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Boundary emergence in inter-organizational innovation: The influence of strategizing, identification, and sensemaking

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Abstract

Purpose: Inter-organizational innovation is becoming an attractive development form in view of the complexity of many of today's innovations. However, inter-organizational innovation does not often lead to the desired results. To understand this paradoxical situation, this paper examines a high-novelty R&D collaboration between multiple organizations with focus on the occurrence of knowledge boundaries and their underlying mechanisms.

Design/methodology/approach: The analysis is based on a grounded longitudinal study of an inter-organizational R&D team. Participant observation data, interviews, and document data have been collected over three years.

Findings: The study identified six different knowledge boundaries characterized by processes of sensemaking, strategizing, and group identification. These three processes were all rooted in continuous attempts at the individual level to reduce uncertainty, and the findings therefore highlight the unexpected consequences of uncertainty reduction. Uncertainty reduction through sensemaking, strategizing, and group identification may reduce the uncertainty at the individual level but also provoke the emergence of knowledge boundaries at the team level, thereby impeding knowledge exchange. Furthermore, the knowledge integration literature highlights that knowledge boundaries are relational, but the identification of a cognitive boundary indicates that some problems are so complex that a knowledge boundary is delimited to the single individual.

Originality/value: Most research on knowledge boundaries has focused on the elimination of knowledge boundaries through boundary objects and boundary spanners, but only little attention has been given to the underlying mechanisms of boundary emergence and dynamics. In this paper, it is argued that to efficiently manage knowledge boundaries, an understanding of their underlying mechanisms is needed.

Keywords: *Knowledge boundaries, inter-organizational R&D, collaborative innovation, complexity, sensemaking, strategizing, social identity, ethnography.*

1. Introduction

In the last decades we have witnessed an increasing number of organizations collaborating in joint innovation projects (Dooley & O'Sullivan, 2007). Many have realized that their internal resources are insufficient to stay ahead of global competition and that they need to look outside the organizational boundaries for complementary knowledge. The motivation of organizations to collaborate with external partners has been extensively explored in the literature, and several different advantages for doing so have been identified: e.g., reduced time to market (Chesbrough & Appleyard, 2007); decreased costs due to the distribution of resources (ibid); access to additional knowledge (Sammorra & Biggiero, 2008); and the prospect of creating *new* knowledge through recombination of knowledge (Kogut & Zander, 1992). However, extant research has also identified a number of challenges and barriers to inter-organizational R&D collaboration (e.g., Salter, Criscuolo, & Ter Wal, 2014; Dooley & O'Sullivan, 2007), and many attempts toward collaboration have failed (Bader, 2008; Park & Ungson, 2001). The reasons for failure are multiple: there is not one but several chains of command (Mandell & Steelman, 2003); IPR issues (Rhoten & Powell, 2007); different work routines, practices, and values (Levina, 2005); different institutional logics about R&D (Bjerregaard, 2010); and asymmetries of goals and interests (Cabrera & Cabrera, 2002). Furthermore, high levels of novelty and complexity in R&D further affect the aspects mentioned above (Dougherty & Dunne, 2012). In high-novelty innovation, traditional project management techniques cannot adequately be used (Lee & Veloso, 2008), and there is often unpredictability regarding how to accomplish a task (Tatikonda & Rosenthal, 2000) because it is difficult to identify relevant variables, factors, and functional relationships, thus making it impossible to foresee and plan the process (Loch, Solt, & Bailey, 2008).

Research on inter-organizational R&D has mainly focused on identifying the challenges of collaboration and the resolution of such challenges, but it has left at the backstage the root causes of the problem (e.g., Barley, Leonardi, & Bailey, 2012; Dougherty & Dunne, 2012; Kellogg, Orlikowski & Yates, 2006; Levina & Vaast, 2005). In this paper, the challenges of knowledge exchange and recombination in an inter-organizational R&D team are studied from the perspective of knowledge boundaries (Dougherty, 1992). This provides a useful lens for understanding the underlying mechanisms of the knowledge-sharing challenges, thus bringing the root causes and mechanisms of knowledge-exchange difficulty to the frontstage. In this paper, knowledge boundaries are defined as a phenomenon that emerges when individuals of different “thought worlds” are *unable* to synthesize their knowledge (Dougherty, 1992) or *unwilling* to share their knowledge (Bouty, 2000). In order to properly understand how knowledge exchange difficulties, and thereby knowledge boundaries, can be managed, we need a better understanding of how various factors influence the practices at the team level of analysis. Therefore, this paper aims at investigating:

RQ1: How and why are knowledge boundaries produced in inter-organizational R&D work?

RQ 2: What are the underlying mechanisms of boundary production?

To answer these questions, the knowledge creation process in an inter-organizational R&D project is examined through the observation of interactions, reflections, and practices as the project unfolded over three years.

2. Knowledge Boundaries

A vast amount of research has identified challenges for knowledge exchange and combination in inter-disciplinary and inter-organizational R&D collaborations, and knowledge boundaries have been identified to be at the core of such challenges; therefore, they deserve special attention. Knowledge boundaries have been a topic of interest in organizational studies for decades (e.g., Kotlarsky, van den Hooff, & Houtman, 2015; Dougherty & Dunne, 2012; Barley et al., 2012; Hardy, Lawrance, & Grant, 2005; Levina & Vaast, 2005; Carlile, 2002/2004; Dougherty, 1992) as well as in more recent studies on innovation networks (Sandberg, Holmström, Napier, & Levén, 2015; Lundberg, 2013; Berends et al., 2011; O'Mahony & Bechky, 2008).

In the 1970s, boundary spanning was considered a matter of establishing an “adequate information processing capacity” (Galbraith, 1973) and a smooth communication across culturally different groups to create a shared syntax or language (Allen, 1977). Later studies highlighted how a common language did not automatically erase knowledge boundaries and that individuals may interpret the shared language and communication differently due to different perceptions of reality (Dougherty, 1992; Carlile, 2004). This opened up to a number of studies on knowledge boundaries that deal with 1) thought worlds and interpretive schemes, 2) willingness to share knowledge, 3) social identity and collaboration, 4) knowledge boundaries and novelty, and 5) the relationships between different knowledge boundaries. These streams of literature will be discussed in the following sections.

2.1. “Thought Worlds” and Interpretative Schemes

Dougherty (1992) was one of the first to question the information processing perspective. In her seminal paper, she introduced to management studies the concept of “thought worlds.” Thought worlds are interpretive schemes that provide “shared assumptions about reality, identify relevant issues, and help people make sense of those issues” (Dougherty, 1992:179). They arise in communities of people who are “engaged in a certain domain of activity who have a shared understanding about that activity” (Dougherty, 1992:182). Typical examples are lawyers, masons, or physicists who formally belong to a certain group, but thought worlds may also be the result of more informal groups, or communities of practice, in which interaction over time leads to shared experiences, practices, and identity (Wenger, 2000). The interpretive schemes created between members of a community of practice are mainly tacit; therefore, when individuals from different thought worlds must exchange knowledge a semantic boundary may emerge (Carlile, 2002) that impedes the synthesis of their respective knowledge and thereby hinders knowledge sharing (Mitchell, Parker, & Giles, 2011; Dougherty, 1992). In order to span the semantic boundary, the tacit knowledge representing one thought world must be made explicit to the other (Nonaka & Takeuchi, 1995). This may

be achieved through active interaction in which the different actors engage in shared activities (Nonaka & Takeuchi, 1995) or through work around so-called boundary objects, which facilitates the externalization of tacit knowledge and the construction of a shared understanding (Dougherty, 1992). The many studies of thought worlds and interpretive schemes have provided an extensive insight into why knowledge sharing can be so difficult and how knowledge can be synthesized, but there is still little knowledge about the dynamics of thought worlds, they are often depicted as a relatively static construct (e.g. O'Mahony & Bechky, 2008; Kellogg et al., 2006; Carlile, 2004), and it is still unclear what role of thought worlds have in projects that last for several years.

