Enabling knowledge sharing

A multi-theory perspective on knowledge sharing in new product development consortia

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Voor Egbert en Linde:
"You are all my reasons"

Preface

Acknowledgements

Preface

When I had finished my master thesis, I was overcome by a feeling of disappointment, a sense of "is this it?". It wasn't the onset of a quarter-life crisis, but the feeling that there was still so much to learn and study. I particularly wanted to know more about knowledge sharing between two or more parties collaborating to innovate. This had been the subject of my master thesis, but I felt like I had just scratched the surface of this complicated issue and I was very keen to explore it further. To me, doing a PhD meant the freedom to study different aspects of knowledge sharing between and within innovative teams. I got to know social network analysis as a tool to analyze knowledge flows between actors, and as the research progressed I saw more and more possibilities of social network analysis. Not only for scientific research, but in practical settings in particular I see added value in analyzing and finding solutions for management issues. Unfortunately, I have discovered that the tool remains as yet unknown. I will make it my goal to change this, convincing others of the added value of social network analysis for practice by demonstrating its strengths.

Furthermore, I feel very privileged that I have been given the opportunity to carry out my research as part of two highly innovative consortia. I enjoyed the empirical part of my study. One of the best parts of my study were my discussions with the professionals in the consortia, learning about the instruments they were developing, and their way of organizing. I am very impressed with the instruments they develop and the passion these professionals have for their work.

Doing a PhD is not easy and I think that many people fail to realize this. When I started my research I had no idea what to expect. Looking back, writing my thesis has probably been one of the most challenging periods in my life. Persons close to me know it has also been an eventful period for me personally. At times I wondered whether I would reach the finish line. But a good friend of mine cheered me up by saying: "You will get there … the only question is what state you will be in when you get there". And yes, I made it to the end! Now that I get to look back, I realize just how much this period has taught me and how it has broadened my horizons. I would like to take this opportunity to express my gratitude to the people who have played such important roles in my journey.

First of all I would like to thank Jacques Boersma and Jan Waalkens for pointing out the option of doing a PhD. Without their encouragement I simply would have overlooked this professional option. I would also like to show my gratitude to my promotores: Jo van Engelen, Roger Leenders and Jan Kratzer. Jo, thank you for seeing the potential in me and for recruiting me as a PhD student. I very much enjoyed the discussions and review sessions in your backyard, thank you for your support. Roger, thank you for your guidance, your patience in explaining statistics to me and for keeping me sharp on the details. Under your supervision I learned to be a better researcher, a better writer and to be more precise in my wording. Jan, thank you for teaching me how to conduct social network analysis and introducing me to the instrument consortia. You always took the time to discuss methodological options, explain things or just drop by to encourage Johanna and me.

The outcomes of my empirical research were largely dependent on the cooperation of the people in the two consortia I studied. I am very grateful to Thijs de Graauw, Frank Helmich, Marco de Vos and Mark Bentum who facilitated the empirical study in the consortia. Thank you for helping me understand the way of work in the field of space science, for reviewing the process and, most of all, for making it possible for me to conduct empirical research in your field of business. Also, I would like to take this opportunity to thank everyone in the consortia who filled out the questionnaire and for participating in the interviews.

Writing a thesis is a quite individualistic job. I was very happy to find that it didn't have to be a lonely job since I had a wonderful group of colleagues to support me. I want to thank my colleagues for making my time as a PhD student so enjoyable. Special thanks go to Frank and Niels, I enjoyed our discussions, conversations and laughs. My thanks also go to my (former) colleagues René, Kristian, Joost, Laura, Thijs, Marian, Ruben, Johanna, Nurul, Marjolein, Derk-Jan, Larissa, Sonja and Martin for their support and for making my work environment and lunches such a pleasure.

Despite my physical or mental absence at many social events during the final stages of my PhD project, my friends and family have always been there for me. I wish to thank all of my friends for standing by me and for taking my mind of things when I tended to lose myself in my work. I would like to take this opportunity to say a special thanks to my paranimphs Marjan and Nanda, first my colleagues, now my close friends. Marjan, you were there from the day I became a PhD student. You have become a dear friend and you got me through hard times. Thank you for being there for me, for our long telephone conversations and for taking me out for high teas or spa treatments when I needed to relax. Nanda, we (literally) travelled through the last two years of my PhD. Thank you for bringing laughter to my project and for becoming my close friend. You have a very positive outlook on life and I still learn from you in many ways.

My family members are a solid basis in my life and have supported me along the way even during the busy periods of writing. Mum, dad, Jorien, Henk, Wiep, Gerben and Willemijn thank you for your support, your concerns, your empathy and of course for baby-sitting Linde while I was writing my thesis. I hope I have made you all proud. Anyone who knows me well, knows I always save the best for last. So finally I want to show my gratitude to my husband Egbert. Egbert, thank you for standing by me, for putting up with me in my anti-social writing periods, for motivating me, for bringing me tea when I was working on my PhD in evenings or at weekends. It is amazing how you put my worries into perspective, encourage me, support me and love me.

Marloes Smit-Bakker
Leusden, 2009

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Introduction

1 Introduction

1.1 New product development consortia

Faster, more efficient, more user-friendly, and more sustainable; products are constantly changing. Organizations cannot afford to stand still, they have to keep developing their products or services as the development of new products and processes increasingly is a focal point of competition (Wheelwright & Clark, 1992). A survey in 2006 amongst more than 1,000 senior executives from 63 countries in all major industries showed that innovation is a key priority for organizations; in 2006 it was a number one priority at 40 percent of the companies and a top three priority at more than 70 percent of the companies. More than 90 percent of the executives said that growth through innovation is necessary for success in their industry (Boston consulting Group, 2006). Doing new product development (NPD) well has become a competitive advantage and necessity (Brown & Eisenhardt, 1995; Clark & Fujimoto, 1991; Wheelwright et al, 1992).

In conducting NPD, more and more organizations arrange their efforts in NPD consortia: systems of co-operating organizations with the objective of developing new products together. The necessity for developing new products in co-operation with other organizations not just emanates from the high costs involved, it also comes from the specialized knowledge from multiple areas of expertise NPD nowadays requires. It is increasingly difficult for one organization to have all areas of expertise necessary for product development available in-house. By co-operating in a consortium, participating organizations have access to the knowledge necessary for the product that is to be developed (Hamel, 1991; Inkpen & Crossan, 1995).

Take for instance airplane development. Compared to 50 years ago this now requires much more specialized knowledge from a large number of areas. Although the product itself has not changed essentially (an airplane still flies, it still has wings and it still carries passengers or cargo), the process now requires many more choices to be made. Safety requirements have become much stricter. Planes have to comply with a wide variety of production systems and airport standards. This means that not only different types of *technical* knowledge are required for building airplanes; specialized knowledge of safety requirements, the variety of standards, the different airports, et cetera is also needed. Because it is almost impossible for one organization to have expertise in all of these areas, in the airplane industry new product development is often organized in NPD consortia.

NPD consortia can be found in almost every branch. Cases of large-scale cooperation are found in aircraft development, space technology, energy, and construction branches. Even in the highly competitive automotive sector where the individual manufacturers carry out R&D activities for their own company and their own competitive advantage, a large share of product development in the automotive sector is conducted collaboratively. In Europe, for instance, automotive manufacturers collaborate under the umbrella of EUCAR (European Council for automotive R&D). EUCAR is a strategic cooperation in research and technological development, in which BMW, DAF, Daimler Chrysler, Fiat, Ford, Opel, Porsche, Peugeot Citroën, SA, Renault, Volkswagen, and Volvo participate. For example, in one of the EUCAR projects, Daimler Chrysler, Ford and Volkswagen combine their strengths to develop a Powertrain. In the EUCAR projects, the partners also include automotive suppliers, research institutes, academia, and public authorities.

