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Knowledge Meshing through Interdisciplinary R&D: The case of the U.S. NIH Nanomedicine Development Centers

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Abstract

As the technological underpinnings of many industries??ranging from life sciences to electronics??have matured, innovation has demanded the collaboration of scientists and engineers across multiple disciplines. This research introduces the notion of a ?knowledge meshing? capability exhibited by interdisciplinary research and development (R&D) teams when they interlace knowledge from multiple disciplines. By comparing the publication and patenting records of researchers from the eight Nanomedicine Development Centers funded by the U.S. National Institutes of Health, we find evidence that the direction and impact of scientific discovery is related to the similarity of the knowledge bases of the researchers involved in the projects. A companion research project pursues a multilevel

analysis to determine the antecedents required to develop an effective team?level knowledge meshing capability.
Lessons from this research will contribute to the effective formation and management of interdisciplinary R&D teams.

**Knowledge Meshing through Interdisciplinary R&D:
The case of the U.S. NIH Nanomedicine Development Centers**

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Abstract

As the technological underpinnings of many industries--ranging from life sciences to electronics--have matured, innovation has demanded the collaboration of scientists and engineers across multiple disciplines. This research introduces the notion of a "knowledge meshing" capability exhibited by interdisciplinary research and development (R&D) teams when they interlace knowledge from multiple disciplines. By comparing the publication and patenting records of researchers from the eight Nanomedicine Development Centers funded by the U.S. National Institutes of Health, we find evidence that the direction and impact of scientific discovery is related to the similarity of the knowledge bases of the researchers involved in the projects. A companion research project pursues a multilevel analysis to determine the antecedents required to develop an effective team-level knowledge meshing capability. Lessons from this research will contribute to the effective formation and management of interdisciplinary R&D teams.

Keywords:

Knowledge meshing capability, Interdisciplinary R&D, Resource-based view, R&D project team

This research program is broken into two parts: the first empirically analyzes the implications of having scientists from multiple disciplines “mesh” their knowledge in terms of the quantity, novelty, and quality of the resultant publications and patents (where publications greatly outnumber patents in this sample). The second part proposes a multilevel analysis to determine the processes by which interdisciplinary R&D teams can create an effective knowledge meshing capability.

Part I
Knowledge Meshing through Interdisciplinary R&D:
The Scientific Output of the U.S. NIH Nanomedicine Development Centers

Although existing literature has addressed approaches for organizing and managing research and development (R&D) (Katz, 1982; Katz & Tushman, 1979; Langfred, 2007; Van der Vegt & Bunderson, 2005) and the business and technology strategy literatures have considered the role of capabilities in organization-level performance (Barney, 1991, 2001; Smith, Collins, & Clark, 2005; Teece, 2007; Teece, Pisano, & Shuen, 1997; Tyler, 2001), limited attention has been paid to the development of capabilities to increase the usefulness of output from revolutionary interdisciplinary R&D (notable exceptions: Birnbaum, 1981; Cummings & Kiesler, 2005 and 2008). At the heart of interdisciplinary R&D success is the collaborators’ ability to “mesh” their knowledge bases, where knowledge meshing can combine existing knowledge into new patterns or where there is co-discovery of entirely new phenomena. Numerous industrial sectors are facing technological advancements leading to interdisciplinary scientific exploration such as the emerging field of nanomedicine in the life sciences sector (Sharp, et al., 2011).

These sorts of revolutionary R&D projects involve the collaboration of researchers from a variety of disciplines, often from many types of organizations (Gelijns & Rosenberg, 1995). For example, in the case of nanomedicine, it is common to have project team members from biology, chemistry, engineering, mathematics, and physics. Deriving successful innovations from such teams requires capabilities in interdisciplinary integration that go beyond more generalized team management capabilities. The focus of this research is to explore the antecedents to successful knowledge meshing capabilities during revolutionary interdisciplinary R&D projects with the goal of extending technology strategy research and informing management practice.

Unlike previous research which has considered *ad hoc* knowledge diversity in project teams (Ancona & Caldwell, 1992b; Jehn, Northcraft, & Neale, 1999; Kearney, Gebert, & Voelpel, 2009; Lovelace, Shapiro, & Weingart, 2001), we suggest that the complexities of nanomedicine and other

advanced interdisciplinary R&D projects *require* that project teams have representation from multiple disciplines—similar to the settings of Birnbaum (1977), Cummings and Kiesler (2005), Edmondson (2003), and Gelijns and Rosenberg (1995). We also recognize that while these teams may be within a single organization they may require participation from across an array of organizations.

To understand knowledge meshing in revolutionary interdisciplinary R&D settings, we chose to examine the eight Nanomedicine Development Centers (NDCs) funded by the U.S. National Institutes of Health (NIH) starting in 2005 and 2006 (Table 1). The NDC project teams are composed of researchers from universities, public research institutes, and medical centers. These projects are more technologically revolutionary than many of the private sector projects analyzed in the existing management literature focused on R&D teams (Chen, Chang, & Hung, 2008; Hirst, Knippenberg, & Zhou, 2009; Katz, 1982). While cooperation across organizational boundaries in the private sector has faced competitive tensions that can give rise to learning races or other opportunistic behavior (Deeds & Hill, 1998; Hamel, 1991; Walter, Lechner, & Kellermanns, 2008), these complex public sector projects typically do not face these sorts of competitive tensions.

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Insert Table 1 about here
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The conceptual framework guiding this research complements existing literature that emphasizes invention as recombination of (known) components common, for example, in engineering settings (Fleming and Sorenson, 2001). Rather than measuring interdependencies as suggested by biological adaptive processes (Fleming and Sorenson, 2001), we focus on the influence of knowledge similarity on the inventive outcome, where knowledge similarity is established by publishing behavior. To measure knowledge similarity, we considered established measures that examine technological relatedness across partners conducting R&D. Prior research has explored whether partners diverge or converge in their capabilities following cooperation, through, for example, strategic alliances or joint ventures (Mowery, Oxley, and Silverman, 1996; Nakamura, Shaver, and Yeung, 1996; Rosenkopf and Almeida, 2003). One approach to assessing overlap in technological capabilities, in particular, is to measure the degree to which one partner's patents cite those of the other before and after the cooperative relationship (Mowery, Oxley, and Silverman, 1996). Another approach to measuring technological similarity compares patent classes found in each firms' patents (Rosenkopf and Almeida, 2003).¹

¹ This use of patent codes to establishing similarity also has been used to compare parent firms' knowledge and that of the start-ups that they have spawned (Boeker, et al., 2011).

As shown in Table 1, the principle investigators (PIs) involved in the focal cooperative R&D projects have not patented extensively (two of the eight PIs leading the Centers have not filed patents according to the records available through 2010), and so we must rely on information from their academic publications to determine whether their pre-cooperative knowledge stocks are similar or dissimilar to those of their team members. By analyzing publishing behavior prior to the formation of their NDC, we are able to characterize knowledge stock similarity of the team members by the primary journals in which they publish. We assume that scientists who publish in the same journals have similar knowledge bases.