2.2 Willingness to Share Knowledge

Since the findings of Dougherty (1992), many subsequent studies on knowledge boundaries have sought to understand knowledge exchange conditions and how knowledge boundaries can be spanned and how an efficient collaboration can be created. For example, knowledge exchange has been found to also depend on the degree to which participants are *willing* to let go of or compromise their invested knowledge (Bourdieu & Wacquant, 1992). When individuals are unwilling to sacrifice or compromise their hard-earned knowledge, a pragmatic boundary may arise (Carlile, 2002; 2004). In collaborations between disciplines or organizations, knowledge is often at stake and people are reluctant to buy into other people's knowledge if this is at the expense of their own knowledge. Being an expert is the result of years of efforts, experiences, and reflections, and sacrificing all or some of this knowledge and expertise has negative consequences at the individual level (Carlile, 2002).

Moreover, *strategic* considerations and differing *interests* affect the degree to which people are willing to exchange knowledge, particularly in inter-organizational collaborations (Gächter, von Krogh, & Haefliger, 2010; Levina & Vaast, 2005). In a study of an inter-disciplinary R&D team, Bouty (2000) found that scientists enacted two exchange strategies: "profitable exchange" and "equitable exchange," indicating that exchange is either purely based on bartering or altruism and sharing without expectations to get something in return. However, her study showed that even when an exchange is made "free of charge," it is still based on an initial strategic calculation. In contrast to this, Gächter and colleagues (2010) found that, in some cases, there are team members to whom fairness is an important quality, and they seem to be more willing to go beyond purely selfish behavior (Gächter et al., 2010). These discrepancies indicate that there is still a limited understanding of what causes an individual to share knowledge.

2.3 Social Identity and Collaboration

Another stream of research suggests that knowledge boundaries are related to *social identity* (Kotlarsky et al., 2015; Kellogg et al., 2006; Dhanaraj & Parkhe, 2006). Collective identities arise as people "collectively engage in discursive practices that produce and reproduce it over time" (Hardy et al., 2005:62). In-group identification provides a sense of belonging, meaning, and enhanced self-esteem to its members, and in this sense, a strong collective identity can facilitate collaboration and knowledge exchange (Tajfel & Turner, 1986; Stets & Burke,

2000). A study also shows that individuals who feel self-conceptual uncertainty are inclined to join groups they identify with, as this can help them reduce the uncertainties related to their conceptual-self (Hogg et al., 2006). Although a link was not made to innovation contexts, it can be argued that in a situation where an expert's knowledge is put to a serious test, doubts and uncertainty about this expertise, and thereby of one's identity, may arise.

However, in-group identification can also lead to tensions as a result of competitive behavior toward other groups and a lack of trust (Harrison & Klein, 2007) as well as perceived status inequality (Liao et al., 2012), suggesting that knowledge boundaries can emerge between groups due to a divide between different collective identities. There is still limited research on the effects of social identity on the emergence of knowledge boundaries, but the abovementioned studies seem to indicate that the topic merits further investigation.

2.4 Knowledge Boundaries and Novelty

With a few exceptions (Dougherty & Dunne, 2012; Carlile, 2004), studies on knowledge boundaries have not explicitly taken into consideration the role of novelty. Nevertheless, assuming that novelty increases the levels of uncertainty, ambiguity, and complexity, and presumably complicates knowledge exchange, it is important to understand the relation between novelty and knowledge boundaries in innovation projects.

Inter-organizational R&D work has typically been established because advanced and novel knowledge is needed to solve the problem in question (Ravasi & Turati, 2005; Van de Ven & Polley, 1992), but at the same time, novelty also constitutes a major challenge to innovation work. Novelty can cause a number of challenges to knowledge elaboration. In inter-organizational R&D projects, there are at least two types of novelty: Novelty related to the technologies and technical knowledge concerned, and novelty related to the "new" organizational context (working in loosely coupled teams with multiple organizations and interacting with people from different disciplines). These two types of novelty lead to several novelty-related challenges; for example, high levels of technological or technical novelty can lead to perceived uncertainty about the process and goals (Loch et al., 2008). In high-novelty innovation projects, it is difficult to identify relevant variables and influence factors, and this in turn makes it difficult to plan ahead in the innovation process, e.g., how long an activity will take or what activities lie ahead (Dougherty & Dunne, 2012; Loch et al., 2008; Tatikonda & Rosenthal, 2000). High-novelty inter-organizational R&D projects also pose organizational challenges. Complex innovation tasks are inherently nonlinear and can therefore not follow the normal linear process models (Dougherty & Dunne, 2012), and because the causal relationships between the various concepts are unclear or even unknown, then standard project management techniques are not always applicable (Kotlarsky et al., 2015). Furthermore, with participants from different thought worlds, high novelty is likely to increase semantic discrepancies among them due to the challenges of ambiguity (Carlile, 2004). Considering that innovation projects, let alone inter-organizational innovation projects, are infused with novelty and ambiguity, this aspect deserves more attention in relation to the knowledge exchange and boundaries in such settings.

2.5 The Relationship between Different Knowledge Boundaries

Previous literature has identified different types of knowledge boundaries: e.g. syntactic, semantic and pragmatic (Allen, 1977; Dougherty, 1992; Carlile, 2004), and more recently boundaries have been related to high novelty contexts: defining product concepts, procedures for creating the project, and projecting forward (Dougherty & Dunne, 2012). These studies have analyzed how such boundaries are spanned through different methods and practices.

In his study of an inter-departmental NPD project, Carlile (2004) investigated how different knowledge boundaries arose in a team of employees from different domains (marketing, design, and engineering). He found that there were syntactic, semantic, as well as pragmatic boundaries in the setting, and he showed how increased novelty leads to increasingly complex boundaries that are increasingly difficult to manage. Carlile thereby implied that a hierarchy exists among knowledge boundaries in which the pragmatic boundary is associated with high levels of novelty, and the syntactic boundary is associated to low levels of novelty (ibid). When the level of novelty increases, one knowledge boundary is replaced by another, and it is therefore suggested that boundary emergence and spanning occur in a linear way and that only one type of knowledge boundary exists at one time. Dougherty and Dunne (2012) identified three new boundary types, and although the scope of the study was not to understand the inter-relationships between these boundaries, it appeared that three types of knowledge boundaries, including defining product concepts, the procedure for creating the project, and projecting forward, co-existed in the setting. It is still unclear how and if one type of knowledge boundary affects another.