This study specifically focuses on NPD consortia in the field of space science. In these NPD consortia, to which we will refer as *instrument consortia*, new instruments for conducting measurements in space are co-designed and co-developed by multiple organizations distributed across different countries. Two types of measurement instruments can be developed in these consortia; ground-based instruments and space-based instruments. Ground-based instruments are set up on earth, and in include antennas for instance. Space-based instruments are launched into space; these are mostly measurement devices on satellites. The instrument consortia are good examples of the type of projects in which multiple partners co-operate to develop new products. Developing instruments for measurements in space requires very specialized knowledge in a range of different areas of expertise. Areas of expertise required include for example: physics, astronomy, electro-engineering, mechanical-engineering, and optical engineering. In general, space research institutes will each have some areas of expertise, but not enough to develop a new measurement instrument individually. Additionally, developing these instruments is very expensive; most NPD projects developing instruments for space science require investments of billions of dollars/Euros. It is difficult for one organization to carry the investments necessary for the development on its own. So both the required specialized knowledge and the high development costs create a need for organizing the development of instruments in consortia.

The instrument consortia are comparable to other NPD consortia as to structure, design process, and organization. They are also comparable in the sense that they also develop a product that is sold, even though this might not seem to be the case initially. Measurement instruments for space are often one of a kind, there are space agencies all over the world building instruments that overlap in the measurements they can do. Competition is getting fiercer due to the rise of, for example, Asian countries. While the instruments themselves are not sold, the data they produce is: research institutes from all over the world can buy observing time on the instrument to collect data. Mostly the institutes involved in the development of the measurement instrument invest money and expertise, and they get observing time in return. They are also given first access to the instrument for observation.

Organizing new product development in consortia brings along an additional challenge. In instrument consortia specialized knowledge from multiple areas is scattered over the participating organizations. To use and combine the specialized knowledge of the participating organizations, and combine it into a new product, knowledge sharing between the consortium members involved is crucial. This will be discussed in detail in the next section.

1.2 The importance of knowledge sharing

To have access to all of the areas of expertise required for development, the overall task of developing a new product is subdivided, with teams set up for specific tasks. For instrument consortia this means the measurement instrument developed is decomposed in modules. The modules are assigned to specific teams. These teams are composed and selected on for their role and expertise in developing that specific module. The teams are selected participating institute or institutes. Within a team the task of developing the module is further decomposed into smaller components, which are then assigned to team members. By decomposing into modules and smaller components, and assigning the development of its modules and smaller components as tasks to teams or team members, the task structure in instrument consortia consists of two layers minimum. At the lowest layer professionals have to execute tasks in order to develop a specific part (modules or components) of the instrument. The professionals are part of teams. The teams together have to complete the overall task of developing the new instrument. This is the second layer in the task structure. Between the tasks of the teams and between the tasks of the team members dependencies exist, because between the parts of the instrument, the modules and smaller components, interfaces exist.

Although decomposition intends to make the number of interfaces manageable, in decomposing the measurement instruments for space science still numerous interfaces exist between modules and smaller components. This is not only because the instruments are made up of many parts, but also because the parts affect each other in a number of ways. An interface exists between two modules if a change to one module affects a change to the other module in order for the overall system to work correctly (Ulrich & Eppinger, 2000). For example, in a measurement instrument for space there is an interface between two modules when there is a signal or data flow between two modules. Two modules can also have an interface when they are placed next to each other in the instrument. Placing two modules together may mean that the geometry of one module cannot be adjusted without having an effect on the geometry of the other module. Also, in addition to affecting each other's geometry there can be effects in vibration or heat when modules are placed next to each other (Ulrich & Eppinger, 2000). When interfaces exist between modules, the design and development of one module has effects on the development of the other component. When module A and B have an interface, this means that the team developing module A has to share knowledge with the team developing module B, about the input, process, and output of their tasks. Knowledge has to be shared between two teams for each interface between the modules they make. Similar interfaces exist between the smaller components made by the team members. Two team members have to share knowledge when interfaces exist between the components they are making. We refer to this one-on-one knowledge sharing as *dyadic* knowledge sharing.

Summing up, the overall instrument is decomposed in modules and smaller components. The tasks of developing the modules is assigned to teams and within these teams the tasks of designing the smaller components are assigned to team members. Interfaces exist both between the modules and between the smaller components. As a consequence, teams that develop modules that have interfaces have to share knowledge about these interfaces. Team members who develop smaller components with interfaces also have to share knowledge about these interfaces. Each interface includes a pair of two teams or two team members. These pairs of teams or team members have to share knowledge about the input, process and output of their tasks, so that they are able to execute their tasks and together develop one instrument that functions.

A challenging factor for instrument consortia is that in contrast to relatively simple tasks where input, process, and outcome can be a priori determined, tasks in the consortia are new and genuine decision tasks (Bystrom & Jarvelin, 1995). Not only are their tasks new, the professionals developing the measurement instrument work at the frontiers of knowledge. The entire motivation for the mission is to develop new scientific knowledge (Linde, 2006). Creating knowledge is at the core of their tasks. Creating new knowledge is based on existing knowledge, by recombining and exchanging existing knowledge (Kogut & Zander, 1992; Nahapiet & Ghoshal, 1998; Nonaka, 1994). Thus, the knowledge creation, which is part of the professional's tasks, also requires that they share knowledge with each other. For knowledge creation, the emphasis is also on one-on-one knowledge sharing in pairs of teams or pairs of team members. Research showed that finding solutions (creating new knowledge) in large groups is not very effective (Monge & Contractor, 2003). This is supported by studies on brainstorming showing that groups where individuals work alone and whose efforts are then aggregated, outperform groups where individuals brainstorm together (Diehl & Stroebe, 1987). However, in the case of the instrument consortia, the teams and team members cannot work alone in finding solutions and creating knowledge. They need each other's knowledge as input for problem solving. The most effective input takes place in groups that are as small as possible: in pairs of two.

The above demonstrates that to make optimum use of the specialized knowledge present in consortia, to execute tasks and to create new knowledge, knowledge has to be shared one-on-one on two levels minimum: in pairs of teams (the inter-team level) and in pairs of team members (the intra-team level). The better the project members are able to share knowledge, the better they are able to anticipate on interfaces, create new solutions, and foresee problems. Overall, it increases the probability they will successfully complete their tasks and meet the quality, time and financial requirements.

The latter is very important for NPD consortia in general. High investments are at stake, time-to-market is very important and the quality of new products is crucial for its success on the market. For the instrument consortia the quality, time, and financial requirements are sometimes extremely high. The quality requirements are high because the quality of the instrument developed determines the quality of the data produced by the instrument. The instruments are very sensitive and their measurements have to be very accurate. If the high quality requirements are not met in the final instrument, this will have serious consequences for the data the instrument can produce. In addition, both ground-based and space-based instruments have to deal with environmental influences. Ground-based instruments are exposed to influences such as rain, wind, and other weather conditions, and to influences of animals like birds. For space-based instruments, the environmental influences are even more extreme. The instrument has to survive the launch of the rocket. After the launch, the life span of a satellite (and the instruments on it) should be at least three-and-a-half years under extreme conditions as far as temperature and other external conditions are concerned. And once the space-based instrument is launched, it is virtually impossible to make adjustments or to repair it in times of complications. This means that the requirements set for the quality of the materials used and the design of the instrument are extremely high.

The stringent time requirements mainly concern the space-based instruments. The space-based instruments are under extra time pressure as they are launched in space by a rocket that has a fixed departure date. Not finishing space-based instruments in time means the launch of the satellite has to be postponed at a very high cost. Practical problems can also occur as the satellites have to be placed in orbit. This depends on many factors, such as climate conditions and the position of the celestial bodies.

The instrument consortia face strict financial requirements because of the very high investments at stake. Complicating factor is the possibility of changing financial restrictions during a project. For most European instrument development projects, the European Space Agency (ESA) has contracts with participating countries. The countries finance the contributions of their institutes. Because the NPD projects extend across several political periods, the financials are influenced by political changes and social developments in the participating countries. This implies that the financial means are not equally distributed over the institutes. Also, it implies that financial restrictions may change during the project as national governments may change during the project, changing the financial support of space science development.

