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Realizing the Need for Rework: From Task Interdependence to Social Networks

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Design rework is a core phenomenon in new product development (NPD). Yet carrying out design rework presupposes recognizing the need for it. I characterize the types of interpersonal knowledge transfer that help developers realize the need for design rework in NPD. As predicted by the NPD literature, I find that individuals who interact frequently with colleagues to address their task interdependences are more likely to realize the need for rework. I also learn that interacting with colleagues who have different expertise in process-related knowledge (as opposed to product-related knowledge) facilitates realizing the need for rework. However, to develop a deeper understanding of how individuals recognize the need for rework when interacting with others, we must expand our views beyond task interdependence and expertise-related factors. In particular, organizational variables—both formal and informal—play a significant role. With respect to formal hierarchical structures, actors of superior rank are less likely to realize the need for rework regardless of whether or not their interacting partner is of superior rank; however, actors of superior rank are more likely to *trigger* realizing the need for rework when interacting with partners of subordinate rank. By examining an organization's informal structure, I discover that the social "embeddedness" of developers (i.e., the energy and attention invested in a dyadic relationship) significantly influences their propensity to realize the need for rework. Several hypotheses are tested in a sociometric study conducted within the development department of a software company, and I discuss the implications for behavioral operations in NPD.

Key words: new product development; rework; social networks; hierarchies; expertise
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1. Introduction

Understanding the drivers of design rework is vital to improving new product development (NPD) performance. In NPD efforts, the notion of design rework is associated with the full or partial repetition of design tasks in response to newly available information (e.g., Krishnan et al. 1997, Smith and Eppinger 1997, Terwiesch et al. 2002). I define rework broadly to be the reconsideration of a task as part of either a corrective action (to fix issues associated with the task itself) or a completion action (to carry out subtasks that were not previously completed). This paper studies one specific aspect of the rework phenomenon: the individual's *realization* (based on her interactions with others) of the need to carry out design rework. Although design rework is a reality in most serious NPD settings, it does not arise unless the stakeholders responsible for executing NPD activities realize the need for it. This paper shows that such realization depends not only on technical but also on people-related factors.

Instances of realizing the need for design rework are common in complex NPD efforts. For example, while developing the BMW seven series (launched in the mid-1980s), managers discovered that they needed to widen the entire vehicle by 40 millimeters. This resulted in redesigning nearly a third of the car's components—and all a mere 2 months before freezing the vehicle's final concept. Managers involved in the redesign effort conceded that the rework "was costly. But without this change, almost everyone agrees the car would have been totally wrong. It would have been too cramped and would have never succeeded in the market like it has" (Pisano 1996, p. 6). More recently, realizing the need for rework as a result of interactions between NPD actors was evident during the development of many systems at Apple (Isaacson 2011). As the first iPhone was being developed, for example, Steve Jobs paid a visit to Jonathan Ive (Apple's chief designer) to discuss how the phone's form failed to match Apple's intentions (Isaacson 2011, p. 373): "Ive, to his dismay, instantly realized that Jobs was right. 'I remember feeling absolutely embarrassed that he had to make the observation'. The problem was that the iPhone should have been all about the display, but in their current design the case competed with the display instead of getting out of the way." The design team did not balk at having to rework the iPhone design, even though it meant starting over in many respects. These examples illustrate two important elements in recognizing the need for design rework. First, new information leads to the realization that corrective and/or completion actions need to be taken. As a result, realizing the need for rework is primarily a social process that requires interactions between development stakeholders. Second, actions associated with design rework—despite being perceived (at first) as negative owing to their undesirable impact on development time and cost—actually have the positive (and perhaps necessary) effect of converging to a higher-quality outcome (Sitkin 1992). In general, failing to recognize the need for design rework can have significant negative implications for product performance. It is therefore important to understand how interacting with other colleagues in the organization helps (or hinders) recognizing the need to carry out design rework.

How does interacting with others help one realize the need for rework? According to the NPD literature, the answer to this question is grounded in the notion of *task interdependence*. Individuals in new product development communicate to coordinate their efforts while resolving their tasks' interdependences (Allen 1977, Dougherty 1992, Gokpinar et al. 2010, Iansiti 1995, Sosa et al. 2004). Hence, development actors involved in highly interdependent tasks are more likely to exchange technical information more often; this makes it possible to understand more deeply the tasks of others, which can facilitate discovering aspects of previously executed tasks that need either correction or further completion (Clark and Fujimoto 1991, Iansiti 1995, Krishnan et al. 1997, Loch and Terwiesch 1998, Terwiesch et al. 2002).[1]

The literature on knowledge sharing can also provide answers to my research question (Argote et al. 2003). This stream of literature has shown that knowledge-related factors, such as knowledge diversity, are likely to influence not only the search and transfer of knowledge between development actors (Reagans and McEvily 2003, Reagans and Zuckerman 2001) but also the outcomes of such knowledge exchanges, such as the generation of creative ideas (Sosa 2011). Knowledge diversity, however, is a complex construct that can be defined at different units of analysis (ties, individuals, dyads, teams, and organizations). In this paper I consider various aspects of knowledge diversity and focus on how the *difference in areas of expertise* of interacting actors affects the likelihood of realizing the need for rework. I find that interacting with colleagues who have different expertise in process-related knowledge (as opposed to product-related knowledge) is the main driver—from the knowledge diversity perspective—of realizing the need for rework.

Despite the relevance of both task interdependence and expertise-related factors, they provide an incomplete view of the individual's realization of the need for rework. People-related factors also matter significantly (Bendoly et al. 2006, Gino and Pisano 2008, Loch and Wu 2005). Indeed, previous work on individual learning in organizations has suggested that social conditions such as group cohesion, mutual trust, and status differences strongly influence interpersonal learning processes (e.g., Edmonson 1999, Lee 2002, Wong 2004). Hence it is crucial to examine the role of these organizational factors.

The literature on organizations has addressed the role of social networks in knowledge sharing (e.g., Argote et al. 2003), but we know little about how an individual's social networks within the NPD organization relate to the rework phenomenon. An important contribution of this paper is uncovering how the social aspects of dyadic relationships influence an individual's realization of the need for rework; in particular, I show that both formal and informal dyadic organizational factors matter significantly (Gulati and Sytch 2007). On the formal side, *organizational hierarchy* puts individuals into superior or subordinate positions, rankings that play a crucial role in determining how workplace social interactions affect an individual's realization of the need for rework. On the informal side, the mutual *social embeddedness* of development actors (Granovetter 1992)—in other words, the energy and attention that each invests in a dyadic relationship—affects (in a nonlinear way) the propensity to realize the need for rework.

Toward the end of examining empirically how interactions among NPD actors facilitate (or hinder) realizing the need for rework, I conducted a sociometric study in the development department of a software development firm. I examined more than 600 dyadic relationships, which constituted their informal organizational structure, in order to study how task interdependence, expertise differential, and the formal and informal social network properties of those dyadic relationships affect recognition of the need for rework.

This paper makes several contributions. It is the first to study an important antecedent of the rework phenomenon: how the individual's propensity to realize the need for rework is influenced by interactions with others. From a *theoretical* perspective, the paper integrates the NPD literature on iterative problem solving with the literature on knowledge sharing and social networks, thereby gaining insight into the mechanisms that lead to the recognition of the need for design rework. From an *empirical* perspective, I was able to measure all technical communications patterns that have been established to address task interdependence between actors in my setting. Doing so allowed me to test for the effects of addressing task interdependence while controlling for the main source of rework at the dyadic level. Thus, capturing separately the technical and social components of dyadic interactions enabled me to examine the behavioral mechanisms by which social networks affect an individual's realization of the need for rework. This examination is critical because my aim was to show that realizing the need for rework is driven not only by technical aspects but also by people-related factors.

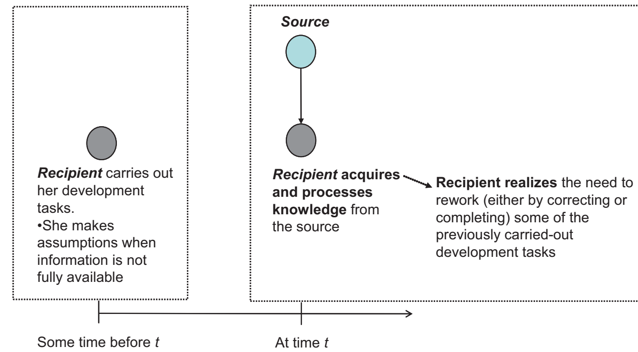
2. Theoretical Framework and Hypotheses

This paper studies the determinants of realizing the need for rework (based on interactions with others). In new product development, such insight occurs when an individual realizes the need to correct or complete some of her design tasks after interacting with other colleagues at work. Because this is a dyadic-level phenomenon, I focus on technical dyadic interactions: the transfer of technical information from the *source* (actor providing information) to the *recipient* (actor receiving information) during NPD efforts (Reagans and McEvily 2003, Sosa 2011). Given this dyadic setting, I define *realizing design rework* as the recipient's realization of the need to rework (either by correcting or further completing) some of her development tasks after receiving technical information from the source.

Consistent with other studies of knowledge management, this paper takes an information processing view to examine organizational dyadic relationships (Borgatti and Cross 2003, Galbraith 1977, Reagans and McEvily 2003, Sosa 2011, Szulanski 2000, Thompson 1967), and much as in Thibaut and Kelley (1986), I view *relationships* as the set of interactions that take place between source and recipient within a finite period of time. In this study I examine the set of technical and social dyadic interactions in a software development organization for a period of 1 year, thereby revealing how knowledge transfer from source to recipient activates the latter's cognitive processes.