Summing up, there are a number of factors and challenges that can hamper efficient knowledge exchange and that produce knowledge boundaries in complex inter-organizational R&D settings. First, the difficulties synchronizing knowledge cause misunderstandings or difficulties of knowledge exchange. Second, the unwillingness to sacrifice invested knowledge may lead to strategic behavior and a bartering mentality that makes knowledge exchange highly random and calculated. Third, group formations based on a collective identity may cause tensions and a lack of trust between groups, which in turn challenge knowledge exchange. Finally, high levels of novelty seem to affect the feasibility of properly planning and organizing the innovation process, thereby potentially increasing the gaps of differences that exist between team members. These hints from the literature on knowledge exchange provide some information into the nature of knowledge boundaries, but insights into the underlying mechanisms leading to their emergence, as well as their inter-relationships, are not yet fully understood.

3. Research Context and Methods

The explorative nature of the research question and objective of this study call for the use of an interpretive, qualitative research methodology. An inductive, ethnographic study of the practices of knowledge exchange and production in inter-organizational R&D settings was therefore conducted. Calls have been made to study knowledge exchange through richer qualitative and practice-based data, to observe and analyze knowledge exchange situations in

action, and to directly study practices, routines, and interactions in the setting, as this provides a solid basis for understanding dynamic processes, emergence, and change (Kotlarsky et al., 2015; Lundberg, 2013; Wenger, 2000).

3.1 Research Context

The case studied in this paper concerns a Danish research consortium (EuroSat) that was established to build up new knowledge on Pervasive Positioning Technology (PPT). Its objective was the development of applied software and hardware solutions within the area of indoor PPT, and in order to develop mature product ideas, the consortium had to first carry out basic research in the domain.

The consortium had defined three different cases, the knowledge of which should provide inputs into different aspects of the PPT technology. One case was about tracking the movements and behaviors of cows, thus enabling farmers to determine changes in their health. In very large stables, detecting altered behaviors among 5000+ cows is a complicated affair, and the PPT technology has great promises for this activity. The second case had to develop solutions to help smoke divers (firefighters). The PPT technology can enable the precise tracking of smoke divers in combination with the precise maps of a building. The third case had to find ways to guide patients in mega-hospitals in their transit from one hospital unit to another (e.g., from radiology to blood test). Patients often get lost on their way, thereby creating delays in the tight schedules. The PPT technology can help create greater efficiency in patient transits. All three cases were based on the premise that indoor positioning is possible. However, at the start of project, this was not the case, and the challenge of the project team was to figure out how satellite signals can enable indoor positioning. There were many challenges working against the team; for example, satellite signals and other types of electronic signals cannot penetrate certain types of building materials. Therefore, the work of the team required both basic research and experimentation, and the project was surrounded by uncertainty from multiple points of view from the beginning to the end.

The consortium consisted of an applied research institute/consulting firm (Organization 2), two software firms (Organization 3 and 4), and a university (Organization 1). For three years, selected software developers, engineers, and computer science researchers worked together to create a “toolbox” consisting of different tools to create hardware and software products for indoor PPT.

Table 1. Sample characteristics

Role in project	Background	Organization
Research manager, supervisor for the PhD students	PhD in Computer Science, Professor	Organization 1
Project manager	Civil engineer	Organization 2
Post.Doc, researcher	PhD computer science, bac. philosophy	Organization 1

Post.Doc, researcher	PhD in computer science,	Organization 1
Post.Doc, researcher, developer (entered after 1 year)	PhD in computer science	Organization 1
Industrial PhD student, researcher	Master in computer science	Organization 3
Industrial PhD student, researcher	Master in computer science	Organization 2
Industrial PhD student, researcher	Civil engineer	Organization 4
Project coordinator, software developer	Master in computer science	Organization 2
Software developer	Software engineer	Organization 2
Software developer	Bachelor in computer science	Organization 1
Deputy PM (left project after 1 year)	PhD in computer science	Organization 2
Undefined (left the project after 1 year)	Civil engineer	Organization 2
Post.doc. (joined the project after 1,5 years)	PhD in computer science	Organization 1

The core research team consisted of representatives of the four participating organizations, and throughout the project, there were between 9 and 14 project members (see Table 1). The team members did not know each other beforehand or only knew each other limitedly, thus making it a new organizational setting with a new group of colleagues. The team members were co-located at the same location more than fifty percent of the time.

According to the founding documents of the consortium, project charters, contracts, and the funding application, the project had no formal management structures, predefined project management process tools, milestones, or specific deliverables. The only indications of management directions were scheduled biannual reports to the steering committee (which did not include any specific measurements or requirements); the nomination of a research manager who oversaw the research work of the project (but who had no formal authority); and a conceptual model indicating that the project had to deliver both basic (academic) research and applied research. How this was to be achieved in practice was not specified anywhere or by anyone. This meant that it was up to the team to determine how to organize, collaborate, and define and measure their deliverables. Therefore, the project can be defined as a high-novelty project from both a technological and organizational point of view.

3.2 Research Method

The research approach focused on the everyday practices of the core team. Parting from a grounded theory approach, it was imperative to pay attention to the contrast between “the daily realities (what is actually going on) of substantive areas” (Glaser & Strauss, 1967:239) and “the interpretations of those daily realities made by those who participate in them (the ‘actors’)” (Suddaby, 2006:633). Therefore, the research was not only based on interviews (people’s interpretations) but also on other data that might provide insight into “what is actually going on.” Data were collected through a longitudinal field study involving non-participant observation and interviews, as well as access to a project wiki, repository, emails,

academic work, reports, and project presentations from April 2008 through January 2011. Fifty-seven project observations (144 hours in total) and thirty-seven semi-structured interviews with R&D project members were conducted and transcribed verbatim throughout the period. Participants were informed that the author was interested in the work practices of R&D professionals collaborating in an inter-organizational setting and in how the innovations emerged through this collaboration.

Observations focused on formal weekly meetings and more spontaneous ones, as well as various test runs of prototypes/demos, workshops, and social events. In addition to ongoing observations, the author conducted formal interviews with all the project participants. When team members started to work on the prototypes and develop their individual research interests, the field researcher was present at all the weekly meetings, tests of the prototypes/demos, workshops, and social events. Upon completion of this phase in January 2009, she conducted another round of interviews with all the participants, complemented by observations of team meetings, workshops, and social events. In the autumn/winter of 2009/2010, another round of interviews with relevant actors was conducted, and this was repeated by another round in the autumn/winter of 2010/2011. Furthermore, the project wiki and software repository were observed in order to register the progress of the development.

The data analysis was carried out through five cycles of coding according to the theoretical sampling principles of the grounded theory method (Strauss & Corbin, 1998:202), thus allowing the researcher to explore emergent themes, collect additional data, and maximize observation opportunities (Glaser, 1978).