Much of the knowledge used in the scientific discovery process is complex and deeply embedded in joint experience and problem-solving by scientists from diverse fields and the associated methodologies involved (McFadyen & Cannella, 2004; Nonaka, 1994; Nonaka & Takeuchi, 1995). Each science and technology discipline has an established language, experience base, norms, obligations and expectations (Nahapiet & Ghoshal, 1998), which can create misunderstandings and conflict (Pelled, Eisenhardt, & Xin, 1999). Therefore, the tacit nature of much of the information needed to mesh disparate disciplines typically can only be combined and exchanged with others who have some level of shared knowledge and experience (Grant, 1996; Polanyi, 1966). This is because the ability to absorb knowledge depends on some common ground (Cohen & Levinthal, 1989; Sampson, 2004). We therefore assume that similarity in knowledge bases allows for ease of cooperation, because of common approaches to conducting science in terms of theorizing and empirical testing while employing a common vocabulary. This leads to our first hypothesis.

Hypothesis 1. Researchers on interdisciplinary R&D teams with greater knowledge similarity will be more likely to coauthor and co-patent as a consequence of collaboration.

While we expect that knowledge similarity will heighten the likelihood of inventive output, we conjecture that knowledge *dissimilarity* will lead to greater *novelty*. We hypothesize that novel, or more radical, science will come about by drawing on disparate knowledge bases, because interdisciplinary interactions add variance into the inventive process. In the mergers and acquisitions literature, dissimilarity characterized as complementary knowledge bases has been found to correspond to novelty (Makri, Hitt, & Lane, 2010: p.618). Previous studies that examine patenting behavior rely on the number of patent classes to quantify novelty (Makri, Hitt, & Lane, 2010), and we will follow this approach when assessing the patents by the NDC collaborators. For their coauthored journal articles, which greatly outnumber their patents, we measure novelty by the number of journals outside of the disciplines of the NDC coauthors to cite their coauthored

articles. We anticipate that the groundbreaking nature of the NDC research will attract a broad base of citations as captured in our second hypothesis.

Hypothesis 2. The greater the knowledge dissimilarity among the coauthors from the interdisciplinary research team, the higher the novelty of their coauthored journal articles and patents following collaboration.

In addition to the quantity and novelty measures of the science resulting from the NDCs, we expect that the quality will be exceptional. To be awarded an NDC grant, the teams went through a rigorous selection process conducted by the NIH. As reflected in our third hypothesis, we expect that journal articles and patents that are coauthored by NDC team members would be of higher quality than their other articles and patents. Following prior literature (Makri, Hitt, & Lane, 2010), we will use the number of citations to measure quality after excluding self-citations.

Hypothesis 3. Controlling for the sources of their sponsored research, the coauthored journal articles and patents resulting from NDC collaboration will be of higher quality than the other articles and patents of the NDC researchers.

The next steps in this research are as follows. First we will finalize the collection of publication data for all of the NDC team members for five years prior to the start of their NDC. Our initial examination of the PIs' publications in the five years prior to the start of their Centers reveals that, on average, the PIs published 43 journal articles in 27 unique journals (Table 2). The journals in which the other team members published will be compared with those of the PIs to calculate the degree of similarity of knowledge bases, *e.g.*, the sum of overlapping journal titles weighted by the number of publications in each as a share of the total journals. The similarity measure will allow us to understand a fundamental antecedent to interdisciplinary collaboration. For the patents in the sample, we will analyze the patent classes. To assess novelty, we will examine the range of journals that cite the coauthored publications, and patent classes in which the NDC-generated patents have been classified. Then the quality of the output from the Center's research will be calculated by analyzing the forward citation rates to the publications and patents that have been coauthored by members of each Center. A further measure of quality will be an examination of the impact factor of the journals in which the NDC team members coauthor. We also intend to analyze the general publishing behavior of the PIs beyond the papers coauthored with Center members following the start date of the NDC to determine whether their publication patterns change. This will require the identification of a control sample of scientists in the same fields as the PIs but who have not participated in interdisciplinary research projects.

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Part II

Managing Revolutionary Interdisciplinary R&D Project Teams: Developing Team Knowledge Meshing Capabilities

The long-term goal of this research is to gain access to the NDC teams to study *why* there is variation in the quantity, novelty and quality of Center output once we control for the similarity across the researchers' knowledge bases. We believe that future breakthrough technologies in a number of fields will require adept knowledge meshing during interdisciplinary R&D, and this research offers an initial step towards capability development.

While the existing literature on teams has addressed approaches for organizing and managing research and development (R&D) teams in general (Katz, 1982; Katz & Tushman, 1979; Langfred, 2007; Van der Vegt & Bunderson, 2005) and the business and technology strategy literatures have considered the role of capabilities in organization-level performance (Barney, 1991, 2001; Smith, Collins, & Clark, 2005; Teece, 2007; Teece, Pisano, & Shuen, 1997; Tyler, 2001), limited attention has been paid to the development of capabilities specifically addressing the management of revolutionary interdisciplinary R&D (notable exceptions: Cummings & Kiesler, 2005 and 2008). Numerous industrial sectors are facing technological advancements leading to interdisciplinary scientific exploration such as the emerging field of nanomedicine in the life sciences sector. These sorts of revolutionary R&D projects involve the collaboration of researchers from a variety of disciplines, often from many types of organizations (Gelijns & Rosenberg, 1995). For example, in the case of nanomedicine, it is common to have project team members from biology, chemistry, engineering, mathematics, and physics. Coordinating such teams requires management skills in interdisciplinary integration that go beyond more generalized team management capabilities. The focus of this research is to develop a conceptual model which links the processes central to successful revolutionary interdisciplinary R&D projects with the goal of extending technology management research and informing management practice.

In order to advance research involving revolutionary interdisciplinary R&D research, we incorporate organization-level, project-level and team-level research to identify the most important antecedents for the creation of an interdisciplinary integration capability, termed the ***team knowledge meshing capability***, by interdisciplinary R&D project teams. Drawing on the strategic capabilities, technology management, and teams literatures, we develop a conceptual model based on the resource-based view of the firm that addresses how superstructure, project-level and team-level commitments to interdisciplinary integration, team knowledge meshing processes, and team cultural orientation lead to a team knowledge meshing capability which enhances performance

outcomes. The model seeks to explicitly capture three primary elements of the resource-based view in the context of interdisciplinary R&D: path dependence, which is operationalized through initial commitment; social complexity, which is reflected in the team-level processes that are created to fuse the interdisciplinary knowledge; and causal ambiguity, which is somewhat attenuated by emergent team culture once R&D is underway (Barney, 1991, 2001). The interactions of these elements result in the development of a knowledge meshing capability at the team level. We derive hypotheses about these components of the conceptual model to inform future empirical analyses as to the critical success factors for managing revolutionary interdisciplinary R&D project teams.

We seek to address three gaps in the literature. First, we extend capabilities research by defining and developing a very specific type of capability associated with R&D team interdisciplinary integration, i.e., a team knowledge meshing capability. Dynamic capabilities researchers have encouraged the examination of the multilevel effects associated with mechanisms organizations use to innovate and how dynamic capabilities are developed from intellectual human capital and lower-level process capabilities (Grant, 1996; Gupta, Tesluk, & Taylor, 2007; Rothaermel & Hess, 2007). We incorporate superstructure, project-level, and team-level contributions to the development of the team knowledge meshing capability, which we posit lead to improved innovative team performance. Second, we contribute to the technology management literature by incorporating many of the factors that prior technology studies have suggested influence technical success and propose that a new construct, team knowledge meshing capability, mediates their impact on performance (Cohen & Bailey, 1997; He, Butler & King, 2007; Hinds & Bailey, 2003; Van der Vegt & Bunderson, 2005). We suggest that the effects on the meshing capability of the research program's superstructure and the initial commitment made by the project team to interdisciplinary integration effect are moderated by team knowledge meshing processes and cultural orientations. Thus, we argue that knowledge meshing processes and cultural orientations do not directly affect team performance but instead play a moderating role. While knowledge meshing processes are necessary conditions for establishing a team knowledge meshing capability, they are not sufficient. Finally, we add to the teams literature by contending that successful revolutionary interdisciplinary R&D projects require the development of a very specific team knowledge meshing capability that goes beyond more generally understood best practices in the teams literature. These revolutionary interdisciplinary projects are distinctive in their need to incorporate the knowledge of scientific experts with very different vocabularies, values, and norms, and require more than the establishment of known team processes and routines.