I am interested in understanding the factors that influence the recipient's realizing the need for design rework at time *t*. (Because such a realization opportunity is contingent upon the recipient's task involvement *before* approaching the source for product-related information, the recipient appears at two different times in Figure 1.) From an information processing perspective, an organizational interaction between two individual actors at time *t* includes the following basic stages: the recipient's *acquiring* knowledge from the source, *processing* that knowledge, and *realizing* the impact of the interaction's outcome. The main focus in this paper is on the outcome of a dyadic

Figure 1 An Information Processing View of Organizational Dyadic Interactions



relationship in which the recipient realizes, after acquiring and processing knowledge from the source, the need to rework some tasks that were previously considered to be finished (see Figure 1).

Although realizing the need for rework ultimately leads to positive results (by aiding the development of high-quality products), the recipient may initially resist recognizing this need because of the time and cost entailed by rework. This means that the source is likely to play a crucial and proactive role in the process that leads the recipient to realize the need for rework. I therefore categorize the hypothesized drivers of rework into two types: (i) *technical* factors (e.g., addressing task interdependence and having different areas of expertise), which enable a source to help recipients recognize the need to carry out design rework, and (ii) *organizational* factors (e.g., actors' positions in the organizational hierarchy and the structure of interacting actors' informal social networks), which determine the willingness of both source and recipient to engage in a dyadic relationship that fosters realizing the need for rework.

2.1. Technical Factors

I consider two technical factors that contribute to the effectiveness of source-provided information at helping the recipient realize the need for design rework: first, the extent of communication between source and recipient devoted to addressing the recipient's task interdependence; second, the extent to which the source's areas of expertise differ from those of the recipient.

2.1.1. Addressing Task Interdependence. Formally, task interdependence is defined as "the amount of information that must be processed between decision makers during the execution of the task to get a given level of performance" (Galbraith 1977). In product development organizations, developers need to obtain information from other colleagues in order to carry out their development activities (Krishnan et al.

1997, Loch and Terwiesch 1998, Smith and Eppinger 1997, Terwiesch et al. 2002). The reason is that product development efforts are typically broken down into manageable subtasks that are assigned to various development actors, who must interact and coordinate among themselves to ensure that the final product works as an integrated whole (Gokpinar et al. 2010, Sosa et al. 2004).

Developers differ in the level of task interdependence they experience and in the effort they expend to address them (Allen 1977, Sosa et al. 2004). In an empirical setting like the one investigated here, some highly interdependent developers need to interact frequently with regard to a range of distinct products and technologies under development whereas other, less interdependent developers interact sporadically regarding a smaller set of products and technologies.

The level of task interdependence determines the need for coordination between development actors and, in addition, provides learning opportunities about the task requirements of others. Interdependences that are more critical not only increase the need for rework but also require more attention from the actors involved, which is manifested by more frequent and intense interactions (Gokpinar et al. 2010, Iansiti 1995, Loch and Terwiesch 1998, Sosa et al. 2004). Such recipient's frequent requests of technical information from the source to address her task interdependence also encourage the source to understand better the scope and requirements of the recipient's task (Krishnan et al. 1997, Terwiesch et al. 2002). Controlling for the need for rework associated with the recipient's task, the more often the recipient goes to the source to coordinate her task interdependence, the more opportunities exist for the source to provide relevant information that informs the recipient about the need for corrective or completion action. This line of thought leads to my first hypothesis.

> **Hypothesis 1 (H1).** *The more frequently the recipient goes to the source for technical communications concerning her task interdependences, the more likely it is that the recipient realizes the need for rework after interacting with that source.*

2.1.2. Expertise Differential. I consider dyadic interactions in organizations whose (diverse) members share a common knowledge platform that guarantees sufficient knowledge sharing. Examples of such settings are software development organizations with "fluid" teams formed by members with diverse customer-related experience (Huckman and Staats 2011) and product design firms formed by members who have complementary areas of expertise and who share knowledge and experience to help each other generate insights about the design challenges at hand (Hargadon and Sutton 1997). In the organization studied here there were 13 areas of technical expertise, all of which were related either to the technologies associated with the products under development or to the various phases of their software development processes.

I define *expertise* as the knowledge that actors have accumulated based on their training or experience and that is relevant to their development activities. One can argue that some expertise commonality (or overlap) is necessary to guarantee sufficient absorptive capacity (Cohen and Levinthal 1990) and to develop a viable common understanding among the members of an organization who interact (Cramton 2001, Monteverde 1995). However, one can also argue that such expertise overlap makes it more difficult to realize the need for rework because interacting with a source who has similar areas of expertise is more likely to reinforce assumptions or past decisions and thus to overlook potential areas of rework or improvement; this dynamic is analogous to the negative effect of the "not invented here" syndrome observed by Katz and Allen (1982) in research and development (R&D) organizations. Given these conflicting views on the effect of expertise differential, it is reasonable to consider whether the *type* of expertise possessed by the respective actors plays a significant role in understanding the relation between expertise differential and realizing the need for rework.

Development actors accumulate knowledge about the products and technologies they develop and also about the processes they carry out during their development effort (e.g., quality control, market analysis, product design). Product-related expertise (know-what) is associated with the specific functional and architectural attributes of the product under development, whereas process-related expertise (know-how) is associated with the procedures and activities associated with product development generally (Garud 1997). I argue that a process-related knowledge differential between actors is more likely than a product-related knowledge differential to facilitate realizing the need for rework because the former allows one to examine the product being developed from distinct (yet relevant) angles, which in turn leads to the discovery of areas in need of rework (Wong 2004).

If a recipient interacts with a source whose area of process-related expertise differs from her own, then the product under development is scrutinized from distinct yet relevant viewpoints. These distinctive views of the product being developed can uncover areas in need of further completion or correction before required levels of product quality can be attained. Thus, I propose my next hypothesis.

Hypothesis 2 (H2). *A recipient is more likely to realize the need for rework when interacting with a source who has different process-related (as opposed to product-related) expertise.*

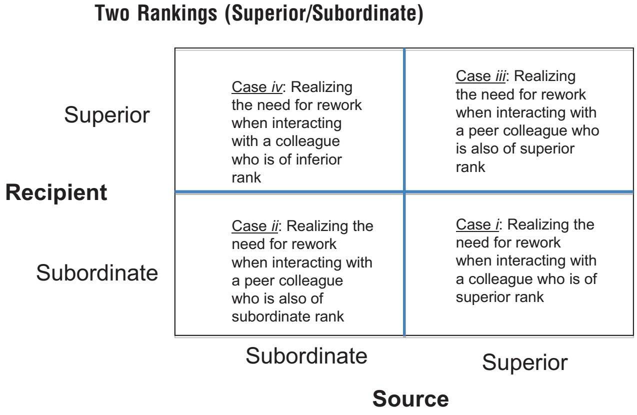
2.2. Organizational Factors

Task interdependences and different areas of expertise are important factors in recognizing the need for rework, but they are not the only ones. People-related factors are also key determinants because they influence decision making in various business processes (Bendoly et al. 2006, Gino and Pisano 2008, Loch and Wu 2005). In this section I consider two people-related factors in order to study how behavioral mechanisms influence an individual's propensity to realize the need for rework (Gulati and Sytch 2007): the relative rank of source and recipient in the organizational hierarchy and the dyadic embeddedness of these actors within their organization's social networks.

2.2.1. Relative Hierarchical Rank. The formal organizational hierarchy of company positions establishes different ranks among development actors. A formal hierarchical structure includes, at the very least, two ranks: superior and subordinate. In such a setting the dyadic relationships are such that source and recipient either share the same rank or have different ranks. Thus, in Figure 2, *Case ii* and *Case iii* describe dyads in which the recipient and source are both of the same rank while *Case i* and *Case iv* describe dyads in which the two actors are of different rank (i.e., one is subordinate and the other is superior). Given this setting, how do the ranks of the two actors involved affect the recipient's propensity to realize the need for rework?

A power-based view of dyadic relationships suggests that actors of superior rank exert more influence on actors of subordinate rank than vice versa (Emerson 1962, Tushman and Romanelli 1983). Power is thus attributed to actors of superior rank because of the dependence relation (Gulati and Sytch 2007, p. 35): "If an actor was more dependent on its exchange partner, the resulting net-positive dependence on the partner, or the partner's dependence advantage, was construed as the source of the partner's power." From this perspective, a more powerful actor has the authority to persuade or demand his subordinate to realize the need for rework (Tushman and Romanelli 1983). The managers in NPD organizations are likely to review carefully the work performed by their subordinates; hence these higher-ranking actors are in a formal organizational position to help (or even demand that) their subordinates recognize the need to rework.

Figure 2 Four Possible Cases of Two Actors (Source/Recipient) And Two Rankings (Superior/Subordinate)



In addition to signifying relative power, each individual's position in the organizational hierarchy also carries a strong and objective signal of her status within the organization—a status that typically reinforces the effect of power imposed by formal authority (Srivastava and Anderson 2011). Because of their higher organizational status, an actor of superior rank is likely to influence subordinates even if he does not depend on them directly.

The relative position in the organizational hierarchy is also relevant on the recipient side because it moderates her process of seeking and accepting help from others. Accepting help from a colleague of different rank may be costly for the recipient in the sense of encouraging others to view her as "inferior" (Lee 1997, 2002); this effect is exacerbated when it is the recipient who is of superior rank, since she may feel that being led to rework via interactions with colleagues could damage her status in the organization (Hofmann et al. 2009).[2] Realizing the need for rework requires a willingness to seek and accept help or feedback from the source. Actors in the subordinate position have lower status and are therefore less likely to worry that asking for help affects their status; in contrast, actors in the superior position will probably be concerned about protecting their high status—which in turn inhibits their seeking out feedback that would point to the need for rework.

Based on the power and status associated with relative positions in a hierarchical organizational structure I argue that recipients of subordinate rank are more *receptive* to realizing the need for rework and that sources of superior rank are more likely to *trigger* the recognition of the need for rework in others. This proposition implies, with reference to the four possibilities depicted in Figure 2, that the effect in *Case i* (a subordinate recipient interacting with a superior source) should be the largest and that the effect in *Case iv* (a superior recipient interacting with a subordinate source) should be the smallest. I therefore propose the following hypotheses.