To meet the extremely high quality and time requirements and anticipate the (changing) financial restrictions, the teams and team members have to successfully complete their tasks and be able to adapt to any changes. If the professionals are able to share knowledge effectively within and between teams, they are better able to successfully complete their tasks and meet the high requirements set for the project in terms of quality and time. Also, they will be able to anticipate and create new solutions for new situations. At the same time, organizing the development of instruments for space science in consortia has consequences for the way people share knowledge with each other. This is not only the case for instrument consortia, but also for NPD consortia in general. From both practice and literature it appears that NPD consortia have trouble sharing knowledge effectively. This constitutes a real challenge for NPD consortia.

1.3 Problems encountered in practice

In practice it seems that professionals working in NPD consortia have great difficulties sharing knowledge effectively. This can result in a range of problems, from failure to meet quality requirements to budget and time schedule overruns. The development of the Airbus A380 provides us with an example of problems encountered in NPD consortia. The Airbus A380 was co-developed by key contractors France, Germany, United Kingdom, and Spain. Partners from Australia, Austria, Belgium, Finland, Italy, Japan, South-Korea, Malaysia, the Netherlands, Sweden, Switzerland, and the US were also involved in the Airbus development and manufacture. Although the Airbus A380 is generally considered a very successful project, its development met with some serious problems. CNN reported a budget overrun of some US $ 1.4 billion (www.cnn.com). Series of delays were announced during the development, even resulting in order cancellations. The knowledge-related problems behind these delays surfaced when Mr. Streiff, Airbus President and CEO, held his speech on 3 October 2006 (he quit the job six days later). He claimed the announced delay of another extra year was due to the mismatch of aircraft parts developed by different teams, which he phrased as follows:

"The root cause of the issue is that there were incompatibilities in the development of the concurrent engineering tools to be used for the design of the electrical harnesses installation. (...) The problem became first apparent when the electrical harnesses were installed into the fuselage: there were mismatches between the designed routing of the electrical harnesses and the real aircraft." (www.atwonline.com)

The components of the electrical harnesses were developed by teams in Germany, UK, France and Spain. The components had functional as well as physical interfaces, but the various teams had failed to share knowledge effectively about these interfaces. The teams had made changes to the design without sharing these with other teams. In the end, this resulted in mismatches in the components (Washingtonpost.com; Cadalyst.com). Changes to the original design should have been made in close collaboration with the teams working on the connecting parts. If the teams had been effectively sharing knowledge about these changes, the other teams could have overseen the consequences of the changes and anticipated them: they would have been able to incorporate them, adapting and synchronizing their own parts.

The development of Airbus is just one example that illustrates how NPD consortia face challenges managing knowledge sharing. In consortia that develop measurement instruments for space, ineffective knowledge sharing causes consortia to be delayed, to overrun their budget, and to fail to meet quality targets.

Problems associated with knowledge sharing in instrument consortia include failure to share knowledge between the "right" persons, or to share it frequently enough (Olla & Holm, 2006; Garon, 2006). Additionally, people in consortia fail to make full use of each others' knowledge and experience acquired in previous projects necessary for the creation of new knowledge

(Dow et al, 2006; Rothenburger & Galaretta, 2006; Garon, 2006). Literature presents a number of reasons why knowledge sharing is so difficult in NPD consortia. Some reasons are similar to the reasons mentioned for consortia in other industries, such as the presence of numerous interfaces, technical fields, multiple stakeholders, highly specialized and compartmentalized knowledge, complex technical solutions, staff changes during the projects, or time barriers (Olla & Holm, 2006; Dow et al. 2006). Additionally, authors report problems in knowledge sharing because professionals working in the consortia do not always perceive knowledge reuse to be “good”, instead, innovation or creation is “better” (Olla & Holm, 2006).

To overcome problems in knowledge sharing, and to increase control by making knowledge sharing manageable, we need to understand the variables that influence knowledge sharing within consortia. As previous research has shown, variables in the context where knowledge is shared have great impact on the way people share knowledge. Many authors therefore support the creation of an ‘enabling’ context as a way to manage knowledge sharing (Davenport & Prusak, 1998; Gupta & Govindarajan, 2000; Kogut et al., 1992; Nonaka, 1994; von Krogh, Ichijo, & Nonaka, 2000). This raises the question of what context variables can be used to enable knowledge sharing. Below I will refer to the “variables that can be used to enable knowledge sharing” as “enablers”. Once we understand how knowledge sharing is enabled, instrument consortia management can better manage and facilitate knowledge sharing to make it more effective and efficient.

1.4 Enablers for knowledge sharing in instrument consortia

We concluded section 1.2 by stating that knowledge sharing in *pairs* of teams and *pairs* of team members is crucial for the teams and team members to execute their tasks and create new knowledge. We referred to this knowledge sharing as *dyadic* knowledge sharing. A dyad is the relation between two actors. A knowledge sharing dyad is a knowledge sharing relation between two actors. Knowledge sharing takes place within the relational context of two actors. In our case this means that knowledge sharing between teams or between team members takes place within the relational context of the teams or team members. Characteristics of this relational context are expected to have an impact on how the teams or team members in the consortia share knowledge one-on-one. The question that we aim to answer is: what are enablers (for knowledge sharing) in the relational context of the teams and team members in the instrument consortia?

The relational context is shaped by the way the consortium is organized, how teams and team members are selected for their tasks, and the nature of their tasks. A combination of two approaches was used to select enablers for knowledge sharing for inclusion in this study. First, the instrument consortia were studied in detail. We abstracted those characteristics in the relational context that are most likely to affect and enable knowledge sharing. Second, a literature study was carried out to find enablers for knowledge sharing in the relational context. We found no research on enablers for knowledge sharing in instrument consortia. The enablers we did find in literature were weighed as to their relevance for instrument consortia. By weighing the variables found in literature and comparing them with the characteristics perceived as affecting knowledge sharing in the instrument consortia, a final selection was made of enablers in the consortia. The results are discussed below.

As discussed, the product developed in instrument consortia is decomposed. The interfaces between the modules and smaller components in which the instrument is decomposed cause the tasks of teams and team members to be highly interrelated. This means the professionals have to share knowledge with each other, across disciplines. Also, the professionals working on the tasks in the instrument consortia stay part of their own organization both functionally and on location. As they carry out their tasks at their own organization, they are not co-located for the duration of the project. Often they have to share knowledge across distances. Because professionals stay part of their own organizations, they can also be involved in other projects outside the consortium. To summarize, the professionals who carry out the tasks and have to share knowledge in instrument consortia, have to deal with highly interrelated tasks, specialists in different areas of expertise, colleagues who are dispersed over several geographical locations, and in some cases projects outside the consortium. From these circumstances we deduct four variables in the relational context that in instrument consortia appear most likely to influence the way knowledge is shared in pairs of teams or team members.

First, numerous *task dependencies* exist between teams and between team members. When people perceive task dependencies, they feel the need to share knowledge. Also they have a better idea about what they should share knowledge. In this sense, task dependencies between teams of team members are expected to enable knowledge sharing. The enabling effect of task dependencies is supported by literature. The effect of task dependencies can be described by what several authors point to as the effect of organizational mode (Dougherty & Hardy, 1996; Cummings & Teng, 2003; Boschma, 2005). Boschma (2005) describes the organizational mode as the way interaction between actors is organized. The organizational mode influences knowledge sharing because it shapes the flow of knowledge, the depth and breadth of interaction, and the incentives for collaboration (Baughn et al, 1997). Task dependencies are a form of organizational mode in that they define where knowledge should be shared, the direction of knowledge sharing and the content the actors should share knowledge of. In this sense the task dependencies as organizational mode may also enable knowledge sharing.

Second, the development of measurement instruments requires detailed knowledge about *different areas of expertise*. Instruments are designed and developed by astronomers, electro-technicians, mechanical engineers, optical engineers, software engineers, et cetera. Many different areas of specialization are present in the project and the professionals working in instrument consortia are each highly skilled in their own specific area. As a consequence, the individual knowledge domains show little overlap. This is expected to have an effect on the way two teams or two team members share knowledge because they may experience problems understanding each other. Findings in previous studies support that differences in expertise have an impact on the way people share knowledge. Terms like 'common knowledge' (Hamel, 1991), 'knowledge gap' (Nonaka & Takeuchi, 1995), and 'knowledge redundancy' (von Krogh et al., 2000) all refer to the relevance of having a knowledge overlap. Several studies indicate that knowledge sharing is facilitated when people have some kind of shared interpretation of knowledge (Cohen & Levinthal, 1990; Dougherty, 1992; Hamel, 1991; Nonaka et al., 1995; Szulanski, 1996). Having an overlap in knowledge is therefore seen as an enabler for knowledge sharing.