In the next section, we review the capabilities literature and extend it to include a new construct—the team knowledge meshing capability. We then develop a conceptual model based on the strategic capabilities, technology management, and teams literatures to explain how superstructure and project commitment, team knowledge meshing processes and team cultural orientations—the antecedents—affect the team knowledge meshing capability. We develop hypotheses linking the elements of the model to team performance as reflected in individual and collective knowledge improvement, project goal fulfillment, efficiency, productivity, quality, and overall achievement. We conclude with a discussion of our contributions to the literature, the implications of our model for theory and practice, and future research directions.

TEAM KNOWLEDGE MESHING CAPABILITY

In the capabilities literature, organizations are a collection of valuable resources that give rise to capabilities. An organization's "resources" can be classified into three general categories: physical capital, human capital, and organizational capital (Barney, 1991). Our study focuses on how interdisciplinary R&D project teams, which utilize fundamental physical, human, and organizational resources, are influenced by initial conditions and their knowledge meshing processes and emergent culture during capability development. **Organizational capabilities**, as we define them, are an organization's ability to repeatedly integrate specialist knowledge to perform a discrete productive task (Grant, 1996). Thus, the term organizational capability involves the ability to manage human capital resources through routines, processes and procedures such that specialist knowledge is applied to a specific task. Building on this prior research, we define the **knowledge meshing capability**, the focus of our study, as the ability of R&D project teams to integrate knowledge from multiple disciplines, thus creating interdisciplinary knowledge through co-invention or by incorporating the technical knowledge from one discipline into that of another.

Our conceptualization of knowledge meshing extends the work of Kodama (1991, 1992) and Adner and Levinthal (2000). Kodama's construct "technology fusion" characterizes innovations that result from the combination of existing technical components from multiple industries—for example, optoelectronics (Kodama, 1991: 3). However, interdisciplinary R&D requires that teams of researchers from different backgrounds not only integrate their existing technical components but fuse their knowledge in a way that creates new interdisciplinary knowledge which advances science (Kodama, 1991, 1992; Nonaka, 1994; Nonaka & Takeuchi, 1995). Adner and Levinthal (2000) suggest that two technologies undergo fusion when the resulting technology is applied to a new application domain. In contrast, the analysis in this research focuses on a more basic level of the innovation process—where fundamental technology

principles from multiple scientific and/or engineering disciplines are integrated and built upon to give rise to the components themselves. We argue that the knowledge meshing process entails the interlacing of fundamental technology principles, frames of reference, approaches to hypothesis development and experimentation (Caudill & Roberts, 1951). Thus, an underlying assumption of our conceptual model is that in order to have an economic impact, R&D projects involving interdisciplinary integration require the development of a knowledge meshing capability to make progress in the research program and ultimately bridge the “research bench” with the marketplace.

Much of the knowledge used in the scientific discovery process is complex and deeply embedded in joint experience and problem-solving by scientists from diverse fields and the associated methodologies involved (McFadyen & Cannella, 2004; Nonaka, 1994; Nonaka & Takeuchi, 1995). Each science and technology discipline has an established language, experience base, norms, obligations and expectations (Nahapiet & Ghoshal, 1998), which can create misunderstandings and conflict (Pelled, Eisenhardt, & Xin, 1999). Therefore, the tacit nature of much of the information needed to fuse disparate disciplines typically can only be combined and exchanged with others who have some level of shared knowledge and experience (Grant, 1996; Polanyi, 1966). This is because the ability to absorb knowledge depends on some common ground (Cohen & Levinthal, 1989; Sampson, 2004). These observations suggest that knowledge meshing projects require participants to jointly experience problem-solving processes and spend time together discussing, reflecting, observing, and interacting (Nonaka & Takeuchi, 1995; Seufert, von Krogh, & Bach, 1999).

To make progress in their research programs, project teams in multidisciplinary fields like nanomedicine need to address “meshing tension” when combining differing methods of conducting R&D practiced by the scientists or engineers involved in the initiatives (Cummings & Kiesler, 2008; Goerzen & Beamish, 2005; Nahapiet & Ghoshal, 1998). On one hand, the researchers involved may enjoy intellectual renewal because of the learning curve required to interact with their colleagues from different disciplines. On the other hand, differences in such areas as theory development, problem identification, the design of experiments, and milestone definition, might create tension when trying to move the project forward. It might simply be easier—not to mention rewarded more explicitly—to spend time on discipline-specific research issues rather than spending time figuring out how to co-invent. Furthermore, the “fanfare” surrounding the announcement of a sizable interdisciplinary project may unduly pressure the researchers to rapidly produce outcomes (Caudill & Roberts, 1951).

In previous studies, knowledge heterogeneity has been found to influence performance and innovativeness (Rodan & Galunic, 2004). For example, in the context of alliances, knowledge

diversity can enhance the breadth, cognitive resources, and problem-solving capacity of alliance partners, but it also can create cognitive gulfs or schisms that make exchange of information difficult and engender outright distrust and acrimony as dissimilar group members may have different vocabularies, paradigms, and objectives (Goerzen & Beamish, 2005).

We argue that a knowledge meshing capability can overcome the inherent tensions in conducting interdisciplinary R&D to realize its revolutionary potential. Unlike previous research which has considered *ad hoc* knowledge diversity in project teams (Ancona & Caldwell, 1992b; Jehn, Northcraft, & Neale, 1999; Kearney, Gebert, & Voelpel, 2009; Lovelace, Shapiro, & Weingart, 2001), we suggest that the complexities of nanomedicine and other advanced interdisciplinary R&D projects *require* that project teams have representation from multiple disciplines—similar to the settings of Cummings and Kiesler (2005), Edmondson (2003), and Gelijns and Rosenberg (1995). We also recognize that while these teams may be within a single organization they are more likely to require experts from across an array of organizations. For example, the U.S. National Institutes of Health (NIH) has funded eight Nanomedicine Development Center project teams composed of researchers from universities, public research institutes, and medical centers. These projects are more complex than many of the private sector projects reported in the existing management literature focused on R&D teams (Chen, Chang, & Hung, 2008; Hirst, Knippenberg, & Zhou, 2009; Katz, 1982). While cooperation across organizational boundaries in the private sector have faced competitive tensions that can give rise to learning races or other opportunistic behavior (Deeds & Hill, 1998; Hamel, 1991; Walter, Lechner, & Kellermanns, 2008), these complex public sector projects may face alternative tensions based on rivalries across individual scientists, disciplines, or research institutions.