Hypothesis 3a (H3a). *A recipient of subordinate rank is more likely to realize the need for rework* *when interacting with a source of superior than of subordinate rank (i.e., the Case-i effect is greater than the Case-ii effect).*

Hypothesis 3b (H3b). *A source of superior rank is more likely to trigger a realization of the need for rework when interacting with a recipient of subordinate than of superior rank (i.e., the Case-i effect is greater than the Case-iii effect).*

Hypothesis 3c (H3c). *A recipient of superior rank is less likely to realize the need for rework when interacting with a source of subordinate than of superior rank (i.e., the Case-iv effect is less than the Case-iii effect).*

Hypothesis 3d (H3d). *A source of subordinate rank is less likely to trigger a realization of the need for rework when interacting with a recipient of superior than of subordinate rank (i.e., the Case-iv effect is less than the Case-ii effect).*

2.2.2. Dyadic Embeddedness. From a behavioral perspective, the willingness of the relevant actors to seek and provide help in work-related matters should play a significant role in determining the recipient's realizing the need for rework. Such willingness is a function of how deeply the recipient is embedded in her social relationship with the source (Burt 1992, Granovetter 1985, 1992). Here I consider the social network construct of *dyadic (social) embeddedness* (cf. Granovetter 1992). This notion is salient in the social network theory of "structural holes," under which dyadic embeddedness (or *constraint*) captures the "proportion of a person's network time and energy that directly or indirectly involves" another person (Burt 1992, p. 54). My basic argument suggests that increased social investment (by source and recipient both) in the dyadic relationship results in stronger motivation and social incentives (i) for the source to help the recipient realize that rework is required and (ii) for the recipient to accept this help from the source. That being said, there are limits on the benefits of dyadic embeddedness. As observed with other dyadic processes—such as the generation of creative ideas or the ease of knowledge transfer—increased embeddedness need not always yield increased benefits (Reagans and McEvily 2003, Sosa 2011).

Let us begin by discussing the essence of the dyadic embeddedness construct. In line with Burt (1992) and Granovetter (1992), I view dyadic embeddedness as a linear combination of two components: a "relational" component (*tie strength*), which is a function of the amount of time and energy that both the source and the recipient invest in their own dyadic relationship, and a "structural" component (*network cohesion*), which is a function of the time and energy that both the source and the recipient invest in their relationships with common contacts (i.e., those who interact with both the source and the recipient). Because these two components account for the proportional energy and attention invested in a dyadic relationship rather than the specific content exchanged by the recipient-source pair, they capture how interacting actors come together on a social basis rather than on technical grounds (Burt 1992, Reagans and McEvily 2003, Sosa 2011).

In social network terms, actors who share a strong social connection are intrinsically motivated to work closely together and thus are willing to devote a large share of their time and energy to quality communication and interaction. That dynamic is captured by tie strength. In essence, realizing the need for rework is triggered by the source's dedication to spending time with the recipient and making her aware of incorrect assumptions by providing feedback that she might view, initially, as undesirable. This argument is consistent with the notion that individual effort and motivation to interact with others at work are important factors in making it easier for the source to transfer knowledge (Boudreau et al. 2003, Reagans and McEvily 2003, Siemsen et al. 2009a). A source is more likely to give negative (but valuable) feedback if he feels psychologically safe in doing so (Siemsen et al. 2009a). From the recipient's standpoint, socially attached sources are more likely to be trusted and thus more likely to facilitate acceptance of the need to rework tasks that were thought to be completed (Levin and Cross 2004). These statements are in agreement with findings that suggest team familiarity leads to better team performance in terms of project schedule and product quality (Huckman et al. 2009). Hence dyadic relationships involving socially connected actors should make it more likely (than in the case of socially distant dyad members) for the source to be willing to help and also for the recipient to accept help, which should increase the chances of recognizing the need for rework.

The positive effects of having a strong social tie with the source are reinforced by the presence of common contacts between the source and the recipient. Such network cohesion at the dyadic level can induce extrinsic (to the dyad) social pressure on the recipient's ability to realize the need for rework based on information provided by the source. The presence of common contacts may support colleagues interacting within a dyadic relationship, thereby encouraging cooperation and thus realization of insights (Coleman 1990). This dynamic is consistent with evidence showing that the presence of common contacts fosters a collaborative environment favorable to innovation

(Obstfeld 2005). In addition, the presence of common contacts can encourage cooperation that supersedes internal competition. If a source is competitive, then the recipient's realization for the need of rework may be compromised: The source may be withholding information that would enhance the recipient's performance. In contrast, the cooperative environment that is promoted by common contacts can mitigate conflicts due to competition and thus facilitate the transfer of knowledge and support from source to recipient (Reagans and McEvily 2003).

Yet there may be a limit to the overall benefits of dyadic embeddedness. Interacting agents who are *too* socially connected (via strong ties) or surrounded by too *many* common contacts can lead to the dyad's converging toward common perspectives and group thinking, which could impair the realization of a need for design rework (Janis 1972). With respect to cognition, excessive dyadic embeddedness could favor convergent thinking that reinforces the status quo and simultaneously hinders divergent thinking that might explore alternative solution paths capable of uncovering the need to rework (Guildford 1950). Relationships that are strongly linked (either directly or indirectly) may lead source and recipient to reaffirm agreed-upon viewpoints and to resist diverging from extant assumptions, which would diminish the positive effect of dyadic embeddedness on the probability of realizing that design rework is needed. I therefore predict a nonlinear relation between dyadic embeddedness and the recipient's realization of the need for rework. Hence I propose my final hypothesis, as follows.

> **Hypothesis 4 (H4).** *The more embedded is the recipient in her social relationship with the source, the more likely it is that she will realize the need for rework (after interacting with that source). However, at some point the marginal returns to additional dyadic embeddedness begin to decline.*

3. The Study

To test the hypotheses stated in section 2, I examined not only the portfolio of products but also the formal and informal organizational structure of the entire development department of a European software development company. The study was part of larger effort to understand and improve coordination and innovation in my research site (Sosa 2008, 2011). The firm, founded in the 1980s, is a public company that is traded on the German stock exchange. It is one of the world leaders for a particular type of application in the software industry, and its principal market consists of business customers. At the time of this study, the firm's NPD organization employed 66 people who worked in 11 organizational groups distributed across three different locations in two neighboring European countries.

3.1. Methods and Data

My sociometric study was also used to examine the knowledge and social drivers of the generation of creative ideas at the dyadic level; some details of the empirical approach are omitted here because they are discussed at length in Sosa (2011). I used two methods to collect the data: semistructured interviews (to understand the firm's portfolio of projects and general organizational structure) and a Web-based survey. The survey was administered to the entire development department at the end of 2005 and covered mainly the activities and interactions taking place that year. The survey was completed by 58 of the 66 people in the development department (88% response rate). Respondent and nonrespondent groups did not differ significantly in their received ratings on the key variables of this study.

I collected network data using a combination of classic sociometric techniques (Wasserman and Faust 1994). I began by providing each respondent with a fixed roster of contacts formed by the 66 people in their development department. The full name and location of each person was clearly specified in the Web-based survey, and respondents were asked to select those they had "gone to" for interactions that significantly affected their work during 2005.[3] The name generator used an information seeking perspective to ensure consistency throughout the survey; that is, all relational questions were formulated from the recipient's viewpoint. In addition, I focused on interactions that affected work in order to concentrate the hypothesis testing on ties that were more likely to be associated with development of any of the organization's products. After respondents identified their contacts, they were asked 16 questions about their relationships with each selected contact so that I could measure the variables of interest.

The unit of analysis is the dyadic relationship as measured from the recipient's viewpoint. Respondents reported 671 relationships, of which 641 involved the development of at least one of the products in the firm's portfolio. After removing the interactions for which source data were missing or incomplete, I was left with a sample of 606 dyadic observations. On average, each respondent reported having work-related interactions with about 12 other colleagues in the organization.

3.1.1. Dependent Variable: Realizing the Need for Rework. The dependent variable captures the propensity of the recipient to realize, based on her interactions with the source, that additional work is needed on previously carried-out tasks. (The nature of this additional work could be related either to "redoing" all or some aspects of the original task or to "extending" the original task by performing additional subtasks.) Because the source and recipient are the *only* actors equipped to assess the outcome of their dyadic relationship accurately, I relied on the recipient to evaluate the ease with which she recognized the need to carry out design rework after interacting with the source. This approach is similar to previous research on knowledge transfer at the dyadic level—which, however, relies on the source side of the dyad to assess the ease of transferring knowledge to the recipient (Reagans and McEvily 2003).[4]

I captured the propensity of realizing the need for rework associated with each relationship by asking respondents to rate (on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree") their level of agreement with the following statement: "When I interact with [name of source contact], I typically realize that I need to REWORK many of the things that I thought were already done. That is, I typically realize that I need to do more work on my tasks than I had originally anticipated." This two-sentence statement merits some discussion. Observe that the second sentence in the statement aims to clarify the first by indicating the nature of the potential design rework triggered by interacting with the source: working on previously defined design tasks, not on tasks that are fundamentally new. This wording expresses the notion that the additional work is needed to fully complete a development effort. Thus, I seek to capture the likelihood of the recipient realizing that corrective (or completion) actions are needed on previously executed tasks—under the reasonable presumption that, according to the recipient, such actions are necessary and ultimately positive. Observe that the modifier "typically" is used in both sentences of the statement; this is needed to make the item relative to the context of the respondent. My dependent variable assumes that each respondent is normally expected to accommodate certain requests to perform design rework and that her response to this survey statement is relative to such a "normal" level. As an illustration, consider a recipient who reports on two dyadic relationships with source *a* and source *b*, respectively. Suppose the recipient (the respondent) "strongly agrees" with my two-sentence statement as regards her dyadic relationship with source *a*. Such a response surely indicates that the recipient typically (i.e., naturally, easily, normally) recognizes the need for rework after interacting with source *a*. Now suppose that the same respondent "strongly disagrees" with the statement as regards her relationship with source *b*. Such a response indicates that the recipient rarely (i.e., only in abnormal circumstances) recognizes the need for rework as a result of interacting with source *b*. So in the first case, the respondent has high propensity to realize the need for rework; in the second case, such propensity is low.[5]

It is important to emphasize that my dependent variable captures the propensity to realize the *need for* rework (based on interactions with a source), not the *amount of* rework.[6] Yet, the need for rework faced by the recipient is clearly an important factor to control for. There are two components determining the recipient's actual need for rework: (i) an unobserved individual-invariant component, for which I control by including individual fixed effects in my regression models, and (ii) a dyadic component specific to each recipient-source pair, for which I control by including a measure of the complexity of the recipient's tasks that are affected by interactions with the source.

