senior engineers and managers working on strategically significant projects were classmates from engineering school, which greatly facilitates their interaction. Our model also suggests some of the dangers of excessively shared mental models and emphasizes the need to deliberately "seed" the team with different mental models.

Preserve NPD routines in the NPD teams. The importance of NPD routines suggests the need for managerial processes that preserve and make them available across projects, in spite of inevitable team turnover. Although many leading firms attempt to document and transfer effective processes in the form of "best practices," NPD routines have a large tacit component that is tied inherently to individual

cognition. Some mechanisms that might be helpful in making such routines available across projects are (1) to ensure that new project teams are seeded with members from successful past teams, (2) to include "supernumerary" team members whose primary task is to learn from effective teams rather than contribute directly to the current task and who then become primary members of subsequent teams, (3) to appoint members of past successful teams as mentors to new team members, and (4) to ensure that the entire membership of the team does not change simultaneously (e.g., institute a system whereby, at most, half the team turns over between projects).

Design intermediate team goals with the purpose of building trust in technical competence. Our model also suggests the importance of performance feedback in building team members' trust in one anothers' competence. A direct managerial implication is that intermediate team goals should be formulated with this in mind. For example, some early successes by which members can demonstrate their technical competence can be invaluable in cementing this element of trust, as well as in setting expectations.

Evaluate the impact of currently popular "virtual office" practices on the efficiency and effectiveness of knowledge creation. The knowledge-management perspective of NPD also raises some significant issues about the optimal way of organizing the NPD effort, especially in a global context. During the past few years, there has been a trend toward creating virtual NPD teams that are distributed across several cities, or even continents. Driving this trend have been strategic factors, such as the creation of competency centers (which might need to work together on specific projects), as well as more tactical goals, such as taking advantage of time differences in team members' locations. Our model suggests that such virtual teams may not be the best vehicles for NPD, because cognition is shaped by the technological and other artifacts that are embedded in the physical setting. A team's efficacy in knowledge creation is influenced by the artifacts and other physical resources in the team's surroundings. Our model suggests that, through the duration of the project, being in the same, information-rich location (e.g., work center) enhances RPI and, thereby, knowledge creation. Similarly, the currently popular practice of "hoteling" (*Fortune* 1994b; *The Wall Street Journal* 1996b), in which employees do not have fixed work spaces but are assigned temporary work areas for the hours they are in the office, does not take into account some of the insights of our model on knowledge creation.

Train NPD team members on knowledge management and distributed cognition ideas. The final managerial implication we point out is that training NPD managers and team members on the set of ideas presented here would be helpful. When sensitized to the potential import and value of the knowledge-management perspective of NPD, managers will find ways to apply it fruitfully while contributing to the refinement and elaboration of the model.

Research Implications

Besides the obvious need to validate our model empirically, some other areas for further research are important. One such area is to study how firms can encourage the development of T- and A-shaped skills. In addition, researchers might explore the costs and trade-offs associated with enhancing such skills. While focusing on several team variables that influence knowledge creation, our model has held constant all organizational-level variables, such as administrative systems and policies (e.g., reward systems), organizational culture, top management support, strategic vision, and other NPD variables (e.g., Yap and Souder 1994). However, these variables are important, and specifying their influence represents a key part of the research agenda. Finally, many finer, testable hypotheses can emerge from our propositions. For example, we propose that NPD routines influence team outcome. Investigating the impact of different types of routines (e.g., for compressed or experiential strategies) (Eisenhardt and Tabrizi 1995) is one way that additional research can add value. The appropriate choice of dependent variable is another issue on which to reflect. Sometimes commercial success may be an appropriate dependent variable (when the marketing plan also is developed by the NPD team); at other times, the amount of knowledge created or the effort the team has put in may be the best indicator. Careful work also needs to be performed on the measurement of knowledge creation itself. Psychology literature provides scales for the measurement of tacit knowledge at the individual level (e.g., Wagner 1985; Westcott 1961), which can guide the development of scales for measuring knowledge creation.

Conclusion

In this article, our main argument has been that NPD management, viewed as a knowledge-creation activity, should emphasize cognitive team processes rather than purely social processes. Using the notions of tacit knowledge and distributed cognition as a basis, we have proposed a model that links team members' and leaders' cognitive attributes and the team's process attributes to the efficiency and effectiveness with which the potential knowledge, resident in the team, is realized as a new product. We believe that the approach outlined here potentially enhances our understanding of NPD as knowledge management.

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