Third, the professionals working together in the consortia are *physically dispersed*. The highly skilled persons working in the consortia come from different organizations participating in the consortia. Although the project members work together in developing a new product, they mostly conduct their tasks while physically located at their own organization. Being in different locations means that the teams and team members have to co-operate over distance, which is likely to influence the way they share knowledge. In literature, several authors argue that knowledge sharing benefits from people meeting face-to-face, which requires a certain extent of physical closeness of the places where they work (Allen, 1977; Cummings & Teng, 2003a; Nonaka et al., 1995). Additionally, one has to be able to find the right person with the knowledge one is searching for. This becomes more complicated in situations where persons are working in separate institutes and are physically dispersed (Hollingshead, 1998a). Seen as a variable that influences knowledge sharing, physical dispersion may hinder knowledge sharing, while co-location may be an enabler for knowledge sharing

Fourth, because the professionals working in instrument consortia stay part of their own organizations, they also continue their day-to-day tasks at their own organization. Sometimes this means they are *involved in other projects* their organization is engaged in, which means they have to divide the time they spend on different projects. In literature these arguments are linked to concepts like project priority (Cumming & Teng, 2003) and intent or motivation (Baugh et al. 1997; Hamel, 1991; Szulanski, 1996). When there is simultaneous involvement in several projects, this may lead to differences in project priority, intent to share knowledge and motivation to share knowledge. Sometimes the team members' priority will be on the tasks in the consortium, at other times their priority shifts to other activities. On the other hand, being involved in multiple projects or tasks outside the consortium means the team members also gain new knowledge outside the project. In literature evidence is found that being involved in multiple projects is may have an enabling effect on the way professionals in the project share knowledge because they may bring additional knowledge to the project (Hollingshead, 1998a).

In addition to the four variables taken from practice, literature yielded an additional variable for the relational context considered to have an enabling effect on knowledge sharing: *cultural or norm closeness*. Concepts such as mutual trust, a common understanding of values and norms (McDermott & O'Dell, 2001), and 'care' (Linde, 2006; Olla & Holm, 2006) have been related to cultural or norm distance. As these authors (and other authors like Allen, 1977; Tushman, 1978) argue, being culturally close, having mutual trust or a common understanding of values and norms may enable knowledge sharing. Although previous research identifies this cultural or norm closeness as an enabler for knowledge sharing, it is less relevant in the instrument consortia discussed in this thesis. Research showed that cultural mixes are common in space science projects, with people being accustomed to different cultures working together (Zabusky, 1995). Trust, another concept related to cultural/norm closeness, is also hardly relevant in instrument consortia. Research demonstrated the relatively small role of trust in knowledge sharing within the specific context of instrument consortia (Bakker, Leenders, Gabbay, Kratzer, & van Engelen, 2006). Therefore, the present study does not include cultural/norm closeness as a knowledge sharing enabler.

To summarize, based on the characteristics of working in instrument consortia, we deducted four variables in the relational context influencing knowledge sharing. After comparing these variables to variables discussed in literature, four possible enablers in the relational context for knowledge sharing in instrument consortia were selected: (1) expertise overlap, (2) co-location, (3) task dependency, and (4) involvement in multiple projects. These variables are labeled *enablers* below.

1.5 Research design

1.5.1 Conceptual model

The enablers identified in the previous section are likely to influence the way knowledge is shared in instrument consortia. With respect to the management of the instrument consortia, the relevant question is whether and how these variables enable knowledge sharing, so that they can be used to manage knowledge sharing to be more effective in instrument consortia. At present, these insights are not sufficiently present. The objective of this thesis is therefore to gain an insight into how the enablers in the relational context affect the way professionals in the instrument consortia share knowledge. Two main concepts are central to this thesis: (1) knowledge sharing and (2) the enablers that influence the way teams and team members in instrument consortia share knowledge. Based on these concepts and their relations an initial conceptual model is presented, which is at the basis of our research (see figure 1-1).

The conceptual model shows the two levels where knowledge sharing takes place; within teams (the intra-team level) above the dashed line and between teams (the inter-team level) below the dashed line. At the intra-team level, dyadic knowledge sharing takes place in pairs of team members. At the inter-team level, dyadic knowledge sharing is one-on-one knowledge sharing between teams. The blocks on the right represent dyadic knowledge

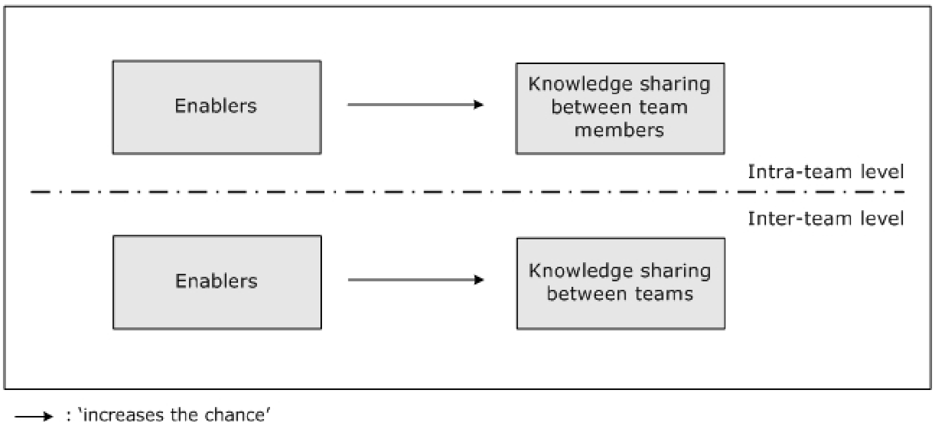

Figure 1-1: Conceptual model

sharing within, respectively between the teams. The enablers for knowledge are presented in the blocks on the left.
So far, we have used the term knowledge sharing without actually clarifying it. The term is defined and discussed below before formulating the research questions central to this thesis.

Knowledge sharing

Different definitions are used for knowledge. Depending on the perspective, the emphasis in the definition is shifted. An approach often used for defining knowledge is the cognitive approach. The cognitive approach is all about 'interpretation'; the team member is seen as an information processing actor (Kogut et al., 1992; Nahapiet et al., 1998; Nonaka, 1994) who creates knowledge by interpreting data and information. Knowledge is defined as: "A fluid mix of framed experience, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information" (Davenport & Prusak, 1998: p.5).

The cognitive perspective focuses on how actors process data and information. By using a cognitive perspective one can answer questions like: why do actors that are exposed to the same information, interpret this information differently and act differently on this interpretation? In this thesis, this cognitive perspective is not very useful, as the focus here is not on how members of instrument consortia interpret knowledge but on the interaction between teams/ team members. The cognitive approach as described above does not focus on the interaction between the actors, but on how actors process the information and knowledge. Therefore we leave the cognitive perspective and instead use a social network perspective. The social network perspective is an approach that allows us to study knowledge sharing as an interactive process. In this approach the definition of knowledge shifts towards a definition of 'knowledge shared', referring to the mix of data and information exchanged between teams or team members, used in the execution of their tasks and the creation of new knowledge. In the present study, *sharing* does not mean that the direction is by definition two-way. It is also possible for one team member to share knowledge with another team member, while the other team member does not share knowledge with him. For example, a team member may send a mix of data and information to a fellow team member by email, which is one-directional. In this study this is also seen as knowledge sharing.

The social network perspective adopted in this thesis enables us to directly study dyadic knowledge sharing between teams and team members and to explore the nature and properties of this knowledge sharing (Contractor, Wasserman, & Faust, 2006). The main difference with other research approaches is that the network perspective is based on an assumption of the importance of relationships among interacting units (Diehl et al., 1987; Leenders, van Engelen, & Kratzer, 2007; Mullen, Johnson, & Salas, 1991). Where other social science approaches usually ignore the relational information, the social network approach differs as it includes theories, models, and applications that are expressed in terms of relational concepts or processes (Contractor et al., 2006; Wellman, 1988). The network perspective is very flexible as it is applicable to different kinds of actors and different kinds of theories, and allows for a multi-theory, multilevel study. In this thesis, adopting a network perspective means that people in instrument consortia are seen as sets of interconnected actors who have to share knowledge to accomplish their tasks.