In the first cycle, the author carried out open coding to analyzing the data and extract thematic categories and their characteristics. The author coded for instances in which there were challenges of knowledge exchange between the team members. The codes were, for example, misunderstandings, stereotyping, absence at team meetings, conflicts, disagreements, differing work practices, different (contrasting) goals, reluctance to act on other's suggestions, and exclusion of team members. At this point, the author developed memos theorizing a write-up of ideas about the codes and their relationships (Glaser, 1978). Based on the codes and memos, the author went back to the extant literature to search for theoretical explanations for these challenges (theoretical coding). The concept of knowledge boundaries appeared to be useful, in that the challenges were largely related to similar or different "thought worlds" (Dougherty, 1992). Based on Dougherty's (1992) overall description of knowledge boundaries, Carlile's (2004) categorization of different types of knowledge boundaries, and Bouty's (2000) notion of willingness to share knowledge, the author went back to the field to test the fit between Carlile's categorizations and characteristics of the identified knowledge exchange challenges. In the second cycle of coding, the data were coded against the features of syntactic, semantic, and pragmatic boundaries (Carlile 2004). Some of the challenges were similar to Carlile's "semantic" and "pragmatic" boundaries, leading to theoretical saturation. These knowledge boundaries were labeled: the "semantic," "organizational," and "interest" boundaries.

However, not all of the observed challenges could be explained by Carlile's boundary categories. For example, in some instances knowledge could not be exchanged simply because the individual team members failed to make sense of their work and the purpose of the project. In other instances, the semantic and syntactic boundaries could not explain the lack of interaction. Prejudice against other team members made certain team members reluctant to interact and include others. The author therefore examined the extant literature to find theoretical explanations for these two phenomena and found that theories of complexity and uncertainty (Lee & Veloso, 2008; Tatikonda & Rosenthal, 2000) and theories of status (e.g., Contu & Wilmott, 2003; Levina & Orlikowski, 2009) and communities of practice (Wenger, 2000) were useful synthesizing devices for the analysis. Next, the author went back to perform the selective coding (Glaser, 1978) of these concepts. Already collected data were re-coded according to these theoretical concepts, and new data (interviews and observations) were collected to test the coherency with the concepts. From this third cycle of coding, the identification of the "cognitive," "professional identity," and "in-group/out-group" boundaries emerged, thus leading to theoretical saturation regarding the first part of the research question.

Next, the author set out to examine the underlying mechanisms of the identified boundaries. Based on the previous codes and comparisons with extant literature, the author coded the "cognitive" and "semantic boundaries" within a sensemaking framework (Weick 1979); the "interest" and "organizational" boundaries within a framing of strategic intent (Mantere & Sillince, 2007) and strategizing (Whittington, 1996); and, finally, the "professional identity" and "in-group/out-group" boundaries within a framing of social identity (Tajfel & Turner, 1986). Finally, these framings were tested through a re-examination of existing data, and the theoretical collection of new data theoretical saturation was reached regarding the underlying mechanisms of knowledge boundaries. With an emergent pattern of the underlying mechanisms for boundary emergence, the author initiated a final round of coding of all the existing data. From the findings regarding sensemaking, strategizing, and group identification, the author could see they appeared to have one common denominator: they all evolved around a constant attempt at the individual level to reduce uncertainty. Thus, the last round of coding sought to test this.

4. Findings

From an analysis of fieldnotes, interviews, and project documentation, a number of specific and distinguished time phases were identified. A particular time phase was characterized by a set of activities and practices that were specific to that time period. The time phases, illustrated in Table 2 below, emerged from the data and were not phases formally defined by the team.

Table 2. Project phases

Phase	Duration	Characteristics
Phase 1	4 months	The team discusses the meaning of important terms, the architectural features, and organizing structures.
Phase 2	4 months	The team begins to work on a state-of-the-art prototype, to test possibilities using existing positioning technologies. Intense code work for prototypes. Informal study groups are established Towards the end of phase 2 the first prototype is ready. A second prototype is initiated, that integrates the research results so far obtained. The researchers begin to consider topics for publication and experimentation is needed.
Phase 3	9 months	Work in sub-groups of interest (emerge informally in phase 2, but in phase 3 they become formalized and inactive individuals are assigned to sub-groups. Researchers are active writing academic publications. Only little prototype work.
Phase 4	6 months	Focus shifts from publications and basic research to work on prototypes. Objectives are more defined - the team must show results. Halfway into phase 4 they realize that much of their work is not integrated in the toolbox. Towards the end the team went on a workshop to get an overview of the status and to plan the the activities for the remaining time.
Phase 5	11 months	Integration of the research results into the toolbox/platform.
Phase 6	4 months	Project wrap up. Finishing the last tasks and getting the last pieces into place

Throughout the phases, six distinct types of knowledge boundaries were identified, which to some extent hindered collaboration and knowledge exchange.

The boundaries are labeled in the following way: cognitive boundary, semantic boundary, interest boundary, organizational boundary, professional identity boundary, and in-group/out-group boundary. They are labeled as knowledge boundaries because they all represent incidents in which knowledge exchange and knowledge sharing were significantly challenged and hindered.

4.1 Cognitive Boundary

All through the project there was uncertainty related to what the team members should do and how they should get there. This made it difficult for individual project members to engage in constructive interactions with their colleagues. They simply felt that they could not ask the right questions, as they did not know what they needed and what the other team members could provide to them or vice versa. The cognitive knowledge boundary represents a limitation of the individual to externalize and internalize certain ideas and knowledge. The cognitive boundary emerged when an individual was incapable of relating other team members' scientific work and knowledge to their own research and knowledge. The cognitive boundary occurred when there was a disruption at the individual level of knowing.

Initially, the team members had a very explorative approach to their work, but they had difficulty making sense (Weick, 1979) of their own knowledge and determining where to start. As an example, three months into the project, one team member expressed:

“But when you don’t know what you are looking for, it can be really difficult to figure out how to attack the problem. Because then you make some assumptions of how to do it – and then you may actually get it wrong.” (Interview)

The team members had difficulties making their tacit knowledge explicit to other team members (Nonaka & Takeuchi, 1995), and this in turn made communication and interaction more difficult. They were conscious of this difficulty, and their inability to make sense of their knowledge also made it difficult to ask for advice. As one team member said:

“When you have a hard time understanding what the hell you are doing, it is difficult, if not impossible, to ask others for input or advice.” (Interview)

Eventually, this affected the interaction in the team, especially in tasks of high uncertainty and ambiguity, thus leading to low levels of collaboration. The cognitive boundary existed throughout the project, but its presence decreased as the project progressed and the single individuals got a clearer idea of their research topics and their connection to the general project themes.

One team member explained in an interview that they had come to a point in which a lot of models had been formalized and that the implementation now worked. This allowed the project to progress more steadily and made the team members more confident.

The cognitive boundary appeared to be rooted in a process of sensemaking (Weick, 1979).

When entering an inter-organizational R&D project, individuals experience a change of environment, an *ecological change*, which, due to a high degree of uncertainty, triggers an act of sensemaking in which he/she tries to attribute meaning to what is going on (Van de Ven & Polley, 1992; Weick, 1979). This is an interpretation process that has the purpose of enabling the individual to make sense of the environment and to act in it (Ravasi & Turati, 2005). However, in some cases the person fails to make sense of the situation and is therefore unable to act. This inability to act produces the cognitive boundary between an individual and his/her team.