Therefore, to better understand how a team knowledge meshing capability is established we integrate theoretical arguments based on the strategic capabilities, technology management, and teams literatures. We develop a conceptual framework to demonstrate how the initial commitments to interdisciplinary research, the interdisciplinary integration processes established by the team, and the research team's culture, are the antecedents to the team's knowledge meshing capability and ultimately influence the team's performance outcomes.

MODEL DEVELOPMENT

The conceptual model guiding this research captures the evolution of interdisciplinary R&D project teams from inception through research execution to results (**Figure 1**). The model includes three antecedents to the knowledge meshing capability: (1) the initial commitments to interdisciplinary research when the project is established, (2) the project team's knowledge meshing processes that evolve, and (3) the project team's culture that emerges during the formative stage. These components are assumed to be the primary contributors to the knowledge meshing capability, which in turn is assumed to be central in driving team performance in the context of interdisciplinary R&D. As discussed below, the elements of the conceptual model are derived from three of the theoretical underpinnings of difficult-to-imitate, valuable resources put forth in the resource-based view of the firm (Barney, 1991, 1986; Dierickx & Cool, 1989; Lippman & Rumelt, 1982): path dependency, social complexity, and causal ambiguity.

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Insert Figure 1 about here

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The elements of the conceptual model are consistent with similar models from the literature on teams such as the "Heuristic Model of Group Effectiveness" of Cohen and Bailey (1997). The initial commitments in our conceptual model incorporate "group composition," "task design," and "organizational context" from Cohen and Bailey (1991); the project team's knowledge meshing processes reflect "internal processes" as well as "external communication"; the project team's culture includes "group psychosocial traits"; and the performance outcomes constitute "effectiveness" (Cohen & Bailey, 1997: 244). The inclusion of the knowledge meshing capability extends the Cohen and Bailey (1997) model, and its inclusion reflects the assumption that the development of this capability to manage team and individual knowledge integration will play a distinguishing role in project performance across organizations. While past research has examined knowledge integration (Grant, 1996), combinative capabilities (Kogut & Zander, 1992; Van den Bosch, Volberda, & de Boer, 1999) and cooperative capabilities (Carmeli & Azeroual, 2009; Cummings & Kiesler, 2005; Smith et al., 2005; Tyler, 2001), knowledge meshing capabilities have not been addressed thoroughly.

Path Dependency: Initial Commitments

The first component of the model builds on the strategic capabilities literature that argues that resource accumulation and capability development is path dependent (Barney, 2001; Teece, et al., 1997). Sydow, Schreyogg, and Koch (2009) extend this stream of research by proposing a

framework explaining how organizations become path dependent using a three phase model. In the first phase, the Preformation Phase, the institutional heritage provides some constraints but a triggering event initiates the path-dependency process. While the triggering event may be small, these authors argue that in organizations path dependence can be triggered by bigger events or even strategies. During the initial phase of team formation in our model (Time 1 in **Figure 1**), the research path is laid out through the initial conceptualization of the research project, including the degree of commitment to the execution of interdisciplinary R&D. The influence of three levels of analysis is considered in this phase: the Project Level—parameters set by those with the authority to initiate the project; the Team Level—the plan of work created by the team members (i.e., how to proceed beyond what was in the formal documentation); and the Superstructure Level—conditions set by the contextual superstructure. Our assumption is that these three levels are the most influential in the organization of the project teams and the specification (at least initially) of the teams' goals and, therefore, interdisciplinary requirements. This assumption is consistent with the notion of combining the “bottom-up” and “top-down” influences on innovation (Gupta et al., 2007), and the argument that at the fuzzy front end of new product development, information flow moves from the organization to the project level across the project interface (Reid & de Brentani, 2004: 181). This migration is stimulated by information integration across the levels linked to the stated strategic context (Reid & de Brentani, 2004: 181).

We propose that the commitment to interdisciplinary integration is the result of the following three conditions: (1) the extent to which project parameters that specify interdisciplinary interactions include the team's scope of work, the personnel assignments to the team, and the milestones and deliverables set when the project is formed; (2) the extent to which a project team's work plan includes whether the percentage of work time committed by each team member is consistent with the need for his/her disciplinary knowledge, as well as the team's commitment to interdependent R&D work processes (Van de Ven, Delbecq, & Koenig, 1976); and (3) the extent to which team members believe the superstructure promotes interdisciplinary interaction through funding, guidance, and expectations set by the governing entity.

We suggest that the commitment to interdisciplinary integration reflected at these three levels at the beginning of the project set the historical starting point for capability development, because they affect the ability and willingness of participating scientists to make the project-specific investments required to reach the espoused project goals (Wang & Barney, 2006). These codified specifications of direction, policies, instructions, and procedures also represent systems capabilities which describe the degree to which behaviors are programmed in advance of execution (Van den Bosch et al., 1999).

We propose that due to path dependence the more committed all of the three levels—project, team, and superstructure—are to interdisciplinary integration at the outset of the project and the better documented these expectations, the more successful the team will be in establishing a knowledge meshing capability.

Proposition 1: The stronger the project team’s formal commitment to interdisciplinary R&D, the more the plan of work incorporates communication and interaction between team members, and the stronger the team’s perceptions of the commitment to interdisciplinary R&D by the governing superstructure, the more likely the team will be to establish a knowledge meshing capability.

In phase two of the path dependency model proposed by Sydow et al. (2009), the Formation Phase, the scope of action is assumed to narrow increasingly because of the “pull” of the evolutionary path created by self-reinforcing processes (Sydow et al., 2009: 693). These processes are associated with the broader organizational context and include the practices and culture that evolve to inform decision makers and provide the self reinforcing loops to form path dependency. Phase three, the Lock-in Phase, is characterized by further restriction of the scope of acceptable options. Because organizational settings are social in character and processes are more complex and ambiguous in nature, organizational paths are not likely to become fully deterministic. Thus, reinforcing dynamics are expected to bring about a preferred action pattern which becomes embedded in social interactions. While complexity and ambiguity represent contextual conditions that encourage reinforcing effects and subsequent path dependency, they neither directly lead to nor represent a necessary condition for path dependence (Arthur, 1989; Pierson, 2000). The path dependent nature of research organizations, even of single laboratories, and of the institutional fields in which they are embedded, has been found to shape major scientific discoveries (Hollingsworth, 2006), and we argue that these same effects will influence revolutionary interdisciplinary R&D project teams.

Social Complexity: Team Knowledge Meshing Processes

As the project team begins its work (Time 2 in **Figure 1**), the processes it uses to fuse knowledge, as well as create its culture, emerge. The development of both knowledge meshing processes and culture requires socially complex interactions, but for the purposes of this research, we wish to focus on the knowledge meshing processes as repeated, socially complex interactions. While culture arises from socially complex interactions, once established, culture assists in addressing causal ambiguity associated with interdisciplinary R&D projects, and hence, as

described below, we concentrate on the relationship between culture and causal ambiguity. The knowledge meshing processes and culture are, respectively, consistent with coordination and socialization capabilities, types of combinative capabilities (Van den Bosch et al., 1999).