Knowledge sharing characteristics

According to the social network perspective and communication literature, knowledge sharing between two persons or teams can take a particular shape depending on its characteristics. The social network perspective is often adopted in communication literature, where multiple characteristics are associated with communication relations (or *ties*). We want to benefit from these insights and use them to study knowledge sharing. It provides us with a broader perspective and may provide more insight into how knowledge sharing between actors takes place. We therefore describe dyadic knowledge sharing relations based on their characteristics. We refer to this as knowledge sharing characteristics. We have already stated that the way of organizing NPD in consortia is expected to impact on the way professionals in the consortia share knowledge. For consortia where instruments for space-science are developed, four possible enablers were selected for inclusion in this thesis. The overlap in expertise the members have, co-location, task dependencies and the involvement in multiple projects are all likely to have an impact on knowledge sharing in three ways. First of all, they are likely to have an impact on the *direction* in which professionals share knowledge. In projects it is often easier for people to share knowledge with others who have similar expertise, with whom they are co-located, and with whom they have task dependency. Two-way knowledge sharing in those situations is easier than in situations where people have different expertise because there may be a threshold for them to approach each other for knowledge sharing or they may not be able to understand each other. When working in separate locations it also becomes more difficult to share knowledge bi-directionally because there may be differences in time-zones or because people cannot identify persons in the other location who have the knowledge they need. When working on one project it is also easier to have two-way knowledge sharing than when working on multiple projects. When working on multiple projects, the time for knowledge sharing becomes limited and priorities may shift. This means that two-way knowledge sharing may be more difficult in this situation. Finally, task dependency is also likely to have an impact on the direction of knowledge sharing. When task dependent, people need each other's knowledge to facilitate two-way knowledge sharing. If there is no task dependency, there is no direct lead to share knowledge, and two-way as well as one-way knowledge sharing may be impaired.

Secondly, the enablers are expected to influence *how often* the professionals share knowledge. In the instrument consortia, the professionals have to deal with physical distances, with professionals who are experts in very different areas, with many task dependencies, and with involvements in multiple projects. The physical distances may hinder the spontaneous moments of knowledge sharing, and they may impair frequent knowledge sharing because people cannot find other persons who have the knowledge they need. The differences in expertise are likely to influence the frequency of knowledge sharing. These can be perceived as thresholds for knowledge sharing; people may find it difficult to approach or understand others with different expertise. Task dependencies are also expected to shape the frequency of knowledge sharing between professionals; where there are task dependencies people have to share knowledge to conduct their tasks. The shifting priorities and time restrictions which result from involvements in multiple projects are also likely to influence how often people share knowledge.

Finally, the variation in expertise overlap, locations, task dependencies and involvement in projects is expected to have an impact on the *content* of knowledge sharing between professionals. Professionals who have different backgrounds, who are not co-located and who are involved in multiple projects are more likely to share knowledge of different contents than professionals who are situated within the same organization, who share a similar background, and who are involved in one project, for instance because they bring knowledge applied in other situations to the consortium. We also expect professionals who are task dependent to share more knowledge of different subjects than professionals who are not.

Thus, the direction, frequency and content of knowledge sharing are included as three knowledge sharing characteristics which may be affected by the enablers. Translated to the dyadic level, where knowledge is shared between two teams of two team members, these knowledge sharing characteristics are reciprocity, frequency, and multiplexity. *Reciprocity* represents the question whether knowledge is shared and whether it is shared one-way or two-way. The second characteristic, *frequency*, captures how often the actors share knowledge. Finally, actors can share knowledge of different contents. In the present study this dimension is included and represented by *multiplexity*. The knowledge sharing characteristics are more extensively discussed and explained below.

Reciprocity

Reciprocity of knowledge sharing indicates whether knowledge is shared and if it is shared one-way or two-way. It reflects the direction of ties. Directional ties go from one actor to another; they have an origin and a destination, whereas non-directional ties have no direction and instead represent a mutual relationship (Wasserman & Faust, 1994). Concerning the reciprocity of the tie, directional knowledge sharing ties can be in one of three states; null, mutual, and asymmetric (Wasserman et al., 1994). A null tie is the state in which there is no knowledge sharing between two actors. When there is knowledge sharing between the actors, the tie can be either mutual or asymmetric. An asymmetric tie between two actors is a tie from one to the other, but none back (Wasserman et al., 1994). Person A approaches his team member B for knowledge, but B does not approach A for knowledge. In contrast, knowledge sharing is mutual when team member A approaches B for knowledge and B turns to A for knowledge sharing.

Frequency

The frequency of a knowledge sharing dyad indicates the strength or quantity of the relation. In our research the frequency is defined by the timeframe in which the teams or team members share knowledge, for example once a week, once a month, et cetera.

Multiplexity

Multiplexity concerns the dimensionality of the content of the knowledge sharing relation. When studying uniplex ties, the different contents of the relations are studied one at a time. When studying two or more relations together, the ties are seen as multiplex. Most network research focused on uniplex relations, but by studying multiplex relations the body of research can be improved (Wasserman et al., 1994). This is also the reason why Monge and Contractor (2003) argue for studying multiplex ties. In case of knowledge sharing ties, the actors may share different contents of knowledge. These can be categorized in multiple types of content that may be shared between team members. The present study distinguishes four categories of knowledge content; know-how, know what, know-why and know-who. The extent to which the different contents of knowledge in ties overlap is denoted by multiplexity (Wasserman et al., 1994).

To sum up, knowledge shared refers to the mix of data and information that is exchanged between actors and used in executing their tasks and creating knowledge. Sharing does not mean that the direction is by definition two-directional. A social network perspective is adopted for studying dyadic knowledge sharing. Three knowledge sharing characteristics are included: the reciprocity, frequency, and multiplexity of knowledge sharing.

1.5.2 Research questions

Having discussed knowledge sharing and the characteristics of knowledge sharing, the conceptual model is refined (figure 1-2).
The refined conceptual model sets out the enablers for knowledge sharing in more detail. The enablers in this study are task dependency, expertise overlap, co-location, and involvement in multiple projects. The enabler 'involvement in multiple projects' is not included at the inter-team level because it rarely happens that entire teams are involved in projects outside the consortium. Moreover, the effect this would have on the knowledge sharing between teams is hard to assess in empirical research. For knowledge sharing, three knowledge sharing characteristics are defined: reciprocity, frequency, and multiplexity. The following research questions can now be formulated:

1. *What is the effect of expertise overlap, co-location, involvement in multiple projects and task dependency on the reciprocity, frequency, and multiplexity of knowledge sharing within teams?*