4.2 Semantic Boundary

If an individual succeeds in making sense of the situation and spans the cognitive boundary, and thereby enacts the interpretations and the meaning created, this interpretation may turn out not to correspond to that of another individual (Dougherty, 1992), and misunderstandings arise to cause the emergence of the semantic boundary (Carlile, 2004).

There were several instances of different interpretations among the team members regarding the meaning attributed to the research topics. Semantic boundaries between team members meant that discussions, knowledge exchange, and eventually sensemaking were difficult as team members applied different meanings into the same concepts. The emergence of

disagreements and misunderstandings led to long and inconclusive discussions and a sense of a lack of progression.

A reason for the emergence of the semantic boundary was that the levels of knowledge, as well as the interpretations of this knowledge, regularly changed. It changed because what in one moment was thought to be “true” was found not to be true in the next moment due to new research findings. The shared knowledge built up in the past no longer represented the knowledge now present in the team (Carlile & Rebentisch, 2003). The team was working on knowledge in the making, and only a very limited amount of their preexisting knowledge was useful or applicable. This meant that there was a constant high degree of novelty and that this had a negative effect on the path-dependent nature of knowledge (Hargadon & Sutton, 1997). Therefore, definitions and agreed-upon meanings were highly unstable and the synthesization of knowledge was hampered (Dougherty, 1992). For example, one team member had to integrate into his own code some code that another team member developed, and there were different interpretations of which format this code should be in and what that format meant. He was annoyed with the repeated adjustments of codes of the other team member:

“I ended up spending more resources fitting it (code) into that (OSGI) format. You see, here you see the requirements to what it should end up like ... how it should be shaped changes basically every time they figure out something new, right! So we constantly code up against a goal that changes.” (Interview)

Eventually the team recognized the existence of misunderstandings (semantic boundaries), and they started to map and discuss their different interpretations in order to synthesize their knowledge. For example, at a group meeting, the team was working on a new document concerning the success criteria of the project, and even if this happened more than one year into the project, the team members still felt that the different concepts were quite vague and that they should have a consistent use of terminology. They came to a common agreement concerning the meaning of the project objectives and general research themes that needed attention, but as they progressed, they realized that they did not have the same interpretations of the specific concepts and processes. Several team members expressed a need for clarification about the meaning of the words used down to the very micro level because there were often misunderstandings in even the smallest discussions.

Nonetheless, spanning a semantic boundary once did not mean that semantic boundaries were eliminated for good in the project. They reappeared whenever new topics or terminology were introduced. In fact, the semantic boundary was never definitely spanned. Rather, due to the evolution of the knowledge in the project, new interpretations continuously emerged.

For the semantic boundary, the sensemaking process was collective: team members engaged in creating a shared understanding (Nonaka & Takeuchi, 1995; Stigliani & Ravasi, 2012); whereas, for the cognitive boundary, the sensemaking process was a cognitive process at the individual level (Weick, 1979). The two processes were inter-related, as one affected the other. An individual may come to an understanding of one concept through collective sensemaking and still be in the process of understanding (and failing) in another concept. This can be explained by the fact that individuals were engaged in numerous different activities but

that the connection between tasks was not always clear.

4.3 Organizational Boundary

There were numerous incidents where team members retained useful knowledge or resources from each other or otherwise obstructed collaboration. As outlined in a number of studies on inter-organizational R&D collaborations, many of these incidents were linked to issues of IPR. Especially in the beginning, when trust had not been fully established, team members were preoccupied with the distribution of IPs. Some of the firm representatives openly expressed that they did not trust the university and that they worried the university would try to claim IPs developed in the firms. Furthermore, two of the participating firms were also competitors, and this resulted in some constraints not to disclose all information in the team. For example, at a team meeting, one firm team member gave an update of his work status and finished his presentation by saying: “This is what I have been working on ... but I am not allowed to give you the code, so I will explain it like this...” In another case, a team member was instructed by his firm to only disclose part of the code, and this created some problems for another team member who had to build his work on this code:

“In connection with the tracker prototype, the idea was that the DR-module should be a part of the prototype. A lot of code had been written in Peter’s firm, but when it got here, there was something that didn’t quite work, but we couldn’t get access to the underlying code, which meant we couldn’t fix it.”
(Interview)

A third way to hinder knowledge sharing was simply to be silent or absent. For example, one of the firms had ignored its contractual obligation to allocate internal resources to the project, and instead of including 2-3 employees, only one employee participated, causing other team members to express annoyance with the firm, and even more so when this one person was perceived to not actively participate in the teamwork.

However, not all instances of knowledge retention were linked to IPRs. In certain cases, the lack of will to share knowledge was related to the different interests of the team members. Sharing knowledge is time consuming, and some team members did not want to waste time on sharing knowledge if it did not fit their own interests. For example, a university member often had the theoretical knowledge needed to complete a functional prototype, but since it was not the primary interest of the university to build refined prototypes, the academic team members did not want to engage in work related to the refinement of prototypes:

“Well, the explanation is that we have another point of departure – it is essentially about whether you predominantly write code or do research. Maybe we didn’t have the same objectives with the platform....” (Interview with university researcher)

This team member chose at times not to participate in prototype building.

The consequence of the organizational boundary was a lack of information sharing of the firms and lack of prototype dedication of the academic researchers. Unlike the semantic

boundary, the organizational boundary decreased as the project progressed. Due to the biannual obligation to deliver a detailed status report and deliverables (e.g., prototypes) to the steering committee, they were forced to interact and produce regardless of whether they wanted it or not. In the weeks leading up to this deadline, the team members worked intensely together on their deliverables. As team members interacted and socialized more intensely, they slowly built up communities of practice (Wenger, 2000), and through these shared practices, organizational interests were either integrated or compromises were made.

4.4 Interest Boundary

Organizational interests were not the only ones to hinder interaction and knowledge sharing. Single team members also showed strong manifestations of individual interests and objectives with the project. The interest boundary differs from the organizational boundary in that it is related to an individual's personal interests and *not* to that of the organization he/she worked for. The interest boundary emerged when there was a conflict of interest between an individual and another individual or group.

The team members were aware of the conflicting interests between personal interests and project objectives, and they rationalized on how to fit their interests into the project objectives. This rationalization did not always succeed:

"There are of course also some differences in interest between what one would like to work on personally and what one thinks is most beneficial to the platform, right. That is, sometimes one has some interests which are not necessarily what one values is the best for the project, right!"
(Interview with team member of a firm)

As a consequence of this way of thinking, there were numerous examples of individuals deliberately making choices that did not follow the objectives of the project.