Because interdisciplinary R&D is dependent upon knowledge meshing, this dependency leads us to decompose knowledge meshing into specific activities to understand the team-level interactions and coordinating mechanisms that give rise to meshing. Knowledge meshing processes reflect the integration activities of the project team and include processes associated with interdisciplinary research, communication, elaboration of task relevant information, and team learning. Interdisciplinary research processes can include ways of conducting interdisciplinary research, e.g., through goal consensus, methods consensus (e.g., how hypotheses should be developed and experiments designed), interpretation of results, adjustment of the research plan, and the incorporation of external knowledge. Research by Ancona and Caldwell (1992a) offer a starting point for existing constructs to capture these activities. We argue that considerations of the level of common knowledge, frequency and variability of communication, the media used within the team (He, Butler, & King, 2007), and the structure or processes teams use to achieve a shared understanding are especially important (Grant, 1996). We also propose that the processes used to elaborate task-relevant information (Kearney, Gebert, & Voelpel, 2009), team learning processes (Van der Vegt & Bunderson, 2005) and the processes used for local and distal learning (Wong, 2004) can all be expected moderate the relationship between the initial commitment to interdisciplinary integration and the development of a team knowledge meshing capability.

While the knowledge creation processes within the team are expected to be socially complex, if they are constructed to heighten the likelihood of knowledge meshing, we expect the greater the chance that a knowledge meshing capability will arise.

Proposition 2: The more focused the interdisciplinary R&D project team's processes are on knowledge meshing, as reflected in how the team conducts interdisciplinary research, their effectiveness of communication, their elaboration of task-relevant information, and their team leaning processes, the more the processes can be expected to positively moderate the relationship between initial commitment to interdisciplinary integration and knowledge meshing capability.

Causal Ambiguity: Team Culture

The strategy literature has argued that organizational culture can serve as a source of sustained competitive advantage (Barney, 1986) and that cultural orientations often differ across levels and functions within a single organization (Tyler & Gnyawali, 2009). Not only is the creation

of a team's culture socially complex, but we argue that cultural orientations developed through social interaction help the team address potentially causally ambiguous situations associated with interdisciplinary R&D projects. While the two other primary elements of the conceptual model—initial commitments and knowledge meshing processes—can be codified to some degree (and may be required to be codified by an external funding source like a government agency), cultural orientations are more tacit in nature and remain largely in the minds of team members.

The teams literature has shown that a team's cultural attributes can affect team task interdependence and performance (Langfred, 2007; Van der Vegt & Bunderson, 2005), and therefore, we anticipate that cultural attributes that evolve during the early phases of an interdisciplinary team project involving scientists that are affiliated with different institutions can moderate initial commitment to knowledge meshing by either encouraging or discouraging the development of knowledge meshing capabilities.

We posit that three contributing elements to the development of a team's cultural orientation are particularly salient in the context of interdisciplinary R&D: (1) collective team identity (Kearney, Gebert, & Voelpel, 2009; Van der Vegt & Bunderson, 2005); (2) shared context (Hinds & Mortensen, 2005); and (3) the level of task and interpersonal conflict (Hinds & Bailey, 2003; Hinds & Mortensen, 2005; Langfred, 2007). We propose that collective team identity (Kearney, Gebert, & Voelpel, 2009; Van der Vegt & Bunderson, 2005) and perceptions of shared context (Hinds & Mortensen, 2005) will positively moderate the path dependent relationship between initial commitment to interdisciplinary integration and the knowledge meshing capability up to a point but at extremely high levels will have a negative moderating effect. Over time as members of the team become socialized, we argue they develop a shared ideology that provides them with an attractive identity as well as collective interpretations of reality that makes knowledge sharing more efficient (Van den Bosch et al., 1999). However, a very strong team identity can restrict the scope of members' search for outside sources of knowledge in ways that contradict shared beliefs limiting their absorptive capacity. We argue that the level of task and interpersonal conflict is expected to have a negative moderating effect on this relationship (Hinds & Bailey, 2003; Hinds & Mortensen, 2005; Langfred, 2007).

Proposition 3a: The interdisciplinary R&D project team's collective team identity and perceptions of shared context will positively moderate the relationship between initial commitment to interdisciplinary integration and the knowledge meshing capability.

Proposition 3b: The interdisciplinary R&D project team's level of task and interpersonal conflict will negatively moderate the relationship between initial commitment to interdisciplinary integration and the knowledge meshing capability.

Knowledge Meshing Effects on Performance

Rare, valuable, and difficult to imitate capabilities give rise to superior performance (Barney, 1991). Research has shown that managerial capability, knowledge creation capability, and knowledge combination capability enhance the performance of work in companies and work units in high technology industries (Carmeli & Azeroual, 2009; Holcomb, Holmes, & Connelly, 2009; Smith et al., 2005). This leads us to posit that multidisciplinary teams that have developed above average knowledge meshing capabilities should perform better than teams that have average or below average knowledge meshing capabilities (Barney & Tyler, 1992). Thus, we propose a direct positive relationship between a team's knowledge meshing capability and their performance. We argue that a team's knowledge meshing capability affects team performance as reflected in collective and individual knowledge improvement (Zhao & Anand, 2009), project goal fulfillment, efficiency, quality, productivity, and overall performance.

Proposition 4: The greater the interdisciplinary R&D project team's knowledge meshing capability the higher project team performance.

DISCUSSION AND CONCLUSION

While the inner-workings of R&D project teams have been examined in the past, a new breed of team—the interdisciplinary team—merits closer examination. The maturation of industries that have helped fuel economic growth in the last half century, such as pharmaceuticals and semiconductors, necessitates ever more sophisticated areas of exploration. We have observed that in emerging fields like nanomedicine with increased technological sophistication has come the requirement of interdisciplinary R&D. While past research has examined how teams function when their membership is cross-functional, very little is known about optimal processes for managing *interdisciplinary* R&D teams.

We develop a conceptual framework informed by the fundamental building blocks of the resource-based view of the firm—namely path dependency, social complexity, and causal ambiguity—that suggests how project-level, team-level, and superstructure-level conditions can influence capability development in the context of interdisciplinary R&D. While the initial commitment to an interdisciplinary research plan sets the team off on a path of R&D, social complexity is encountered when the team develops the processes required to fuse their knowledge,

and the culture the team fosters can mitigate causal ambiguity. Our conceptual model suggests that it is out of these team-level interactions that a knowledge meshing capability arises. The knowledge meshing capability then becomes the determinant of team performance in the interdisciplinary R&D setting.

We believe that future breakthrough technologies in a number of fields will require skill in managing interdisciplinary R&D teams. The conceptual model developed here recognizes the complexity that we encountered in our initial observations of these types of teams and conversations with project leaders. While initial commitments to interdisciplinary integration often need to be explicit, once the team work starts unfolding, the emergent culture and processes by which the team members actually fuse their knowledge sets can reinforce the commitment, deepen it, or even thwart it. By researching multiple interdisciplinary R&D projects in a particular industrial sector, lessons can be formulated for key managerial considerations when forming and overseeing such teams.

OPPORTUNITIES FOR FUTURE RESEARCH

To assist managers, whether in the public or private sectors, with approaches to managing the meshing of knowledge across disciplines, the next step is to test the proposed conceptual model. In the future, we plan to empirically examine the relative importance of initial commitment, team knowledge meshing processes, and team cultural orientation in the creation of a team knowledge meshing capability that leads to superior team performance. We are very interested in determining whether multiple approaches to managing the interdisciplinary R&D process co-exist or whether there are systematic team-level routines and managerial actions that lead to superior results.

We are in the process of requesting access to advanced interdisciplinary R&D teams in the life sciences to test the model. While there is heterogeneity in the projects that we are investigating in terms of their research areas and goals, all of their research goals require interdisciplinary interaction and many of their performance outcomes are similar and are measured primarily at the team level.