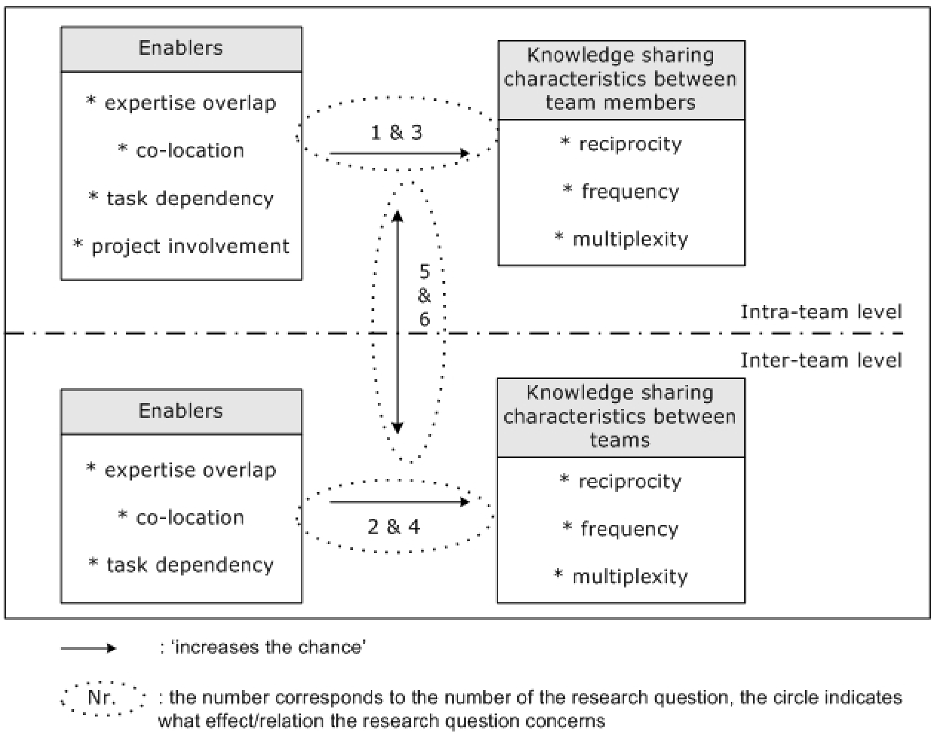

Figure 1-2: Refined conceptual model

2. *What is the effect of expertise overlap, co-location, and task dependency on the reciprocity, frequency, and multiplexity of knowledge sharing between teams?*

The conceptual model defines the first and second research question by dotted circles numbered one and two. The first research question specifically relates the enablers to the dyadic knowledge sharing characteristics at the intra-team level (between team members). The second research question aims to gain an insight into the effects of the enablers on knowledge sharing characteristics at the inter-team level, where dyadic knowledge sharing takes place between teams. Because no existing theory specifically explains knowledge sharing characteristics between and within teams in instrument consortia, we looked for existing theories with mechanisms to explain the knowledge sharing in the instrument consortia. We chose to set up a multi-theory framework to test propositions from different theories and see which theory best explained dyadic knowledge sharing in instrument consortia and to be able to present a more nuanced image. This meant that in addition to conducting empirical research on knowledge sharing itself, we adopted a multi-theory perspective in which we compared (competitive) social theories to explore which mechanisms best explained the effects of the enablers on the knowledge sharing characteristics.

The theoretical exploration of this thesis includes the following two research questions:

3. *Compared on explanatory strength, which theory best explains the effects of enablers on knowledge sharing characteristics within teams?*
4. *Compared on explanatory strength, which theory best explains the effects of enablers on knowledge sharing characteristics between teams?*

The conceptual model defines these questions by dotted circles numbered three and four.

Literature and management generally do not distinguish between managing knowledge at the intra-team and at the inter-team level. It is not uncommon for the same tools to be used at both levels. However, it should be explored whether there are differences in how knowledge is shared at the intra-team and at the inter-team level. A difference may imply that different approaches should be adopted for influencing the knowledge sharing at the two levels. For theory development it should also be explored whether there are differences between the two levels, instead of aggregating from one level to the other without taking possible differences into account. Thus, from both a practical and a theoretical point of view, there are arguments for comparing knowledge sharing at the intra-team level with knowledge sharing at the inter-team level. Two additional research questions on the comparison of knowledge sharing at the intra- and inter-team level were therefore included:

5. *What are the differences between the intra-team level and inter-team level in the effects of enablers on knowledge sharing characteristics?*

6. *Do the intra-team and inter-team level differ on the theories best explaining knowledge sharing?*

The following section describes how the research questions are answered and how the thesis is set up.

1.5.3 Research process and outline thesis

This study started with a literature review, applied to the specific context of instrument consortia. The resulting framework of theories was used to formulate propositions about the relations of the enablers and the knowledge sharing characteristics. Chapter 2 discusses this framework of theories. The propositions in the framework of theories are explored in an empirical study. The focus of this thesis is on instrument consortia, therefore the empirical study was conducted within this specific context. Chapter 3 sets out the design of the empirical study. Data was gathered and analyzed on two levels: knowledge sharing in dyads at the intra-team level and at the inter-team level. The fourth chapter presents the results of the study of knowledge sharing at the intra-team level, thereby answering research question 1 and 2. Chapter 5 explores knowledge sharing between teams, answering research questions 3 and 4. And, by comparing the results at the intra-team level with the results at the inter-team level, we gain an insight into the differences and similarities of knowledge sharing at both levels, thereby answering research question 5 and 6. Chapter 6 concludes the thesis by summarizing the research questions and findings, discussing the practical and theoretical implications, the study and directions for future research.

Chapter 2

Explaining intra-team knowledge sharing in instrument consortia

2 Explaining knowledge sharing in instrument consortia

2.1 Introduction

This chapter focuses on establishing a framework of theories to offer propositions on how and why people in instrument consortia share knowledge. There are social theories that offer potential explanations in the form of mechanisms on why and how actors form knowledge sharing ties with each other: theories of self-interest, of mutual interest and collective action, transactive memory theory, contagion theories, exchange and dependency theories, proximity theory, and theories of network evolution. Forming an overarching theory that explains knowledge sharing behavior in instrument consortia is be based on existing theories. It is likely that multiple mechanisms simultaneously shape knowledge sharing behavior. Based on the research design three social theories are selected that may explain how and why actors form ties with each other within the context of instrument consortia. This selection is made in section 2.2. The social theories used are the Transactive Memory theory, the Social Exchange theory, and the Proximity theory. The previous chapter identified four enablers likely to affect knowledge sharing in instrument consortia: (1) task dependency, (2) expertise overlap, (3) co-location, and (4) involvement in multiple projects. How the enablers are related to knowledge sharing depends on how and why people form knowledge sharing ties. Because Transactive Memory theory, Social Exchange theory and Proximity theory are based on different mechanisms, it is expected that the theories propose different effects of the enablers on knowledge sharing characteristics. Sections 2.3, 2.4, and 2.5 discuss the propositions that follow from Transactive Memory theory, Social exchange theory, and Proximity theory concerning the effects of the enablers on knowledge sharing characteristics. The effects of the enablers each theory proposes are discussed separately for each characteristic of knowledge sharing. For example, for the effect of task dependency on reciprocity of knowledge sharing, we will discuss how task dependency will influence reciprocity according to Transactive Memory theory, Social Exchange theory, and Proximity theory. Subsequently, we will formulate propositions for the effects of respectively co-location, task dependency, and involvement in multiple projects on reciprocity for each of these three theories.

Similarly, propositions are formulated for frequency and multiplexity of knowledge sharing. The propositions that follow from the three social theories concerning reciprocity are formulated in section 2.3. For frequency of knowledge sharing, the propositions are formulated in section 2.4, and propositions for the effects of the enablers on multiplexity are formulated in section 2.5. A summary of the chapter and an overview of the framework of theories is given in section 2.6.

2.2 Theories explaining knowledge sharing

Considering the specific context of instrument consortia, what mechanisms underlie knowledge sharing between persons within these consortia? Such mechanisms usually follow from a theory that explains the phenomena studied. The applicability of such theories highly depends on the context in which they are developed. While there are theories that may** offer explanations on how and why people share knowledge, there is a lack of empirical testing and stipulation in the specific context of instrument consortia.

Nevertheless, several social theories attempt to explain the generic existence and emergence of (knowledge sharing) ties between actors and the mechanisms behind it. Monge and Contractor (2003), in their review of existing literature on networks, identify a wide array of social theories accounting for different properties of networks and network ties. These social theories are categorized into families, which are summarized, together with a brief description in table 2-1.

Social theories explaining networks

Theory	Short description
Theories of self-interest	Focus on how individuals make choices that favor their personal preferences and desires by creating ties that enable them to seek goals they wish to achieve.
Theories of mutual interest and collective action	Centers on the question how coordinated activity produces outcomes that are unattainable by individuals acting alone.
Transactive Memory theory	Explores how decisions to form network ties are influenced by what individuals think others know.
Contagion theories	Looks into the spread of ideas, messages, attitudes and beliefs through some form of direct or indirect contact.
Exchange and dependency theories	Explains the emergence of networks based on the distribution of resources across the members of the network.
Proximity theory (and homophily)	Explains network emergence based on the similarity of actors' traits as well as their similarity of location.
Theories of network evolution	Focuses on mechanisms of variation, selection, retention, and struggle or competition as explanations for the emergence of relations.