As a result, team members calculated whether participating in an activity was worth the effort. Their behavior reflected a mindset based on bartering in which no resources or knowledge were provided if nothing was given in return or if it did not provide any benefits to the person (Bouty, 2000); for example:

"To me, it is more important to get one more publication on my list than developing a super cool software platform (...) from a purely egoistic point of view, there are more points in it for me if I start working towards the next publication rather than working further on my software to make it fit in." (Interview with a team member of the university)

The interest boundary was rooted in a preoccupation of the young team members for their future career prospects. Should they work in academia or in industry? In the case of conflicting decisions, they would act based on what was strategically most advantageous. As one of the team members from the university expressed:

"I sense that Roger is much more strategic now in relation to his firm. We talk a lot about how we can position ourselves strategically." (Interview)

One consequence of the interest boundary was withdrawal from team activities. There were several examples that if a particular task did not fit with a team member's personal interests or skills, then he/she was not willing to get involved. For example, one team member from the consulting firm explained that he found it frustrating to write a paper because he did not have the skills or interest to do so.

The interest boundary was in some instances spanned, in other instances not. It was particularly strong in the periods between the steering committee deadlines and then decreased in the time right up to the deadlines. This was due to a general acceptance among team members that prototypes must be delivered to the steering committee, whether these activities coincided with their individual interests or not.

The dynamics behind the interest boundaries can be explained through Bourdieu and Wacquant's idea that knowledge is invested and is therefore "at stake" in a knowledge exchange situation (Bourdieu & Wacquant, 1992). Learning and accumulating knowledge is hard work and the result of years of learning effort and experience, and much time is invested in the activity; therefore, people are often reluctant to acquire new knowledge that makes their existing knowledge obsolete (Carlile, 2004). The interest boundary reflects this and is similar to Carlile's "pragmatic boundary" (Carlile, 2004). This acquired knowledge was reflected in the interests of the individuals in the setting. Further translating this discussion into a practice perspective, we may find explanations from the concepts of *strategic intent* (Mantere & Sillince, 2007) and *strategizing* (Whittington, 1996), insofar that individuals in organizations make strategic choices that affect the strategy of the organization and that the strategic intent of individuals is partially formed by coherent interests and by divergent interests (Mantere & Sillince, 2007). The team members had strategic intent that was sometimes coherent with the objectives of the project, sometimes not. Having a strategy for action reduces uncertainty by providing a purpose and intent (Nonaka & Takeuchi, 1994), which in turn enables and motivates an individual to act. When an individual has a very determined strategic behavior, his/her actions may obstruct the possibilities and actions of others, thereby hindering knowledge exchange and knowledge sharing. A consequence of this is the lack of trust that leads to isolation.

In this paper, a distinction is made between organizational boundaries and interest boundaries because there were many instances in which an individual's interests were actually in opposition to the interests of the organization the person worked for. By understanding the process of strategizing as both an individual preference and an organization-specific preference, we get a broader understanding of why individuals in inter-organizational settings sometimes behave in ways that are not related to organization-specific goals.

4.5 Professional Identity Boundary

At the beginning of the project, team members labeled themselves and each other according to their educational background, their approach to research, or their role in the project, and these labels did not always correspond with their organizational affiliation. For example, some industrial PhDs categorized themselves as scientists based on their perception of themselves. Categorizing oneself and others to a particular group caused prejudice among

project members and consequently affected knowledge exchange (Kellogg et al., 2006). One example was the demarcation between scientists and developers. The scientists perceived a difference in work ethics and expressed that developers were not passionate about their job. For example, one scientist said:

“As a researcher, there is nobody else who does it for you! Whereas, those who are just developers; well, they kind of sit and wait for someone to get them started. They don’t have their own project in quite the same way. And it is quite clear that in a project like this the efficiency lies with those who have their own project and are passionate about it – that is clear!” (Interview, scientist)

Scientists found it mundane to worry about software quality. To them, developing code was a practical and necessary task, but not an important or complicated task, nor was it interesting or challenging. Their many comments about developers indicated that a hierarchy existed between the two groups.

Developers complained that the scientists considered themselves to be too important to do programming and that they deliberately tried to avoid the coding tasks. Both scientists and developers perceived such tasks as “practical,” and there was no prestige related to them.

The categorization of members expanded to other spheres of the interaction and was produced and reproduced (Hardy et al., 2005). When developers came up with propositions in meetings and daily activities, they were often ignored by the scientists, and the developers felt that because they were not a part of the science-community, their suggestions did not have the same impact as their scientist colleagues. During a weekly meeting, the team discussed which location they should choose for carrying out a test. This was important, as it was the first working prototype to be submitted to the steering committee. Peter, a developer, suggested that instead of doing the test in a nearby mall, they could use a hardware store because it had both indoor and outdoor facilities. None of the scientists supported his idea and immediately began to pack their things to leave, after which the meeting was adjourned, and no conclusions regarding the test site suggestion were reached.

The professional identity boundary gave rise to a specific distribution of roles and tasks. Early on, scientists were in charge of project management and coordination, whereas developers had more practical administrative roles. This distribution of roles was observable in almost all the weekly meetings. For example, during a weekly meeting, Martin, a scientist, said: “Okay, let’s move on to ‘publications’ (a point on the agenda).” Martin reported the various publication initiatives in progress. George, a scientist, added his comments and suggested certain changes in the focus of some articles. Martin then turned to Jack, a developer, and said: “Jack, will you take notes?” Jack nodded.

The professional identity boundary had several interconnected consequences. The scientists sometimes felt that the developers obstructed a fluid academic discussion by being too practical:

“Take a person like Roger (a developer), who is like very ‘engineerish’: his requirement inputs are of such a low practical level that they sometimes block our free academic discussions. Of course this also helps us keep our feet on the ground ... but it is clear that there are some cultural differences.” (Interview, scientist)

Soon the scientists began to hold meetings without inviting the developers, and the developers felt excluded from the circle of scientists:

“There is clearly the impression that you are visiting when you go talk to them (the scientists) – I mean – you always get an answer to your questions, but you don’t necessarily get invited to their next brainstorm anymore.” (Interview developer)

When individuals identify with a group, they evaluate the members of that group more favorably and positively than members of other groups, thereby leading to prejudice toward other groups, but it also provides the basis for self-esteem and uncertainty reduction (Mullin & Hogg, 1999). The professional identity boundaries in this case represent examples of professional prejudice, and it led to a lack of trust, to conflicts, and eventually to the exclusion of some individuals from knowledge exchanges (Harrison & Klein, 2007). Moreover, when more groups exist within in a team, one group will often be more powerful than the others, and this power acts as a barrier to peripheral group members (Levina & Orlikowski, 2009; Contu & Willmott, 2003).

The professional identity boundary was strongly felt by the developers and strongly expressed by the scientists, but halfway into the project, the professional identity boundary diminished: the developers slowly earned the professional respect of the scientists. There are two explanations for this: first, the developers had insisted on taking part in the research tasks. The developers were active members of a number of study groups and sub-teams that formed in the project. In these sub-teams, there was intense interaction, and over time, the prejudice seemed to be substituted by traits of communities of practice (Wenger, 2000). Second, the developers were active in the integration of the different clusters of codes that had been developed in the project. In the second half of the project, the steering committee became more demanding in terms of deliverables, and, therefore, prototypes formally gained more importance than scientific experiments and journal articles, thus indicating a shift in power from one profession to another (Contu & Willmott, 2003). One developer in particular made a noticeable effort to take care of the project management and coordination activities that no one else cared to take, and through his effort to integrate and coordinate, he gradually gained respect among the scientists, who expressed their appreciation in interviews and even in weekly meetings.