Two additional areas merit further attention. First, the controls for the empirical testing of the model need careful construction. The inherent difficulty in each R&D project requires assessment, because even the strongest commitment to interdisciplinary integration, the successful development of meshing processes, and a strong team culture oriented towards integration, may not be able to overcome insoluble technical problems. Also, the nature of the R&D project needs classification. In some cases the team members will be expected to co-invent, where they jointly pursue a segment of the research program. In other cases, participation will be more sequential in

nature, and the hand-off between disciplines will be paramount. These types of cases will conceivably require heterogeneous meshing processes so any cross-sectional comparisons will need to control for difference in project structure. Finally, if the potential performance outcomes are weighted differently across project teams, e.g., some teams emphasize high quality publications where others emphasize commercial products, again, cross-sectional comparisons will need to take such differences into account if optimal processes and cultures vary when goals vary.

Second, while the conceptual model presented in this paper incorporates three levels of analysis—superstructure, project-level, and team-level—whether to emphasize the individual team members’ knowledge stocks and prior experience with interdisciplinary R&D merits further consideration. While we believe that team-level interactions are crucial in the development of knowledge meshing capabilities, it is conceivable that individual-level knowledge endowments could trump even the most successful collaborations. This is to say that having a “star” scientist on the R&D team, who is a thought-leader in a particular discipline, might outperform even the most “functional” team, because the person might have a greater innate ability to conceive of technological breakthroughs or the person’s knowledge depth might allow for more adept anticipation of interdisciplinary integration pitfalls. Alternatively, “stardom” might breed jealousy within the project team and detract from cooperation.

We believe that studying the phenomenon of knowledge meshing in a variety of fields like nanomedicine and nanoelectronics will ultimately contribute to our understanding of the processes that produce novel technological solutions (Hargadon & Fanelli, 2002). This understanding will help managers cultivate the capabilities required for successful revolutionary interdisciplinary R&D.

Table 1. Overview of NDC PIs' Publication and Patenting Behavior

Nanomedicine Development Center Principle Investigator (PI)	# Team Members (excluding PIs)	# Journal* Articles (2001-2010)	# Journal* Articles w/Center Team Members (2001-2010)	# Patents** (2001-2010)	# Patents** w/Center Team Members (2001-2010)
1) Nanomedicine Center for Mechanobiology Directing the Immune Response					
Inst: NYU School of Medicine, 2005					
PI: Dustin, Michael	13	142	5	2	1
2) Cellular Control: Synthetic Signaling and Motility Systems					
Inst: U.C.S.F, 2005					
PI: Lim, Wendell A.	3	81	1	2	0
3) National Center for Design of Biomimetic Nanoconductors					
Inst: Univ of IL Urbana-Champaign, 2005					
PI: Jakobsson, Eric G.	15	48	18	0	NA
4) Center for Protein Folding Machinery					
Inst: Baylor College of Medicine, 2005					
PI: Chiu, Wah	15	128	52	0	NA
5) NDC for the Optical Control of Biological Function					
Inst: U.C./LBNL, 2006					
PI: Isacoff, Ehud	17	80	15	6	3
6) Center for Cell Control					
Inst: U.C.L.A., 2006					
PI: Ho, Chih-Ming	9	84	5	5	1
7) Phi29 DNA-Packaging Motor for Nanomedicine					
Inst: Univ of Cincinnati, 2006					
PI: Guo, Peixuan	25	111	15	5	0
8) Nanomedicine Center for Nucleoprotein Machines					
Inst: GA Tech Research Corp., 2006					
PI: Bao, Gang***	7	127	2	7	1

NA=Not Applicable

*Source: SciFinder.

**Source: SciFinder and U.S. Patent & Trademark Office (<http://www.uspto.gov/>)

***This center has two additional PIs who are not yet included in these counts.

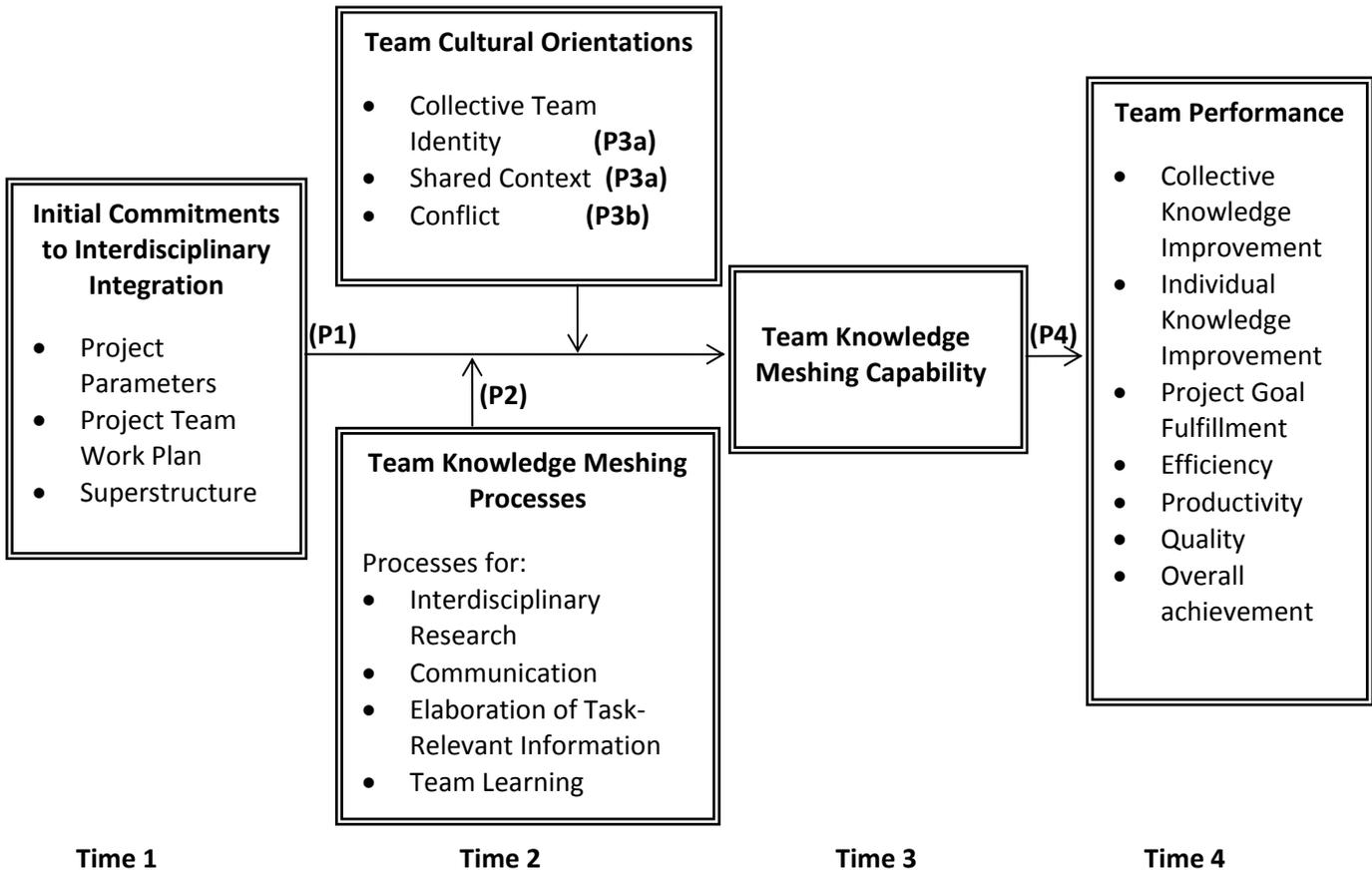
Table 2. NDC PIs' Publication and Journal Count in Five Years Prior to Center Formation