Table 2-1: Social theories explaining networks (based on Monge & Contractor, 2003)

Theories of *self interest* focus on how individuals make choices based on the consideration of what is best for them. The theoretical mechanisms of self-interest seek to explain an actor's attributes based on the focal actor's configuration of relations with other actors and the attributes of these actors.

Theories of *mutual interest and collective action* attempt to explain how coordinated activity produces outcomes unattainable by individual action (Monge & Contractor, 2003). An example of a theory of mutual interest is the public goods theory that focuses on how people are persuaded to contribute to the creation and/or maintenance of public goods so that everyone in the collective will be able to use them.

Transactive memory theory explains the forming of ties between actors based on what and whom the actors think others know. Transactive Memory systems are distributed repositories of knowledge elements that are tied together by linkages.

Contagion theories address questions concerning the spread of ideas, messages, information, et cetera through direct and indirect contacts. Contagion theories are based on a disease metaphor, as it explains networks as conduits for 'infectious' attitudes and behavior (Leenders, 1995).

Exchange theories attempt to explain why actors exchange resources based on the resources the other actors can offer them and the resources they themselves can offer to other actors.

Proximity theory is a form of homophily theory, based on the notion that similarity facilitates communication (Brass, 1995). Proximity theory tries to explain why actors form ties by their proximity. In this case proximity refers to 'closeness' in a broad sense, for example the similarity in backgrounds, or the similarity in level of education.

Theories of *network evolution* are based on the evolutionary mechanism that operates to select the changes (or variation as it is often referred to) that improve the survival of the species (Kauffman, 1995). In that sense it is a theory for development with improvement and fundamentally a theory of change.

These social theories offer explanations for network phenomena. Some explanations are overlapping, some are complementary, and some are contradictory. Different mechanisms proposed by the theories can operate simultaneously, sometimes reinforcing each other and sometimes restraining one another. The theories also provide us with possible competing explanations for how and why actors form knowledge sharing ties with each other. However, none of the theories has been applied to knowledge sharing in instrument consortia yet. Additionally, as Monge and Contractor (2003) argue, most likely no single theory can account for the complex motivations actors have for forming ties. For both reasons, this study has adopted a multi-theory approach to study knowledge sharing behavior in instrument consortia. By using multiple theories, it is possible to account for different characteristics of knowledge ties at different levels. Monge and Contractor mention two other advantages of a multi- theory approach: the amount of variance explained can be increased and the use of multiple theories stimulates the exploration of networks through different prisms (2002).

The selection of relevant theories to study knowledge sharing in instrument consortia takes place based on the criteria that follow from our study design and the choices made in the conceptual model. There are three main criteria the theories must meet. They have to:

1. explain effects of variables on knowledge sharing
2. have a static view
3. be applicable at the dyadic level

Re 1: The focus of our research (following from the research model and questions) is on explaining how certain enablers lead to knowledge sharing relations. We intend to explain the sharing of knowledge itself and not its consequences. Theories included in the theoretical framework should have a similar focus. This means that theories of self-interest, contagion theories, theories of mutual interest and collective action are not appropriate for our study. Theories of self-interest focus on the results individuals achieve by engaging in relations. For knowledge sharing, theories of self interest focus not on explaining knowledge sharing itself, but on the outcomes that an individual can achieve by sharing knowledge. Contagion theories do not fit the objective of our study because they would focus on the results of the knowledge sharing relations, instead of on how the relations emerged. Theories of mutual interest explain phenomena that are collectively established. This means theories of mutual interest would also try to explain the results of knowledge sharing and not whether and how the actors would engage in knowledge sharing relations. Theories of collective action focus on the individual behavior compared to the behavior of a collective. Theories of collective action would explain individual knowledge sharing in comparison with collective knowledge sharing. This falls outside the scope of this study.

Re 2: For empirical limitations, our research design adopted a static view on knowledge sharing relations. We limited our study to the relations at a certain moment in time instead of studying how knowledge sharing relations change over time. Therefore, theories of network evolution do not fit our research because these theories evolve around the dynamics of relations.

Re 3: The current study focused on knowledge sharing at the dyadic level, in pairs of team members and in pairs of teams. This made the theory of collective action unsuitable for this study, as it focuses on individual behavior compared to the behavior of a collective. The current study did not include the individual level.

To summarize, the theories of self interest, of mutual interest and of collective action, contagion theories, and theories of network evolution fell outside the scope of our research design. The three theories that did meet the criteria were transactive memory theory, social exchange theory and proximity theory. These theories were included in our study to build a framework for studying knowledge sharing within the instrument consortia. The theories offer general explanations for how ties are formed and exist in dyads of persons; they still need to be applied to our context. The theories and the explanations the offer for knowledge sharing ties are discussed;

and, subsequently, the theories are applied to the specific context of knowledge sharing dyads in instrument consortia.

Some of the theories have evolved over time and therefore have different versions. We used a skeleton version of each theory to interpret and use the basic principles of the theories. This is sufficient for the current study as the study is explorative of nature and aims to gain insight in the general explanatory value and predictive power of the theories.

2.2.1 Transactive Memory theory

The concept of transactive memory systems was first described by Wegner (1987). Studying dating couples, Wegner noticed that persons who had a history together, tended to rely on each other to obtain, process, and communicate information from distinct areas of expertise. Wegner labeled these shared systems for encoding, storing and retrieving information, Transactive Memory Systems. This concept has been further developed in the Transactive Memory (Lewis, 2003) theory, which provides evidence that group members divide the cognitive labor for their tasks over members specializing in different areas of expertise (Wegner, Erber, & Raymond, 1991). Transactive Memory theory specifies the relationship between the memory systems of actors and the communication that occurs between actors (Wegner et al., 1991). Transactive Memory theory states that someone's idea of another actor's knowledge is the reason for sharing knowledge with the other. At the dyadic level, this means that the theory of transactive memory predicts how an actor selects and shares knowledge based on what he thinks the other knows (Contractor & Monge, 2002).

Three processes are distinguished in Transactive Memory theory: (1) *directory updating*, (2) *information allocation*, and (3) *retrieval coordination* (Wegner et al., 1991).

Directory updating is the process where team members gain knowledge of the other members' specialized expertise (Palazzolo, 2005). In addition, the team members come to understand their own areas of expertise within their system (Hollingshead, 1998b). This knowledge of both the others' and their own areas of expertise can be used to identify sources for information sharing within the team. If the Transactive Memory System is to function, the team members need to know exactly who to ask for the information they need. Research has shown that the extent to which actors know who has what knowledge can affect the quality of their decisions (Littlepage, Robison, & Reddington, 1997). In this context Wegner et al. (1991) concluded that persons involved in close relationships agreed more about the relative expertise of each other in different areas opposed to strangers. In an organizational setting knowledge of who has what expertise can be acquired by working together (Hollingshead, 1998a; Hollingshead, 1998b; Moreland, Argote, & Krishnan, 1998), by being trained together (Yuan, Fulk, & Monge, 2007), or simply by using a company's 'yellow pages'. These studies also demonstrated that when team members are able to accurately recognize each other's expertise, this has a positive effect on performance. More recent research focuses on communication and information exchange critical for maintaining expertise recognition (Palazzolo, 2005). This shifts the attention more to the processes of knowledge sharing. Palazzolo argues that the processes of information allocation and retrieval is where efficiency and effectiveness of the Transactive Memory System can be measured and influenced (Palazzolo, Serb, She, Su, & Contractor, 2006). Information allocation and retrieval coordination are the processes of processing, storing and allocating information.

Information allocation is the process where one team member forwards information to another team member whom he believes is most qualified to process and encode the information for future access (Palazzolo, 2005). This serves two purposes. First, actors have a limited capacity to process and store information. If the actor recognizes the knowledge as potentially useful or in the area of expertise of a fellow member, he decides to pass it to that person. This makes him no longer responsible for the information, and his cognitive capacity can be used for areas of expertise for which he is responsible. This makes the Transactive Memory System more efficient. Second, this process supports the development of the transactive memory system by reinforcing the differentiation in the team (Hollingshead, 1998b); the team members become more expert in their own areas of expertise.