Similarly to other network studies (e.g., Borgatti and Cross 2003), I relied on a single question to measure my network variables of interest. Note that Marsden (1990) finds that answers to relational questions are generally reliable when used (as in my survey) with roster methods that facilitate respondents' recall, and Freeman et al. (1987) find that network questions are highly reliable when inquiring about "typical" interaction patterns. Hence I chose a single item to assess the propensity of realizing the need for rework associated with each dyad because I wanted to minimize the risk of respondents dropping out of the survey when faced with too many relational questions and because the host organization wanted to minimize the number of redundant questions.

3.1.2. Independent Variables. *Addressing task interdependence* of actor *i* involves her acquiring technical information from other colleagues in order to carry out her development activities. In my research site, developers needed to exchange technical information related to the various products they were developing. During the time period covered by this study, the development department was working on seven technologically distinct products. I captured the *technical* communication patterns involving each of the seven products under development. Each respondent (recipient) was asked to indicate, for each colleague identified as a source and for each of the seven products under development, how often (0 = never, 1 = rarely, 2 = sometimes, 3 = very often, 4 = always) she went to the source "to discuss product-related matters during this year." Responses to these questions were used to build my measure of the average extent of product-related communication involved in addressing the task interdependence of recipient *i* with respect to source *j*. Note that the 5-point scale employed is ordinal because I was not interested in measuring communication frequency *per se*; rather, I use the reported product-related communications to measure the recipient's average coordination effort with a source in addressing her task interdependence vis-à-vis products under development. This measure is equal to the sum of product-related communication frequencies initiated by recipient i with source j divided by the number of distinct products about which they were communicating:

$$avg\_product\_communication_{ij} = \frac{\sum_{k=1}^{7} product\_communication_{ij}^{k}}{\sum_{k}^{7} \delta_{ij}^{k}},$$

where $product\_communication_{ij}^{k}$ captures the frequency of the communications initiated by recipient i with source j about product k. Here $\delta_{ij}^{k} = 1$ if $product\_communication_{ij}^{k} > 0$ and $\delta_{ij}^{k} = 0$ otherwise. This measure captures how much communication, on average, addressed the task interdependence experienced by recipient i concerning the development of a product that needed input from source j. Because Hypothesis 1 refers to the benefit of repeated technical communications concerning a given product, an average measure is appropriate. Nonetheless, I also tested the marginal effects of each of the seven $product\_communication_{ij}^{k}$ terms to examine whether there are significant differences between the effects of addressing the task interdependence associated with each product. Finally, I checked that my results are robust to using a sum of all the product-related communications instead of their average.

In order to measure the *expertise differential* between recipient and source, I first needed to capture the actors' areas of technical expertise. Toward this end, I asked each respondent to indicate "the areas in which they considered themselves experts (or with significant professional experience)." Respondents could select (as many as appropriate) from a list of 30 items, which had previously been grouped into 13 categories or areas of expertise. The list of items, which provided a more granular description of each area of expertise, was assembled by a technical product manager and was reviewed and approved by the firm's VP of development so that context validity was maximized. Seven of the 13 categories were product-related areas of expertise that corresponded to the seven distinct technologies associated with each product under development; the other six categories were process-related areas of expertise: "process and product management," "product conception," "product construction," "bug fixing and maintenance," "product support," and "customer attention." A respondent is considered to be an expert in any area for which she marked at least one item keyed to that area; for each such respondent i I defined two binary vectors, **p** and **q**, that capture (respectively) the individual's product-related and process-related expertise profiles. I then devised two measures of expertise differential based on the Euclidean distance between the profiles of recipient i and source j (cf. Wasserman and Faust 1994):[7]

$$product\_expertise\_differential_{ij} = \sqrt{\sum_{k=1}^{7} (p_{ik} - p_{jk})^2},$$

where $p_{ik} = 1$ if individual i is an expert in product-related area k and $p_{ik} = 0$ otherwise, and

$$process\_expertise\_differential_{ij} = \sqrt{\sum_{k=1}^{6} (q_{ik} - q_{jk})^2},$$

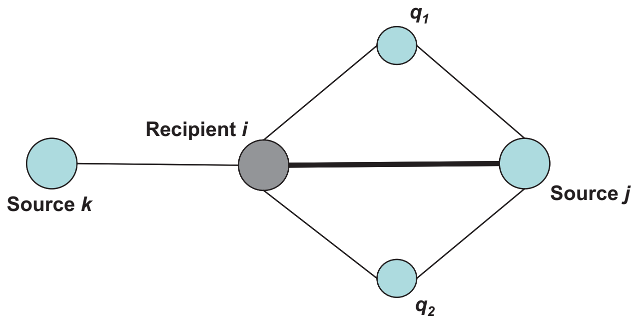
where $q_{ik} = 1$ if individual i is an expert in process-related area k and $q_{ik} = 0$ otherwise.

Relative hierarchical rank: Because the focus of my study is a firm's R&D department, the formal organizational structure was predominantly flat. Even so, two hierarchical levels (a superior rank and a subordinate rank) were officially recognized by the organization. Individuals of superior rank were managers or group leaders within the R&D unit. Because each person in my organization was either a superior or a subordinate, each dyad could be uniquely classified as belonging to one of the four categories illustrated in Figure 2: *Case i*, recipient is subordinate and source is superior (*source_superior*); *Case ii*, both recipient and source are subordinate (*both_subordinate*); *Case iii*, both recipient and source are superior (*both_superior*); or *Case iv*, recipient is superior and source is subordinate (*recipient_superior*). I therefore define three dummy variables indicating the relative ranks of members in any of the sample dyads (*both_superior* is taken as the reference category).

Following Burt (1992, p. 54), I measure the *dyadic embeddedness* of recipient i with source j as "the proportion of i's network time and energy that directly or indirectly involves j." Figure 3 shows that recipient i has a *high* level of dyadic embeddedness with source j (because i has a strong tie with j and also has interactions with two other colleagues, q_1 and q_2, who are contacts that i has in common with j) but that recipient i has a *low* level of dyadic embeddedness with source k (because i has a weak tie with k and no common contacts with k).

Before writing the mathematical expression that measures my construct of interest, I discuss how social interactions among the research site's interdependent actors are captured. As in most of the social network literature, I use two indicators to measure the social involvement between actors: overall communication frequency and dyadic closeness (Burt

Figure 3 Social Embeddedness of Recipient *i* with Respect to Sources *j* and *k*



Recipient *i* is more socially embedded in her relationship with source *j* than in her relationship with source *k*

1992, Marsden and Campbell 1984, Reagans and McEvily 2003). Respondents were first asked to indicate their average communication frequency (for any reason: technical, social, or managerial) with the identified source contact during the year 2005 (daily, weekly, several times per month, monthly, less often). I remark that this overall measure of communication frequency captures all types of communications and not merely the seven product-related technical communications upon which the measure *avg_product_communication* is based. Respondents were then asked: "How close is your working relationship with [name of source contact]? (Very close—this person is among my strongest contacts; Close—we like discussing and solving issues together; Less than close; Distant—we interact only when strictly necessary)."[8] Finally, I measured interaction intensity as the average z_{ij} of closeness and frequency. (I also computed interaction intensity as the *product* of these two variables and obtained substantively similar results.)

The first component of dyadic embeddedness, *tie strength* (or *relational* embeddedness), captures the direct involvement of actor i (the recipient) in the relationship with actor j (the source). Tie strength is denoted by p_{ij}, and it is defined as the proportion of the recipient's total interactions that are invested in the relationship with source j (i.e., as a result of i's seeking out *or* being sought out by j). This approach is consistent with previous network studies that transform tie intensity into a proportional measure of tie strength (Burt 1992, Reagans and McEvily 2003, Sosa 2011). Thus we have

$$p_{ij} = \frac{z_{ij} + z_{ji}}{\sum_q (z_{iq} + z_{qi})} \quad \text{for} \quad i \neq j.$$

This measure allows us to capture how the focal actor i allocates her time and attention to the different people with whom she interacts at work. It is worth noting that, because my arguments behind Hypothesis 4 do not explicitly assume directionality of interactions, I measure the strength of a tie based on *all* the communications in which the actors were involved as either seeker or provider of information. In this way, I account for the proportional amount of energy and attention that actor i spends with actor j relative to all the interactions in which actor i is involved (Burt 1992).