Nanomedicine Development Center Principle Investigator (PI)	# Journal Articles*	#Unique Journal Titles*
1) Mechanobiology Directing the Immune Response		
PI: Dustin, Michael	56	30
2) Synthetic Signaling and Motility Systems		
PI: Lim, Wendell A.	47	34
3) Biomimetic Nanoconductors		
PI: Jakobsson, Eric G.	23	14
4) Protein Folding Machinery		
PI: Chiu, Wah	60	28
5) Optical Control of Biological Function		
PI: Isacoff, Ehud	26	14
6) Cell Control		
PI: Ho, Chih-Ming	40	29
7) Phi29 DNA-Packaging Motor		
PI: Guo, Peixuan	40	26
8) Nucleoprotein Machines		
PI: Bao, Gang***	51	39
<i>Average</i>	43	27

*Source: SciFinder.

FIGURE 1.

Interdisciplinary Integration Capability Development and Outcomes



REFERENCES

- Adner, R., & Levinthal, D. 2000. Technology speciation and the path of emerging technologies. In Day, G. S., Schoemaker, P. J. H. and Gunther, R.E. (Eds.), *Wharton on managing emerging technologies*: 57-74. New York: John Wiley & Sons, Inc.
- Ancona, D. G., & Caldwell, D. F. 1992a. Bridging the boundary: external activity and performance in organizational teams. *Administrative Science Quarterly*, 37: 634-665.
- Ancona, D. G., & Caldwell, D. F. 1992b. Demography and design: predictors of new product team performance. *Organization Science*, 3(3): 321-341.
- Arthur, W. B. 1989. Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal*, 99: 116-131.
- Barney, J. 1986. Organizational culture: can it be a source of sustained competitive advantage? *Academy of Management Review*, 11(3): 656-665.
- Barney, J. 1991. Firm resources and sustained competitive advantage. *Journal of Management*, 17(1): 99-120.
- Barney, J. 2001. Resource-based theories of competitive advantage: a ten-year retrospective on the resource-based view. *Journal of Management*, 27: 643-650.
- Barney, J., & Tyler, B. B. 1992. The attributes of top management teams and sustained competitive advantage. In L. R. Gomez-Mejia & M. W. Lawless (Eds.), *Advances in global high-technology management*: 33-47. New York: JAI Press Inc.
- Birnbaum, Philip H. 1977. Assessment of Alternative Management Forms in Academic Interdisciplinary Research Projects. *Management Science*, Vol. 24, No. 3: 272-284.
- Birnbaum, Philip H. 1981. Contingencies for Interdisciplinary Research: Matching Research Questions with Research Organizations. *Management Science*, Vol. 27, No. 11: 1279-1293.
- Boeker, Warren, Sandip Basu, Arvin Sahaym, and Michael Howard. 2011. Knowledge Inheritance and the Quality of Knowledge of New Ventures. Working paper, University of Washington.
- Carmeli, A., & Azeroual, B. 2009. How relational capital and knowledge combination capability enhance the performance of work units in a high technology environment. *Strategic Entrepreneurship Journal*, 3: 85-103.
- Caudill, W., & Roberts, B. H. 1951. Pitfalls in the organization of interdisciplinary research. *Human Organization*, 10(4): 12-15.
- Chen, M., Chang, Y., & Hung, S. 2008. Social capital and creativity in R&D project teams. *R&D Management*, 38(1): 21-34.
- Cohen, S. G., & Bailey, D. E. 1997. What makes teams work: group effectiveness research from the shop floor to the executive suite. *Journal of Management*, 23(3): 239-290.
- Cohen, W. M., & Levinthal, D. A. 1989. Innovation and learning: the two faces of R&D. *Economic Journal*, 99: 569-596.
- Cummings, J. N., & Kiesler, S. 2005. Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science*, 35(5): 703-722.
- Cummings, J. N., & Kiesler, S. 2007. Coordination costs and project outcomes in multi-university collaborations. *Research Policy*, 36: 1620-1634.
- Cummings, J. N., & Kiesler, S. 2008. Who collaborates successfully? Prior experience reduces collaboration barriers in distributed interdisciplinary research. *Proceedings of the ACM 2008 conference on Computer supported cooperative work*: 437-446.
- Deeds, D. L., & Hill, C. W. L. 1998. An examination of opportunistic action within research alliances: evidence from the biotechnology industry. *Journal of Business Venturing*, 14(2): 141-163.
- Dierickx, I., & Cool, K. 1989. Asset stock accumulation and sustainability of competitive advantage. *Management Science*, 35(12): 1504-1511.

- Edmondson, A. C. 2003. Speaking up in the operating room: how team leaders promote learning in interdisciplinary action teams. *Journal of Management Studies*, 40(6): 1419-1452.
- Fleming, Lee and Olav Sorenson. 2001. Technology as a complex adaptive system: evidence from patent data. *Research Policy*, 30: 1019-1039.
- Gelijns, A., & Rosenberg, N. 1995. The changing nature of medical technology development. In Rosenberg, N., Gelijns, A. C., and Dawkins, H. (Eds.), *Sources of medical technology: Universities and industry*: 3-14. Washington D.C.: National Academy Press.
- Goerzen, A., & Beamish, P. W. 2005. The effect of alliance network diversity on multinational enterprise performance. *Strategic Management Journal*, 26: 333-354.
- Grant, R. M. 1996. Prospering in dynamically-competitive environments: organizational capability as knowledge integration. *Organization Science*, 7(4): 375-387.
- Gupta, A.K., Tesluk, P.E., & Taylor, M.S. 2007. Innovation at and across multiple levels of analysis. *Organization Science*, 18(6), November–December: 885–897.
- Hamel, G. 1991. Competition for competence and inter-partner learning within international strategic alliances. *Strategic Management Journal*, 12(Summer): 83-103.
- Hargadon, A., & Fanelli, A. 2002. Action and possibility: reconciling dual perspectives of knowledge in organizations. *Organization Science*, 13: 290-302.
- He, J., Butler, B. S., & King, W. R. 2007. Team cognition: development and evolution in software project teams. *Journal of Management Information Systems*, 24(2): 261-292.
- Hinds, P. J., & Bailey, D. E. 2003. Out of sight, out of sync: understanding conflict in distributed teams. *Organization Science*, 14(6): 615-632.
- Hinds, P. J., & Mortensen, M. 2005. Understanding conflict in geographically distributed teams: the moderating effects of shared identity, shared context, and spontaneous communication. *Organization Science*, 16(3): 290-307.
- Hirst, G., Knippenberg, D., & Zhou, J. 2009. A cross-level perspective on employee creativity: goal orientation, team learning behavior, and individual creativity. *Academy of Management Journal*, 52(2): 280–293.
- Holcomb, T. R., Holmes Jr., R. M., & Connelly, B. L. 2009. Making the most of what you have: managerial ability as a source of resource value creation. *Strategic Management Journal*, 30: 457-485.
- Hollingsworth, J. R. 2006. A path-dependent perspective on institutional and organizational factors shaping major scientific discoveries. In J. Hage & M. Meeus (Eds.) *Innovation, science, and institutional change*: 432-442. New York: Oxford University Press.
- Jehn, K. A., Northcraft, G. B., & Neale, M. A. 1999. Why differences make a difference: a field study of diversity, conflict, and performance in work groups. *Administrative Science Quarterly*, 44(December): 741-763
- Katz, R. 1982. The effects of group longevity on project communication and performance. *Administrative Science Quarterly*, 27: 81-104.
- Katz, R., & Tushman, M. 1979. Communication patterns, project performance, and task characteristics: an empirical evaluation and integration in an R&D setting. *Organizational Behavior and Human Performance*, 23: 139-162.
- Kearney, E., Gebert, D., & Voelpel, S. C. 2009. When and how diversity benefits teams: the importance of team members' need for cognition. *Academy of Management Journal*, 52(3): 581-598.
- Kodama, F. 1991. *Analyzing Japanese high technologies: The techno-paradigm shift*. London: Pinter Publishers.
- Kodama, F. 1992. Technology fusion and the new R&D. *Harvard Business Review*, 70(4): 70-77.
- Kogut, B., & Zander, U. 1992. Knowledge of the firm, integration capabilities, and the replication of technology. *Organization Science*, 3: 383-397.