4.6 In-group/Out-group Boundary

The professional identity boundary was closely linked to another type of boundary, namely the in-group/out group boundary, in the sense that the latter seemed to substitute the first.

About eight months into the project, a number of study groups and sub-teams were formed to look into specific research themes. The “membership” in the groups was purely based on interest of the individual member, and they soon became closely knit communities of practice (Wenger, 2000). These sub-groups consisted of a mix of scientists and developers and were therefore not a representation of professional identity. The in-group/out-group boundary is the boundary that exists between a sub-group and the rest of the team. It emerged when a sub-group was not sharing knowledge with team members outside their own group and when team members outside the sub-group were indifferent to the details of their work. Sub-groups

evaluated whether it was relevant to share their knowledge with the other team members or not. At a certain point, there were four sub-teams in the project, and team members did not generally know what was going on in the other sub-groups, other than just the overall details.

“For instance, I don’t know what Jack’s next step is. What he is juggling with ... or Paul for that matter. Well, I do know peripherally that he is writing articles with some other colleagues right now and that they are working on something, but I don’t need to know exactly what he is doing! But then again, if something relevant comes, it would be nice to have a peripheral knowledge about it.” (Interview)

In some situations, team members outside the sub-groups felt excluded from knowledge, and the first consequence of the in-group/out-group boundary was a lack of syntactic understanding concerning certain aspects of the project (Carlile, 2004):

“Well, at times I kind of go: ‘Ah, that’s what they are working on!’ because sometimes there are things I didn’t really get – either because I didn’t understand what they said at a meeting or because sometimes things happen that I don’t really know (...) it would just be nice to have an idea of what is going on (...) it is nice enough to be informed once in a while.” (Interview)

While the division into sub-groups was meant as a way for fewer people to work more intensely on a specific topic, it also caused the exclusion of others. One team member described one of the sub-groups as a closed group.

This exclusion was not just an exclusion from the knowledge generated in the sub-groups, but it also represented an exclusion from decision making, as an increasing number of decisions were made in the sub-groups rather than at weekly team meetings.

The in-group/out-group boundaries were consistent throughout the project, but they were also spanned, and work elements from the sub-groups were gradually moved to the platform or toolbox.

The sub-groups formed new communities of practice (Wenger, 2000), and the formation of sub-groups provides an example of how peripheral members can move to the core group, or form a new core group, through more intense interactions (e.g., small group discussions, group search, meetings, etc.) (Probst & Borzillo, 2008). Once the peripheral members took part in more intense discussions, they became legitimate members of a group (Brown & Duguid, 1991), and the professional identity boundaries were broken down to be substituted by a sub-group boundary.

The effects of group formations on knowledge exchange are therefore ambiguous. On one side, they exclude out-group members from access to knowledge, but on the other side, strong group formations may also enhance intense knowledge exchange and creation within the in-group, as in this project where sub-groups were highly efficient in the production of prototypes and research publications.

The six knowledge boundaries emerged and reemerged throughout the project, but the impact of each boundary type on the knowledge production varied. Some boundaries were more salient at the initial stages of the project (e.g., the semantic boundary and organizational boundary) while others occurred more frequently toward the end (e.g., the interest boundary

and in-group/out-group boundary). Some were less noticeable in topical moments such as the time leading up to a publication deadline or a steering committee meeting. Common for all was that they were never completely eliminated. Some were spanned but re-emerged or were re-produced later in the project. The study also shows that multiple knowledge boundaries existed simultaneously, then disappeared, and sometimes re-emerged at various paces.

Table 3 provides an overview of the six knowledge boundaries, their nature, their consequences, and the actors implicated in the production of the boundary.

Table 3. Knowledge boundaries

Boundary	Description	Consequence	Actors	Example
Cognitive	Emerged when an individual was unable or unwilling to see the relevance of others' scientific work and knowledge to their own	Difficulties getting started Difficulties interacting	From one individual to other team members	<i>"When you have a hard time understanding what the hell you are doing, it is difficult, if not impossible, to ask others for input or advice."</i>
Semantic	Emerged when individuals interpreted something differently because they drew on different domains of expertise.	Misunderstandings Disagreement. Two different paces of knowledge development	One individual vs. another individual	<i>"Position Quality: there we started at the first meeting by clarifying: what is the quality of a position? but this quickly turned into something very loose and undefined. So in the end we didn't quite know how to structure our discussion."</i>
Organizational	Emerged when members of one organization retained useful information from the team or otherwise made collaboration difficult.	Limited knowledge sharing Lack of trust Prejudice	One organization vs. the project (enacted by individuals)	<i>"This is what I have been working on ... but I am not allowed to give you the code, so I will explain it like this..."</i>
Interest	Emerged when there were different interests among the project members.	Withdrawal from activities	One individual vs. the project	<i>"We do have different interests, and this means that perhaps we're working towards different goals; we prioritize different goals. We do have different success criteria in the project."</i>
Professional Identity	Emerged when scientists and developers viewed each other in a negative light and had difficulty collaborating.	Exclusion	Scientists vs. developers	<i>"There is clearly the impression that you (the developers) are visiting when you go talk to them (the researchers) – I mean – you always get an answer to your questions, but you don't necessarily get invited to their next brainstorm anymore"</i>
In-group/Out-group	Emerged when individuals from one sub-group were not aware of what was going on in the other sub-projects	Lack understanding of Exclusion Lack of coordination	One sub-group vs. Team members	<i>"I am not a part of the Location Modeling group, for example, and then it is kind of peripheral what I know about what's happening there. So the groups are sort of closed."</i>

Bringing together the findings in the study, we can explain the underlying mechanisms of the boundaries identified in this study by three theoretical constructs: 1) sensemaking, 2) strategizing, and 3) group identification. They are processes enacted by the single individual in order to reduce perceived uncertainty and enable action. When a number of individuals from different organizations and disciplines interact in a complex R&D project, they react to the uncertainty and seek to reduce it. First, they simply try to make sense of their surroundings, either through individual or collective sensemaking processes. When successful, this process gives an individual the ability to act, but when it fails, the participant will withdraw from collaborative tasks or group

discussions, thus leading to cognitive boundary. Similarly, when a group is successful in collective sensemaking, this reduces uncertainty and provides the collective ability to act. However, when different interpretations exist between participants, misunderstandings arise that lead to disagreements of meaning. Furthermore, individuals try to minimize uncertainty by defining a set of guiding rules for dealing with the challenges and identifying possible strategies to apply when determining what move to make next. This too gives a sense of purpose and provides an ability to act. The consequence of such strategies is a goal-oriented behavior in which the actions of one individual may obstruct the actions or possibilities of others. This leads to mistrust and thereby reduced interaction and knowledge sharing (cf. interest boundaries and organizational boundaries). The third way to reduce uncertainty is to team up with similar others to avoid isolation in dealing with the challenges at hand. Group identity gives a sense of belonging, security, and self-esteem. However, the consequence is also the division between in-groups and out-groups, thus leading to exclusion and a lack of interaction between groups (cf. professional identity boundary and in-group/out-group boundary). When sensemaking failed, strategic behaviors clashed, strong group identifications divided the team members, and knowledge boundaries arose, which negatively affected the knowledge exchange processes in the setting. Figure 1 below illustrates the abovementioned relation between uncertainty reduction, failed sensemaking, strategic behavior, social identity, and the emergence of knowledge boundaries.