The second component of dyadic embeddedness, *network cohesion* (or *structural* embeddedness), takes into account the indirect involvement of actors i and j through their common contacts q. The involvement of the recipient i with third parties q that are common to source j is assessed using the indirect constraint (c_{ij}) measure proposed by Burt (1992):

$$c_{ij} = \sum_q p_{iq} p_{qj} \quad \text{for} \quad q \neq i, j.$$

This measure captures the *network cohesion* surrounding the dyadic relationship (ij) of interest (Reagans and McEvily 2003, Sosa 2011). A relation with a common contact q is strong to the extent that the recipient has a strong relationship with the common contact (p_{iq}) *and* the common contact also has a strong relation with the source (p_{qj}). To assess the overall strength of these indirect connections surrounding the focal relation between recipient and source, we need only sum over all their common contacts. Observe that, because p_{iq} measures the proportion of the recipient's total interactions invested in the relationship with actor q (as a result both of i's seeking out q and of i's being sought out by q), this measure properly captures the presence of common contacts even if actor i did not seek out actor q but instead was sought out by actor q (i.e., if $z_{iq} = 0$ and $z_{qi} > 0$).

Finally, I construct my dyadic embeddedness measure by summing the two components just described, which capture the direct and indirect involvement of recipient i in her relation with source j:

$$dyadic\_embeddedness_{ij} = p_{ij} + \sum_q p_{iq} p_{qj} \quad \text{for} \quad q \neq i, j.$$

It is important to emphasize that this measure is based on proportional measures of the overall communication frequency (not only for technical matters but also for social and managerial reasons) and of the closeness between recipient i and j. Hence this variable captures the overall social attributes of the dyadic relationship (ij), not the properties of the corresponding task interdependence. This distinction is necessary if I am to test for the effects of social networks in the presence of the effects of technical communication addressing task interdependence. Nonetheless, to disentangle further my social network variable from my (average) product communication variable, I devised an analogous measure of dyadic embeddedness based on dyadic closeness only (i.e., excluding overall communication frequency). My results are robust to this alternative way of measuring dyadic embeddedness.

3.1.3. Control Variables. A detailed description of each control variable is given in Table 1. Panel A of the table summarizes the basic indicator variables for common knowledge background (Reagans and McEvily 2003). Much as in Sosa (2011), I also control for the types of interactions performed by each dyad (Panel B). Finally, I control for the content of the knowledge that flows from the source to the recipient (Panel C). In addition to these control variables, there are two important controls that merit special discussion: dyadic task complexity and ease of generating creative ideas.

3.1.3.1. Dyadic task complexity: Since my dependent variable measures the propensity to realize the need for rework after interacting with the source, it is crucial to control for whether the interactions with the source concern tasks that are more or less likely to involve rework. (Here I emphasize that this control should capture whether the source interacts about "something" that is likely to involve rework regardless of the source's own actions.) An important indicator of the task's likelihood of involving rework is the extent to which it depends on other tasks (Krishnan et al. 1997, Smith and Eppinger 1997, Terwiesch et al. 2002): A task is more likely to require rework if it is downstream of other tasks. I do not know the precise scope of the tasks carried out by each individual, but I do know that they all carry out development tasks for at least one of the seven products under development. I assess the complexity of recipient i's task (concerning product k) by counting the number of inputs that recipient i received from other colleagues concerning product k: $\sum \delta_{i+}^{k}$, where (as before) $\delta_{ij}^{k} = 1$ if $product\_communication_{ij}^{k} > 0$ and $\delta_{ij}^{k} = 0$ otherwise. Thus a source who interacts with a recipient about a more complex task is more likely to interact about issues that require rework by the recipient. My overall measure of dyadic task complexity then sums the recipient's task complexity for the products about which the source provides input. Formally,

$$dyadic\_task\_complexity_{ij} = \sum_{k}^{7} \left[\delta_{ij}^{k} \left[\sum \delta_{i+}^{k} \right] \right].$$

My results are fully robust to calculating *dyadic_task_complexity* in terms of the ordinal product-related communication frequencies instead of their binary variables.

3.1.3.2. Ease of generating creative ideas: As described by Sosa (2011), I measure the propensity of the recipient to generate creative ideas after interacting with the source by asking the recipient to rate, on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree," their level of agreement with the following statement (Sosa 2011, p. 8): "When I interact with [name of source contact], it is easy for me to generate NOVEL creative solutions and/or ideas. These NOVEL ideas can be either related to our products or the way we do things." I use this variable (i) as a control variable in my regression models predicting realizing the need for rework and (ii) as a second dependent variable in an alternative estimation procedure (used as robustness checks) based on a system of two simultaneous equations.

Finally, I control for unobserved heterogeneity across individuals by including fixed effects for each recipient and source (Reagans and McEvily 2003, Stuart 1998). Including individual fixed effects in this manner serves to model how the hypothesized factors explain the variation in realizing the need for rework while controlling for any unobserved heterogeneity among actors. These individual fixed effects control for any *individual-invariant* tendency of recipients to report high (or low) levels of realizing the need for rework as well as for any tendency of some sources to be viewed as more effective catalysts than other sources for such rework realization.

3.2. Analysis and Results

My dependent variable is the propensity (as assessed by the recipient) to realize the need for rework after interacting with a colleague. The hypotheses are tested on a sample of 606 dyads with complete information. Table 2 provides descriptive statistics and correlations of variables used in my analysis. Because the dependent variable is ordered and discrete, I estimated ordered logit regression models (shown in Table 3) with individual fixed effects for each dyad's recipient and source and then clustered robust standard errors by recipient (Greene 2001). Because the cutoff points in the ordered regressions are approximately equidistant, it would be no less reasonable to assume a linear scale for the dependent variable. I therefore estimated linear regression models analogous to the ones reported in Table 3, obtaining similar patterns of results. I also tested the robustness of my results by considering the recipient's generation of creative ideas (based on interactions with the source) as an endogenous variable, estimating a system with two simultaneous equations via three-stage least squares (3SLS). Results based on 3SLS regressions are consistent with those presented here.

Table 1 Description of Control Variables

Panel A: common knowledge background	
Same gender	Indicator variable that captures whether or not the source and recipient are of the same gender.
Collocation	Indicator variable that captures whether or not the source and the recipient were collocated (were at the same site).
Across organizational groups	Indicator variable that captures whether or not the source and the recipient were assigned to the same organizational group (within the R&D unit). There were 11 organizational groups.
Tie duration	Indicator variable determined by asking respondents whether or not they went to the source “for any type of (important) interactions *before* the development of the radical product kicked off.” (To facilitate respondents’ assessments of the duration of their dyadic relationships, I used the launch date of the most recent company-wide product development project—rather than a specific calendar date—as the reference. The kickoff for this project occurred during the year prior to my data collection).
Structural equivalence	I measured the structural equivalence of recipient and source in order to capture the similarity of these actors’ social networks. For this measurement I determined the Euclidean distance between their individual network patterns and then reversed its sign (cf. Reagans and McEvily 2003, Wasserman and Faust 1994). Controlling for the proximity of the actors’ social networks is particularly relevant when testing the effects of dyadic embeddedness, which is also a function of those networks.
Panel B: interaction types	
Managerial, social, and consultation-type interactions	I defined dummy variables to indicate whether the recipient would communicate with the source for managerial, social, and consultation reasons (Allen 1977). For *managerial interactions*, respondents were asked if they went to the source “for advice or help if [the respondent] had a managerial question or ran into an organizational issue at work.” In order to control for dyadic sources of positive affect, such as friendship relationships, I capture *social-type interactions* by asking respondents if the source were one of those people “with whom [the respondent] likes to spend his or her free time. That is, people with whom [the respondent] gets together for informal social activities such as going for lunch, coffee breaks, dinner, drinks, movies, visiting one another’s homes, and so on.” Finally, to measure technical knowledge acquisition outside the coordination effort associated with products under development (i.e., *consultation-type interactions*) from the recipient’s point of view, respondents were asked if they went to the source “for (technical) advice to learn about a novel (for the respondent) technical topic, or when [the respondent] encounters a particularly hairy technical problem.”
Panel C: tie content	
Knowledge codifiability	*Knowledge codifiability* is “the degree to which knowledge can be encoded” (Zander and Kogut 1995, p. 79). This trait has been shown to influence dyadic knowledge sharing, which makes it an important factor to control for (Reagans and McEvily 2003, Sosa 2011). To measure codifiability, respondents were asked to rate (on a 7-point Likert scale) their level of agreement with the following statement (Reagans and McEvily 2003): “The information received from [name of source] is typically well documented in writing (i.e., memos, reports, manuals, e-mails, faxes, etc.).”
Fraction of knowledge newness	Not all the technologies developed at my research site were in the same state of flux: one “radical” product involved the most recent technologies whereas the other six products employed distinct “legacy” technologies. Because the content of product-related communications can therefore be seen as a mix of new and legacy technical issues, I control for the radical–legacy mix. I devised a dyadic measure of the *fraction of knowledge newness* as the communication frequency associated with the radical product divided by the sum of all the communication frequencies for all product-related interactions for that dyad (Sosa 2011).
Dyadic knowledge breadth	*Dyadic knowledge breadth* was measured by counting the number of distinct product-related interactions associated with each relationship. Hence the value for this variable ranges from “1” (interactions concerning one product only) to “7” (interactions concerning all seven products under development). In order to account for the unequal frequency of product-related interactions, I used two alternative measures of dyadic knowledge breadth: for each relationship, *infrequent* dyadic knowledge breadth counts the number of product-related interactions that occurred “rarely” and *frequent* dyadic knowledge breadth counts the number of such interactions that occurred “frequently” (Sosa 2011).
Indirect knowledge flows	Because two of my hypothesized effects deal with addressing task interdependence *and* communications through common contacts, it is important to control for average product-related communications that flow from the source to the recipient through their common contacts. Such indirect flows may affect the recipient’s realizing the need for rework to the extent they may reinforce the task interdependence that triggered the dyadic relationship. I therefore devised the following measure of the indirect (average) product communication: $Indirect\_product\_communication = \frac{\sum_{r=1}^{7}\left(\sum_{q} z_{r,iq}\cdot z_{r,qj}\right)}{\sum_{r=1}^{7} ctp_{r,i,j}}$. Here $z_{r,iq}$ measures (on a scale from 0 = never to 4 = always) the frequency with which actor i went to actor q for technical information about product r, and $ctp_{r,ij}$ is a binary variable that indicates whether or not recipient i received technical information about product r through at least one contact common (a common-third party) to actors i and j. I also employed alternative measures of indirect knowledge flows (as defined in Sosa 2011) and obtained similar results with respect to my hypothesized effects.