- Langfred, C. W. 2007. The downside of self-management: a longitudinal study of the effects of conflict on trust, autonomy, and task interdependence in self-managing teams. *Academy of Management Journal*, 50(4): 885-900.
- Lippman, S. A., & Rumelt, R. P. 1982. Uncertain Imitability: An Analysis of Interfirm Differences in Efficiency under Competition. *The Bell Journal of Economics*, 13(2), Autumn: 418-438
- Lovelace, K., Shapiro, D. L., & Weingart, L. R. 2001. Maximizing cross-functional new product teams' innovativeness and constraint adherence: a conflict communications perspective. *Academy of Management Journal*, 44(4): 779-793.
- Makri, Marianna, Michael A. Hitt, Peter J. Lane. 2010. Complementary Technologies, Knowledge Relatedness, and Invention Outcomes in High Technology Mergers and Acquisitions. *Strategic Management Journal*, 31: 602-628.
- McFadyen, M. A., & Cannella Jr., A. A. 2004. Social capital and knowledge creation: diminishing returns of the number and strength of exchange relationships. *Academy of Management Journal*, 47: 735-746.
- Mowery, David C., Joanne E. Oxley, and Brian S. Silverman. 1996. Strategic Alliances and Interfirm Knowledge Transfer. *Strategic Management Journal*, Vol. 17, Winter Special Issue: 77-91.
- Nahapiet, J., & Ghoshal, S. 1998. Social capital, intellectual capital, and the organizational advantage. *Academy of Management Review*, 23(2): 242-266.
- Nakamura, Masao, J. Myles Shaver, and Bernard Yeung. 1996. An empirical investigation of joint venture dynamics: Evidence from U.S.-Japan joint ventures. *International Journal of Industrial Organization*, Vol. 14, Issue 4, June: 521-541.
- Nonaka, I. 1994. A dynamic theory of organizational knowledge creation. *Organization Science*, 5: 14-37.
- Nonaka, I., & Takeuchi, H. 1995. *The knowledge-creating company*. New York: Oxford University Press.
- Pierson, P. 2000. Increasing returns, path dependence, and the study of politics. *American Political Science Review*, 94: 251-267.
- Pelled, L., Eisenhardt, K., & Xin, K. 1999. Exploring the black box: an analysis of work group diversity, conflict, and performance. *Administrative Science Quarterly*, 44: 1-28.
- Polanyi, M. 1966. *The tacit dimension*. Garden City, NY: Doubleday.
- Reid, S. E., & de Brentani, U. 2004. The fuzzy front end of new product development for discontinuous innovations: a theoretical model. *Journal of Product Innovation Management*, 21: 170-184.
- Rodan, S., & Galunic, C. 2004. More than network structure: how knowledge heterogeneity influences managerial performance and innovativeness. *Strategic Management Journal*, 25: 541-562.
- Rosenkopf, Lori and Paul Almeida. 2001. Overcoming Local Search Through Alliances and Mobility. *Management Science*, Vol. 49, No. 6, June: 751-766.
- Rothaermel, F. T., & Hess, A. M. 2007. Building dynamic capabilities: innovation driven by individual-, firm-, and network-level effects. *Organization Science*, 18(6): 898-921.
- Sampson, R. C. 2004. Organizational choice in R&D alliances: knowledge-based and transaction cost perspectives. *Managerial and Decision Economics*, 25(6-7): 421-436.
- Seufert, A., von Krogh, G., & Bach, A. 1999. Towards knowledge networking. *Journal of Knowledge Management*, 3: 180-190.
- Sharp, Phillip A., Charles L. Cooney, Marc A. Kastner, Jacqueline Lees, Ram Sasisekharan, Michael B. Yaffe, Sangeeta N. Bhatia, Tyler E. Jacks, Douglas A. Lauffenburger, Robert Langer, Paula T. Hammond, Mriganka Sur. 2011. The Third Revolution: The Convergence of the Life Sciences, Physical Sciences, and Engineering. White paper, MIT.

- Smith, K. G., Collins, C. J., & Clark, K. D. 2005. Existing knowledge, knowledge creation capability, and the rate of new product introduction in high-technology firms. *Academy of Management Journal*, 48(2): 346-357.
- Sydow, J., Schreyogg, G., & Koch, J. 2009. Organizational path dependence: opening the black box. *Academy of Management Review*, 34(4): 689-709.
- Teece, D. J. 2007. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. *Strategic Management Journal*, 28: 1319-1350.
- Teece, D. J., Pisano, G., & Shuen, A. 1997. Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7): 509-533.
- Tyler, B. B. 2001. The complementarity of cooperative and technological competencies: a resource-based perspective. *Journal of Engineering and Technology Management*, 18: 1-27.
- Tyler, B. B., & Gnyawali, D. R. 2009. Managerial collective cognitions: an examination of similarities and differences of cultural orientations. *Journal of Management Studies*, 46(1): 93-126.
- Van de Ven, A. H., Delbecq, A. L., & Koenig Jr., R. 1976. Determinants of coordination modes within organizations. *American Sociological Review*, 41: 322-338.
- Van den Bosch, F. A. J., Volberda, H. W., & de Boer, M. 1999. Coevolution of firm absorptive capacity and knowledge environment: organizational forms and combinative capabilities. *Organization Science*, 10(5): 551-568.
- Van der Vegt, G. S., & Bunderson, J. S. 2005. Learning and performance in multidisciplinary teams: the importance of collective team identification. *Academy of Management Journal*, 48(3): 532-547.
- Walter, J., Lechner, C., & Kellermanns, F. W. 2008. Disentangling alliance management processes: decision making, politicality, and alliance performance. *Journal of Management Studies*, 45(3): 530-560.
- Wang, H. C., & Barney, J. 2006. Employee incentives to make firm-specific investments: implications for resource-based theories of corporate diversification. *Academy of Management Review*, 31(2): 466-476.
- Wong, S. 2004. Distal and local group learning: performance trade-offs and tensions. *Organization Science*, 15(6): 645-656.
- Zhao, Z. J., & Anand, J. 2009. A multilevel perspective on knowledge transfer: evidence from the Chinese automotive industry. *Strategic Management Journal*, 30: 959-983.