Figure 1. Knowledge boundaries in inter-organizational R&D and their underlying mechanisms

5. Theoretical and Practical Implications

5.1 Theoretical Implications

This study has three main implications for the existing knowledge on inter-organizational R&D collaborations. First, it depicts a complex picture of knowledge emergence that goes beyond a hierarchic and linear representation of boundaries as suggested by Carlile (2004). Multiple knowledge boundary types may exist in a project either simultaneously or consecutively, and the study suggests that knowledge boundaries are highly contextual. Different tasks or practices determine which boundaries emerge. In a three year project, it is difficult to keep track of different types of knowledge boundaries, but by relating these to certain tasks or practices, it becomes easier to identify them and foresee their emergence. The paper therefore links the existing knowledge exchange literature on thought worlds (e.g., Dougherty, 1992), strategic behavior (e.g., Bouty, 2000), identity (e.g., Kellogg et al., 2006) and novelty (e.g., Dougherty & Dunne, 2012) with specific project tasks or practices, thus providing insight into the underlying mechanisms of different knowledge boundaries.

The second theoretical implication of this study is that it highlights the unexpected consequences of uncertainty reduction. Literature on novelty and complexity in R&D projects has studied how teams manage their tasks to reduce complexity and uncertainty through boundary spanning activities (e.g., Kotlarski et al., 2015; Dougherty & Dunne, 2012; Carlile, 2004). Reducing uncertainty is seen as one of the first necessary steps in a problem-solving process (Loch et al., 2008), and as such, it is considered a good thing to be able to reduce uncertainty. However, this paper shows that the continuous inclination to reduce uncertainty at the individual level has a cost for knowledge integration. Reducing uncertainty through the processes of sensemaking, strategizing, and group identification may indeed reduce the perceived complexity at the individual level, but at the same time, these processes may actually provoke the emergence of knowledge boundaries at the team level because they provoke an increase of boundaries between individuals.

The third theoretical implication of this study is the identification of a cognitive knowledge boundary and, in general, the impact of individual attempts to reduce uncertainty. Most studies on knowledge boundaries (e.g., Dougherty & Dunne, 2012; Levina & Vaast, 2005; Carlile, 2004) are rooted in a practice theoretical perspective (Bourdieu & Wacquant, 1992), thereby focusing on what can be derived directly from investigating practice, whether through direct observations or ex-ante accounts of such practices. The practice perspective intentionally ignores cognitive aspects, as it is claimed that a focus on cognition is obsolete because it is already embedded in practice. However, this study shows that when concepts and tasks are so complex that individuals cannot make sense of them, they become unable to act, which is something invisible to investigators of practices. A pure practice investigation can therefore not detect one of the very important reasons for knowledge exchange impediments. This paper suggests that a greater focus on cognition, through the triangulation of multiple sources of process-related data, is necessary if we are to fully understand the dynamics of knowledge exchange and creation in complex settings. This also implies a situated approach to the study of knowledge boundaries, indicating that different methodological approaches are needed for different contexts.

5.2 Practical Implications

The findings of this study have some clear implications for practitioners and policymakers. The most important managerial implication of this study is that project managers in high-novelty inter-organizational R&D projects must coordinate the uncertainty reduction in the team. The constant attempts of people to reduce uncertainty, through sensemaking, strategizing, and group identification, led to the emergence of undesired knowledge boundaries, but such attempts are inevitable in this context. In practice, coordinating uncertainty reduction therefore means ensuring that the different participating organizations agree on a shared direction as well as agree to leave their participating employees with some level of autonomy. Agreed-upon directions are necessary to diminish ambiguity in the interpretations of team members, whereas autonomy is necessary to free team members from constraints imposed by their employing organizations. When shared directions are in place, participating organizations can leave it up to their employees to work in the project within the given frames. This implies that project management in a complex inter-organizational R&D project is not only about managing tasks and people downwards *within* the project team but also managing “*upwards*” in the hierarchy, thus convincing the executives of the participating organizations to let team members work autonomously and at the same time regularly coordinate emerging discoveries and directions with the executives to create a frame within which the project team can proceed. This also has implications for the executives of the participating organizations, in that their work no longer consists only of initiating the project, establishing a project team, and determining the very general goals of the project; rather, their active involvement is required throughout the project duration. From a policy perspective, there are implications regarding projects that are fully or partially financed by government funding. Here, the role of the project manager and a more active involvement of the executives of the participating organizations should be outlined as requirements in the project management statements.

At the team level, the project manager can actively use the knowledge of the underlying mechanisms of knowledge boundaries. Being knowledgeable that some boundaries are more dominant in relation to certain tasks and activities, and other boundaries in relation to others, the project manager may be particularly alert toward these boundaries when the team is working on a given task or activity. The study showed that as the team began to divide into a number of sub-groups, the organizational boundary and, to some extent, the interest boundary diminished as team members began to build up a community of practice. The work in the sub-groups also diminished the cognitive and semantic boundaries because the team members of these sub-groups interacted more intensely and thereby built up a shared understanding of the tasks and concepts. The division into sub-groups to some extent also eliminated the professional identity boundary because the professional boundaries became less important in the sub-groups. This could lead to the conclusion that sub-groups are the “magic bullet” of knowledge integration. However, as the study shows, the sub-groups also created strong knowledge boundaries, which impeded knowledge integration (the in-group/out-group boundary). A project manager should therefore pay attention to creating sub-groups at strategically advantageous moments, while at

the same time ensuring that the boundaries around the sub-groups do not become hermetic and create in-group/out-group boundaries. One way of avoiding knowledge boundary emergence in the wake of sub-groups is to make sure team members are members of two or more sub-groups or that team members occasionally rotate from one sub-group to another.

5.3 Future Research and Limitations

This study has identified the boundaries at play in a complex inter-organizational R&D setting, and it put to the frontstage their underlying mechanisms. However, the study has some limitations. For future research, it would be interesting to gain a deeper understanding of how multiple boundaries are spanned or managed and to what effect. Moreover, this study represents one project in one domain. It would be interesting to verify and to test that the findings from this study are present in other inter-organizational R&D consortia. Furthermore, more research is needed to understand the cognitive aspects of knowledge boundaries. In this paper, the cognitive boundary was identified; however, previous research has largely renounced examining the effects of individual knowledge boundaries on the collective sensemaking and problem-solving capabilities. To what extent does the cognitive boundary affect knowledge exchange, and, more importantly, at what point in the social interaction is the cognitive boundary spanned and knowledge exchange possible? These are relevant questions to study further in order to expand our knowledge of inter-organizational innovation management and knowledge exchange.

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