Table 3 shows the coefficients for the regression models predicting the propensity to realize the need for rework. Model 1 includes the control variables. Most importantly, the effect of *dyadic_task_complexity* is positive and significant, which suggests that if a recipient interacts with a source about more complex tasks (which are more likely to require rework) then she is, as expected, more likely to recognize the need for rework than after interacting with a source about simpler tasks (which are less likely to need rework).

Model 2 tests Hypothesis 1, which predicts that addressing task interdependence is positively associated with higher propensity to realize the need for rework. The positive and significant coefficient for *avg_product_communication* is in line with H1: on average, the greater is the extent of the recipient’s product-related communication with a source, the

Table 2 Descriptive Statistics and Correlations (n = 606)

Variables	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Propensity to realize the need for rework	3.83	1.16	1.00																							
2. Ease of generating creative ideas	4.90	1.16	−0.06	1.00																						
3. Same gender	0.79	0.41	0.01	−0.02	1.00																					
4. Collocation	0.55	0.50	0.01	0.18	−0.01	1.00																				
5. Across group boundaries	0.71	0.46	0.06	−0.13	0.04	−0.12	1.00																			
6. Tie duration	0.73	0.44	−0.06	0.03	0.09	−0.01	−0.02	1.00																		
7. Structural equivalence	−24.50	5.29	0.05	0.08	−0.10	0.33	−0.48	0.09	1.00																	
8. Managerial type	0.46	0.50	0.02	0.19	0.00	0.07	−0.16	−0.07	0.02	1.00																
9. Social type	0.56	0.50	0.03	0.29	−0.02	0.31	−0.18	0.12	0.19	0.22	1.00															
10. Consultation type	0.87	0.34	0.13	0.12	0.06	0.04	−0.11	0.04	0.06	−0.14	0.04	1.00														
11. Knowledge codifiability	5.14	1.29	−0.21	0.53	−0.07	0.07	−0.10	0.00	0.06	0.10	0.16	−0.05	1.00													
12. Knowledge newness	0.54	0.36	−0.12	0.03	−0.05	0.04	−0.05	−0.34	−0.17	0.04	−0.09	−0.03	0.04													
13. Knowledge breadth (frequent)	1.36	0.96	0.02	0.15	0.09	0.01	−0.22	0.16	0.14	0.24	0.21	0.08	0.03	−0.24	1.00											
14. Knowledge breadth (infrequent)	0.61	1.01	0.01	−0.05	0.05	−0.13	0.01	0.17	−0.09	−0.04	0.03	0.03	−0.08	−0.25	−0.12	1.00										
15. Indirect product communication	21.74	20.89	0.00	0.05	−0.18	0.00	0.08	−0.18	−0.15	0.18	0.00	0.01	0.03	0.36	0.00	−0.21	1.00									
16. Dyadic task complexity	28.23	31.99	0.11	−0.10	0.06	−0.21	0.01	0.17	−0.14	−0.04	0.00	0.09	−0.15	−0.20	0.43	0.57	0.04	1.00								
17. Average product communication	2.41	0.98	−0.05	0.15	−0.12	0.12	−0.09	−0.20	0.07	0.19	0.04	−0.03	0.07	0.33	0.12	−0.59	0.49	−0.23	1.00							
18. Product expertise differential	1.35	0.56	−0.03	0.02	0.04	−0.08	0.18	0.01	−0.22	−0.04	0.01	−0.13	0.04	−0.07	−0.03	0.07	−0.09	−0.03	−0.15	1.00						
19. Process expertise differential	1.43	0.50	0.13	−0.08	0.07	−0.04	0.20	−0.03	−0.16	0.05	0.00	−0.07	−0.14	−0.17	0.01	0.09	−0.06	0.11	−0.05	0.08	1.00					
20. Both subordinate rank	0.55	0.50	0.07	0.02	−0.20	0.09	−0.15	−0.09	0.23	−0.25	0.01	−0.03	0.15	0.05	−0.21	−0.13	0.00	−0.25	0.06	0.08	−0.22	1.00				
21. Recipient superior rank	0.13	0.34	−0.10	−0.05	0.07	−0.08	0.06	0.06	−0.16	−0.10	−0.02	0.05	−0.13	−0.09	0.11	0.25	−0.06	0.44	−0.15	−0.10	0.12	−0.43	1.00			
22. Source superior rank	0.24	0.43	0.08	0.00	0.08	0.03	0.06	−0.01	−0.08	0.28	−0.02	−0.01	−0.03	0.02	0.05	−0.10	0.06	−0.13	0.08	0.00	0.15	−0.63	−0.22	1.00		
23. Dyadic embeddedness	0.09	0.05	−0.02	0.21	0.00	0.41	−0.43	−0.04	0.55	0.12	0.15	0.08	0.18	0.05	0.10	−0.21	−0.08	−0.30	0.24	−0.27	−0.14	0.15	−0.15	0.00	1.00	
24. Tie strength	0.06	0.05	−0.02	0.22	0.00	0.37	−0.38	−0.04	0.44	0.14	0.14	0.07	0.19	0.05	0.08	−0.21	−0.09	−0.31	0.22	−0.23	−0.11	0.13	−0.16	0.02	0.98	1.00
25. Network cohesion	0.03	0.01	0.00	0.06	−0.01	0.40	−0.44	0.01	0.70	0.01	0.12	0.07	0.06	0.02	0.11	−0.13	−0.01	−0.12	0.20	−0.28	−0.18	0.17	−0.06	−0.09	0.61	0.43

Note. Correlation coefficients greater than |0.11| are significant at $p < 0.01$.

Table 3 Regression Results Predicting the Propensity to Realize the Need for Rework (n = 606)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Creative idea generation	0.453** (0.211)	0.445** (0.213)	0.440** (0.215)	0.444** (0.215)	0.429** (0.213)	0.434** (0.213)
Same gender	0.459 (0.707)	0.414 (0.722)	0.421 (0.702)	0.420 (0.705)	0.402 (0.712)	0.396 (0.727)
Collocation	0.250 (0.417)	0.297 (0.414)	0.213 (0.423)	0.232 (0.429)	0.147 (0.414)	0.128 (0.414)
Across group boundaries	−0.095 (0.348)	−0.077 (0.339)	−0.112 (0.346)	−0.129 (0.342)	−0.033 (0.347)	−0.024 (0.351)
Tie duration	−0.240 (0.385)	−0.265 (0.387)	−0.248 (0.386)	−0.247 (0.387)	−0.366 (0.389)	−0.397 (0.395)
Structural equivalence	−0.030 (0.040)	−0.045 (0.042)	−0.034 (0.042)	−0.036 (0.043)	−0.087* (0.051)	−0.094* (0.057)
Managerial type	−0.167 (0.306)	−0.179 (0.306)	−0.190 (0.316)	−0.218 (0.313)	−0.248 (0.304)	−0.236 (0.307)
Social type	0.527* (0.318)	0.506 (0.316)	0.490 (0.323)	0.480 (0.329)	0.392 (0.338)	0.396 (0.331)
Consultation type	−0.438 (0.402)	−0.417 (0.399)	−0.426 (0.410)	−0.453 (0.399)	−0.462 (0.391)	−0.462 (0.396)
Knowledge codifiability	−0.316* (0.171)	−0.329* (0.173)	−0.306* (0.177)	−0.320* (0.180)	−0.347* (0.180)	−0.353* (0.180)
Knowledge newness	−0.678 (0.779)	−0.578 (0.745)	−0.467 (0.786)	−0.421 (0.784)	−0.434 (0.763)	−0.423 (0.760)
Knowledge breadth (frequent)	−0.442 (0.277)	−0.381 (0.261)	−0.315 (0.262)	−0.292 (0.265)	−0.320 (0.256)	−0.312 (0.258)
Knowledge breadth (infrequent)	−0.525*** (0.191)	−0.264 (0.234)	−0.220 (0.238)	−0.163 (0.232)	−0.170 (0.234)	−0.158 (0.234)
Indirect product communication	0.014 (0.009)	0.013 (0.009)	0.014 (0.009)	0.014 (0.009)	0.014 (0.010)	0.014 (0.010)
Dyadic task complexity	0.032*** (0.009)	0.027*** (0.010)	0.024** (0.010)	0.023** (0.010)	0.022** (0.010)	0.021** (0.010)
Average product communication		0.455** (0.221)	0.430* (0.224)	0.469** (0.225)	0.385* (0.221)	0.395* (0.221)
Product expertise differential			−0.010 (0.238)	−0.039 (0.255)	0.012 (0.257)	0.026 (0.261)
Process expertise differential			0.543*** (0.193)	0.575*** (0.191)	0.557*** (0.194)	0.561*** (0.188)
Both subordinate rank				6.502*** (1.405)	7.160*** (1.412)	7.283*** (1.489)
Source superior rank				5.879*** (0.872)	6.056*** (0.886)	6.099*** (0.905)
Recipient superior rank				0.237 (0.940)	0.873 (0.974)	0.974 (1.015)
log(Dyadic embeddedness)					1.035** (0.520)	
log(Tie strength)						0.696** (0.340)
log(Network cohesion)						0.416 (0.479)
Log-pseudolikelihood	−547.982	−545.542	−542.463	−533.611	−531.359	−531.191
Pseudo-R^2	0.340	0.343	0.347	0.353	0.356	0.356

Note. Models include fixed effects for each source and recipient interacting in any dyad. Standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$ (two-tailed).

easier it is for that recipient to realize the need for rework. Hence, the more requests to a source made by the recipient concerning a product's technical matters, the more acquainted the source becomes with her task-related needs *and* the more useful the source becomes in helping the recipient realize that rework is necessary. These results yield a baseline model that is fully consistent with the NPD literature, which has traditionally suggested that high levels of task interdependence are associated with greater coordination needs and more effective design rework (Krishnan et al. 1997, Loch and Terwiesch 1998, Terwiesch et al. 2002). Finding empirical evidence for the effect of addressing task interdependence is important not only for validating this prediction in the context of software development but also for showing that knowledge and (in particular) people-related factors significantly influence realizing the need for rework for reasons that transcend task interdependence. My results are robust to alternative measures of addressing task interdependence: including seven predictors (corresponding to technical communications about each of the seven products under development) yields seven positive coefficients of which three are at least marginally significant, and none of them is significantly different from the others; using a total sum of product-related communications (instead of an average per product) also yields a positive and significant coefficient (0.413, $p < 0.023$).

Model 3 tests Hypothesis 2, which predicts that recipients who interact with sources with whom they have greater process-related expertise differential have a greater propensity to realize the need for rework. In line with H2, Model 3 yields a positive and significant coefficient for process-related expertise differential while the coefficient for product-related expertise differential is negative and nonsignificant. In addition, the difference between the two coefficients is (marginally) significant ($p < 0.054$). Excluding product-related expertise differential also yields a positive and significant coefficient for process-related expertise (0.544, $p < 0.005$.) The distinction between product- and process-related expertise is important because an overall measure of expertise differential based on all 13 areas yields a positive and significant result (0.576, $p < 0.016$), yet this result masks the finding that it is not product-related but only process-related expertise differential that significantly contributes to the recipient's realizing the need for rework.

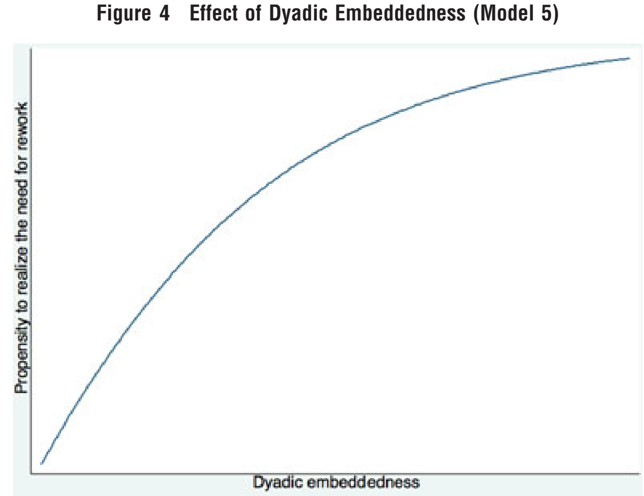
Model 4 tests Hypotheses 3 by including three indicator variables to capture relative hierarchical rank between the recipient and the source. The baseline category corresponds to dyads in which recipient and source are each of superior rank (*Case iii*). In order to test H3a, which posits that a recipient of subordinate rank is more likely to realize the need for rework when interacting with a source of superior rank than when interacting with a source of subordinate rank, I must test for whether the coefficient of *source_superior* is greater than the one of *both_subordinate*. I find that these two coefficients are not significantly different ($p < 0.477$). Yet the coefficients for *source_superior* ($\beta = 5.879$) and *both_subordinate* ($\beta = 6.502$) are greater than zero and greater also than *recipient_superior* ($\beta = 0.237$), which strongly suggests that a recipient of subordinate rank is more likely to realize the need for rework than is a recipient of superior rank (independently of the rank of the source). I find support for Hypothesis 3b: the positive and significant coefficient for *source_superior* indicates that a source of superior rank is more likely to trigger realizing the need for rework on recipients who are of subordinate than of superior rank. I do not find support for H3c, as the coefficient of *recipient_superior* is not significant; hence, the source's rank is immaterial to the propensity to realize the need for rework by a recipient of superior rank. Finally, I find support for H3d: That the coefficient for *recipient_superior* is significantly smaller than the coefficient for *both_subordinate* ($p < 0.0001$) indicates that a source of subordinate rank is less likely to trigger realizing the need for rework by recipients of superior than of subordinate rank.

I examine the effects of dyadic embeddedness in Model 5. This model includes a logged version of dyadic embeddedness with a positive and significant coefficient, which supports the positive (with decreasing returns) relationship predicted by Hypothesis 4. Figure 4 shows the positive (with decreasing rate) relationship between dyadic embeddedness and the propensity to realize the need for rework, as predicted by Model 5. I logged dyadic embeddedness to test explicitly for the decreasing marginal returns predicted by H4. Such a model fit the data better (i.e., it yielded a less negative log-pseudolikelihood) than did an alternative model that included a positive and nonsignificant linear effect of dyadic embeddedness (5.355; $p < 0.346$). Model 5 also provided a better fit than did another model that included a linear term of dyadic embeddedness that is positive but nonsignificant (17.074; $p < 0.139$) as well as a quadratic term that is negative and nonsignificant (−36.932; $p < 0.206$).

Finally, Model 6 includes the two components that constitute the dyadic embeddedness variable: tie strength and dyadic network cohesion. In order to test H4 further, I logged both tie strength and network cohesion. The coefficient estimate for tie strength is positive and significant, and that for dyadic network cohesion is also positive but nonsignificant. (I estimated two alternative models to test the linear and quadratic effects of both tie strength and dyadic network cohesion; no significant coefficients were found.) The implication is that the effect of dyadic embeddedness is driven mainly by the proportion of energy and attention invested by the recipient in seeking out the source (and by the source in responding to the recipient). This finding is consistent with the observation of Granovetter (1992, pp. 34–35), who suggests that relational embeddedness has "quite direct effects on individual economic actions" whereas structural embeddedness "typically has more subtle and less direct effects."

An important empirical issue in my setting concerns causality, in particular with respect to the effect of dyadic embeddedness. Does the social proximity of the relationship lead to realizing the need for rework, or does realizing the need for rework intensify the relationship's social proximity? Because my study is cross-sectional, testing for reverse causality is difficult, and finding appropriate instrumental variables for key predictor variables at the dyadic level would clearly be a daunting task. That being said, one could still argue that realizing the need for rework leads to stronger social ties. A conclusive test for this possibility requires longitudinal data. Lacking such data, I checked for the possible significance of reverse causality by estimating the interaction effect of tie duration and dyadic embeddedness (see Burt 1992). The argument behind this test is that, if dyadic embeddedness leads to more realization of the need to rework and if this leads in turn to a more embedded relationship with the source, then older ties are more likely to be exposed to such a reinforcing effect; the result would be a significantly positive interaction effect of dyadic embeddedness and tie duration in my regression models (Repenning 2002). I find that the interaction between tie duration and dyadic embeddedness is nonsignificant, which suggests that reverse

Figure 4 Effect of Dyadic Embeddedness (Model 5)



causality may not be an important issue ($p < 0.235$). A similarly nonsignificant result is obtained when I test for the interaction between tie duration and tie strength ($p < 0.403$).

As mentioned previously, a major limitation of organizational studies investigating dyadic outcomes is the lack of independent sources to measure the dependent variable. That issue is relevant because results could be artificially inflated by common-method variance (Podsakoff et al. 2003), given that my dependent variable and some of the independent variables (such as task interdependence) are constructed using data provided by the recipient in each dyad. However, this consideration is less of an issue with network variables, which are constructed using data that involve all actors in the sample. Furthermore, previous theoretical results have shown that the risk of common-method variance affecting statistical results is lower in large models that test for nonlinear effects (Siemsen et al. 2009b). Even so, I assess the possibility of significant common variance among the key variables of interest by conducting Harman's one-factor test. In essence, this test incorporates the variables of interest into a factor analysis to determine whether or not the results of the "unrotated" factor solution load onto a single factor; the underlying assumption is that, if a substantial amount of common-method variance were present, then a single factor would be identified by this test (Podsakoff et al. 2003). When I run Harman's one-factor tests for the dependent variable with the key independent variables of interest, the variables actually load onto two factors (corresponding to positive eigenvalues that are smaller than unity). This finding should further mitigate any concerns that common-method variance may be driving some of my results.

4. Discussion

Design rework, the partial (or full) correction (or completion) of a task in response to the arrival of new information, is a core phenomenon in new product development. However, such rework can occur only if the relevant stakeholders recognize the need for it. I investigate the technical and organizational characteristics of dyadic situations in which an individual realizes (as a consequence of her interactions with others) the need to carry out design rework.

This study shows that considering only technical factors (e.g., task interdependence and expertise-related factors) yields an incomplete view of the rework realization phenomenon; that is, behavioral features also matter. In particular, the relative hierarchical rank and social embeddedness of actors within a source–recipient dyad play a major role in the recipient's propensity to realize the need for rework.

I find that, in line with the NPD literature, interacting more frequently with colleagues to address product-related task interdependence increases the chances of discovering opportunities to carry out design rework (Krishnan et al. 1997, Loch and Terwiesch 1998, Terwiesch et al. 2002). The more product-related information is exchanged between the dyad members, the more the source understands the recipient's task requirements and the more capable the source becomes of helping the recipient identify tasks that require correction or completion. This insight assumes that frequent product-related communications are associated with high levels of task interdependence. If that assumption is valid, then the combination of highly interdependent actors and insufficient communication between them will likely result in missed opportunities to realize the need for rework, which can eventually lead to product quality issues (Gokpinar et al. 2010).

Although product-related communications with the source render the source more capable of helping the recipient realize the need for rework, sources are more helpful still when they have process-related expertise in areas that are nonredundant with respect to the recipient's areas of expertise. My results show that a process-related (as opposed to a product-related) expertise differential favors realizing the need for rework. This finding suggests that interacting with people who have distinct areas of process-related expertise is important for challenging current assumptions and decisions, which may be needed to identify areas of rework. Putting together the results related to H1 and H2, we see that both product-related and process-related knowledge matter for realizing the need for rework. Yet they matter in different ways: Product-related knowledge is key for triggering a realization of the need for rework if such knowledge is exchanged frequently when coordinating interdependent product development tasks; diversity of process-related knowledge contributes to realizing the need for rework by providing different lenses for viewing the technical problems that invariably arise during the development of new products and technologies.

My results indicate that—in addition to task interdependence and expertise differential—behavioral aspects (as captured by formal and informal social network patterns among developers) are important determinants of realizing the need for rework. On the formal side, by examining the relationship between the relative hierarchical ranks of interacting actors and the realization of a need for rework, my results shed light on how the formal authority and status associated with members of an organizational hierarchy affect the likelihood of realizing the need for design rework. The results reported here suggest that the power and status asymmetries of an organizational hierarchy (i.e., actors of superior rank are more powerful and possess higher status than those of subordinate rank) translate, at least partially, into the social aspects that govern recognition of the need for rework. I show, for example, that individuals of superior rank are more likely to trigger rework recognition when the recipient is of subordinate rank. This suggests that individuals of superior rank are more likely to be viewed as catalysts in the phenomenon of realizing the need for rework and are less likely to be perceived as seekers of feedback that would help them achieve such realization. I also show that individuals of subordinate rank are more likely to trigger realizing the need for rework by colleagues of subordinate than of superior rank. Given this set of results, I need to consider the possibility that flatter organizational hierarchies (even for the design of complex systems) may be better equipped to increase the chances of recognizing the need for rework.

On the informal side of social networks, my results suggest that the time and energy invested in a dyadic relationship trigger social forces that foster the propensity to recognize the need for rework. The positive association between dyadic embeddedness and realizing the need for rework provides evidence for this assertion. However, I also find evidence that this association is not linear. As the embeddedness of actors in a dyad increases, the marginal benefits of that embeddedness on realizing the need for rework declines. Given the relevance that the strength of social interactions has on the recognition of areas that require rework, then it becomes crucial for managers of technical organizations to understand more deeply the patterns of social interactions among developers in their organization.

In addition to learning about the key drivers of realizing the need for rework, we have also learned that realizing the need for rework is distinct from generating potentially creative ideas (Sosa 2011). Even though both processes depend on knowledge and social factors at the dyadic level, they exhibit subtle but significant differences. The effects of frequent interactions and knowledge diversity on rework realization differ from their effects on creative idea generation. Recipients more easily realize the need for rework when interacting more frequently about product-related matters, and such recognition for rework is even easier when interacting with a source who has distinct areas of process-related expertise. Yet a recipient is more likely to generate creative ideas when she interacts frequently with a source—about diverse technical topics—*regardless* of his area of expertise. In the social domain, dyadic embeddedness has a positive effect on both rework realization and creative idea generation. But in contrast to the case of rework realization, common contacts have a negative and significantly constraining effect on the generation of creative ideas.

One limitation of this study is related to my broad definition of "rework" as referring to both corrective and completion actions. Although both action types involve doing more work than originally anticipated, the differences between correction and completion may be significant enough to warrant future investigation. From an empirical viewpoint it should be emphasized that I measure the *recipient's* perception of her ability to realize (based on her interactions with the source) the need for design rework. That orientation does limit our insights to those deriving from the recipient's perception, which is consistent with treatments in previous social network studies of dyadic knowledge sharing (e.g., Levin and Cross 2004, Reagans and McEvily 2003). The propensity to realize the need for rework (i.e., what my dependent variable measures) is expected to be *correlated* with the effectiveness of realizing the need for rework (i.e., with the number of situations in which an actor realizes the need for rework as a proportion of the total number of situations in which the actor should have realized the need for rework). An interesting direction for future work in this area would be investigating the *extent* to which these two constructs are correlated and identifying the factors that might contribute to any significant deviation between them.

Although this paper studies the dyadic processes leading to recognition of the need for design rework, it is unlikely that all design rework is necessary. Design rework could be excessive or insufficient, and in either case the outcome is detrimental to the performance of product development. Future work along these lines would benefit from studying the knowledge and behavioral factors that lead to excessive or unnecessary rework. In addition, it is also important to understand a special type of rework—namely, when the interaction that could trigger realizing the need for rework is *omitted*. Previous work has shown that, when there is task interdependence to be addressed, a lack of technical interactions could lead to rework (Gokpinar et al. 2010, Sosa et al. 2004). The absence of technical communication not only may cause rework but also may make it less likely that the "recipient" will realize the need for rework. Hence the recipient would have to realize this need in ways that do not involve the source (e.g., by examining a prototype or the output of an experiment). It is important in such cases to investigate, empirically or experimentally, the behavioral drivers of such missed opportunities to realize the need for design rework.

This sociometric study offers empirical evidence that supports most of my hypothesized effects, but both the nature of my data and the limitations imposed by my dyadic unit of analysis suggest caution when attempting to generalize the reported findings. Clearly, external validation of the results presented here is needed—another opportunity for interesting future research.

Finally, this paper contributes to *behavioral operations*. This nascent field is defined as "the study of human behavior and cognition and their impacts on operating systems" (Gino and Pisano 2008, p. 679). However, behavioral operations extends beyond individual heuristics and biases to include social interactions in organizations (Loch and Wu 2005). New product development is an information processing effort that requires the interaction of developers to resolve uncertainties, which inevitably leads to design iterations and design rework (Dougherty 1992). It is interesting that I find realizing the need for rework to be a function of formal and informal social network factors of development actors. The individual realization required to recognize the need for design rework is a social process, which is good news for managers, because influencing social interactions in the workplace allows them to address such individual biases as anchoring, overconfidence, and confirmatory bias (Gino and Pisano 2008). In other words, recognizing the need for rework is hindered by designers who are anchored on incorrect (or no longer valid) assumptions, who are too confident about a solution's feasibility, or who listen mostly to those colleagues who do not challenge their views. Although an individual of superior hierarchical rank may be at greater risk of exhibiting some of these biases, they can be mitigated by realizing that not all colleagues with whom one interacts (even under conditions of task interdependence) are equally likely to yield the recognition of the need to rework. In particular, development agents benefit by seeking technical knowledge from colleagues who have distinct process-related areas of expertise—that is, irrespective of their rank in the organizational hierarchy. Communicating with such "distant" colleagues requires dedication and special effort, which are found in strong and cohesive ties.

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Notes

[1]I emphasize that design rework is not the same as design iteration. Although both terms refer to the correction or completion of a previously executed task, design rework is unexpected, and so its necessity must be discovered; in contrast, some amount of design iteration is expected even though its precise nature might be unknown (Clark and Fujimoto 1991, MacCormack et al. 2001).

[2]An illustration of the dyadic case in which a recipient of superior rank struggles to realize, somewhat reluctantly, the need for rework after interacting with a source of subordinate rank (*Case iv*) is the episode in which Steve Jobs recognizes the need to rework the Apple Store's original layout after receiving feedback from Ron Johnson, who had been hired to contribute to the concept's development (Isaacson 2011, p. 472).

[3]The exact wording of the survey question was: "Please indicate whether you have gone to any of the following people for either technical, knowledge, or managerial interactions during this year 2005. Note that we are interested in the people that you have gone to for important interactions that have significantly impacted your work at [the firm] in the year 2005. Do not mark those people with whom you interact casually or for trivial matters only." The definitions of "technical," "knowledge," and "managerial" interactions were introduced previously in the survey.

[4]In organizational studies whose unit of analysis is the dyad, an important empirical challenge is that interacting agents are typically the ones who can best evaluate the dependent variable of interest. For example: Reagans (2005) assesses tie strength by using data—on communication frequency and emotional closeness—that were provided by the interacting actors; Labianca et al. (1998) rely on self-reported data to study the link between interpersonal relationships and perceptions of conflict; and Levin and Cross (2004) use self-reported data on perceived receipt of useful knowledge to study the mediating role of trust in effective knowledge transfer within three distinct organizations.

[5]To test further the consistency of the two-sentence statement used to measure my dependent variable, I collected data from an independent sample of 29 European executives from various European firms enrolled in an executive education program focused on "Strategy, Leadership, and Innovation." Respondents completed a short survey concerning their interactions with *one* colleague of similar rank with whom they interacted for work-related matters in the last year. Respondents were asked to rate—on a 7-point Likert scale ranging from "strongly disagree" to "strongly agree"—their level of agreement with each of the following two independent statements: (i) "When I interact with my colleague I typically realize that I need to REWORK many of the things that I thought were already done," and (ii) "When I interact with my colleague I typically realize that I need to do more work on my tasks than I had originally anticipated." Analyzing the responses to these two questions allowed me to verify the internal consistency of the two sentences that constitute this paper's dependent variable statement. The Cronbach's alpha reliability coefficient of 0.85 was (as expected) significantly greater than 0.70, the threshold that typically qualifies a composite scale as a highly reliable indicator of the underlying theoretical construct of interest.

[6]Although likely to be correlated also with the recipient's *effectiveness* at realizing the need for rework (i.e., the number of actual realizations divided by the number of situations in which the recipient should have realized the need for rework), my dependent variable does not actually assess such effectiveness.
[7]One might consider using the notion of "expertise overlap" (Reagans and McEvily 2003, Sosa 2011) to measure overall expertise differential. However, such an approach would fail to distinguish between product-related and process-related expertise differential because the corresponding measures would be undefined for all dyads exhibiting zero expertise in either of these two areas.
[8]The survey questions concerning communication *frequency* and *closeness* yielded qualitative responses, and so I transformed them, based on the log-multiplicative association model developed by Goodman (1984), into scaled variables when calculating my network variables (for details, see Sosa 2011).

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