Retrieval coordination is where information that is needed is retrieved from others based on knowledge of the relative expertise of the members in the system (Wegner, 1995). Retrieval coordination occurs when a member seeks specialized information from the person in the team who is an expert in that area to help execute the task when his personal knowledge base is not sufficient (Hollingshead, 2000; Hollingshead, 1998a; Hollingshead, 1998b; Liang, Moreland, & Argote, 1995; Moreland et al., 1998).

Transactive Memory theory seems particularly suitable for studying (dyadic) knowledge sharing in instrument consortia as it focuses on how persons utilize each other’s expertise. This theory is also valuable since directory updating in instrument consortia may be complicated as physical distances and the temporary character of the project make it difficult to gain an insight into each other’s expertise. Although research has found a positive relationship between transactive memory systems and group effectiveness in groups composed of coworkers and work groups in laboratory settings (Lewis, 2003), research on the processes of knowledge sharing in transactive memory systems is lagging behind. Research on transactive memory has mostly been conducted in laboratory settings, on intimacy relations and in small groups. Little research is done within the context of organizational teams (Akgun, Byrne, Keskin, Lynn, & Imamoglu, 2005). This seems to be changing with authors like Palazzolo (2005) and Yuan et al. (2007), who studied transactive memory systems within the context of work teams. As far as we know, Agkun et al. (2005) are the first to apply Transactive Memory theory to NPD teams. Applying Transactive Memory theory to NPD teams, the authors suggest that team members must utilize each other as an external memory aid to add to and improve their own memories; people in NPD teams use their transactive memory system to retrieve and combine necessary information to complete the project successfully. Through an empirical study at group level, Akgun et al. (2005) found that transactive memory systems in NPD teams were positively associated with team learning, speed-to-market and new product success. When using Transactive Memory theory to explain knowledge sharing dyads in instrument consortia, the main idea is that a team member bases his knowledge sharing on the knowledge he believes the other team member has. The team member reduces his cognitive work load by passing on knowledge that he does not need to a team member whom he believes can benefit from it. Also, the team member forms knowledge sharing ties with other team members whom he thinks have the knowledge he needs.

2.2.2 Social Exchange Theory

The origin of Social Exchange theory lies in the work of Homans (1958) and Blau (1964b). In their original definition of Social Exchange theory Homans and Blau intended to explain the emergence of dyadic relationships by means of exchange mechanisms. With the work of Emerson (Monge et al., 2003), the scope was broadened beyond the dyad. Emerson was also the first to explicitly analyze the structure of exchange and to explicitly consider social structure as both product and constraint on the exchange relations within exchange theory. Since then many authors have been elaborating on social exchange theories, and the application of social exchange theories to organizational studies has resulted in studies of power, leadership, trust, and ethical behavior (Cook, Emerson, & Gillmore, 1983).

In Social Exchange theory, whether or not two persons create, maintain, and dissolve network ties is based on the resources and attributes they possess and need, which resources the other has and needs and the access they have to alternative knowledge sources. If there is a potential exchange in resources between two people, for example the exchange of knowledge, the knowledge sharing tie is created. A discrepancy in resources is then a condition for the creation of ties (Emerson, 1972). Social Exchange theory is therefore based on two principles: (1) an actor can be modeled as motivated by interests and rewards/punishments, and (2) most interaction consists of the exchange of valued items.

Contractor and Monge (2002) found Social Exchange theory to be an appropriate theory explaining why people form dyadic knowledge exchange ties. In the specific case of instrument consortia Social Exchange theory is valuable for explaining knowledge sharing because professionals from different organizations have to collaborate. The professionals have diverse knowledge so in principle they have something to offer each other. However, it is difficult for them to have an overview of the alternative sources for knowledge. When applying Social Exchange theory to the context of knowledge sharing, the explanation this theory offers for knowledge sharing behavior would be that two persons have knowledge sharing ties based on the knowledge they possess and need, and whether they have alternative sources for the knowledge they need. In the context of the people working in instrument consortia, Social Exchange theory would explain the existence of knowledge sharing dyads by the knowledge both parties have to offer each other. In other words: in dyads, when an actor believes another actor can offer him knowledge and that he can offer the other actor knowledge in return, the actor is more likely to approach the other actor for knowledge sharing. This also implies that following Social Exchange theory, in knowledge sharing ties there is a preference for balanced relations. To summarize, in the Social Exchange theory, the value that actors ascribe to other actors' knowledge has a considerable effect on how actors share knowledge.

2.2.3 Proximity theory

Initially, Proximity theory was concerned with the physical distance between persons and the effect this distance has on their communication. Proximity theory started with the work of Festinger et al (1950) who found that being physically proximate increases the probability that actors meet and interact and, thereby, it increases the likelihood that actors communicate. Other authors followed by studying the relation between physical proximity and communication (Gilly & Torre, 2000; Katz & Allen, 1985; Monge, Rothman, Eisenberg, Miller, & Kirste, 1985; Morgan, 2004; Rice & Aydin, 1991). Through these studies the basic thought of Proximity theory was derived: persons who are physically close are more likely to meet each other and communicate. Thus Proximity theory was originally concerned with meeting in the sense that when people are physically close their communication is facilitated because when they have a physical location in common this offers them the opportunity to meet each other. In other articles, this concept is extended to cover other kinds of proximity, for example organizational proximity (Monge et al., 2003). Thereby being close or proximate was extended to other dimensions. The basic notion of Proximity theory was generalized to the notion that when people experience closeness, they are more likely to form ties. "Close" now not only means physically close, but also refers to being close in a more abstract form, for example being close in thought worlds, or in culture. In this sense Proximity theory is a specific form of the homophily theories (Homans, 1958); the more the actors have in common, the closer they are and the more likely they are to form ties. Two lines of reasoning support this notion: the theory of similarity-attraction (Byrne, 1971; Heider, 1958), and the theory of self-categorization. Based on the work of Heider (1958), the similarity-attraction line of thinking argues that similarity reduces the psychological discomfort that may rise from cognitive or emotional inconsistency. The theory of self-categorization (Turner & Oakes, 1989) argues that individuals define their social identity through a process of analyzing their social environment. Stereotyping and depersonalization of self-perception are at the core of this process. When individuals categorize themselves as being a certain type, they accentuate similarities with others who they think are of a similar type.

Translated to knowledge sharing dyads, the explanation Proximity theory offers for two actors forming a knowledge sharing tie is whether they are 'proximate/close' in the sense that an actor is more likely to share knowledge with an other actor if they have more in common. In the instrument consortia the extent to which these mechanisms play a role in knowledge sharing remains to be explored as project members are not always physically close and in their expertise may also experience little closeness with their fellow project members. At the same time they are highly organizationally proximate in terms of their task dependencies.

As Monge et al. (1985) concluded, more proximity research has been conducted in the interpersonal than in the organizational context. Many studies on proximity have focused on the effects on communication, and have taken place in settings varying from highly controlled settings (Conrath, 1973; Wells, 1965; Zahn, 1991), to more natural organizational settings for employees in general (Allen, 1977; Pinto, Pinto, & Prescott, 1993) and R&D settings in specific (Hollingshead, 2000). Concerning knowledge sharing, several studies argued that proximity is necessary for transferring tacit knowledge (Nooteboom, 2000; Torre & Gilly, 2000). Torre and Gilly (2000) discuss the concept of proximity as applied within regional industrial studies. Concerning knowledge, they state that relations involving tacit knowledge exchange imply geographical proximity. Applying proximity theory to knowledge sharing dyads, Proximity theory would explain how and why two actors share knowledge based on how proximate they are. The closer one actor is to another, the more likely they are to share knowledge. Proximate in this sense means how much actors have in common on certain aspects.

2.3 Propositions for the effects of the enablers on knowledge sharing characteristics

Transactive Memory theory, Social Exchange theory and Proximity theory each propose general mechanisms through which the existence of knowledge sharing dyads can be explained. The main argument of Transactive Memory theory to explain knowledge sharing is that an actor bases his knowledge sharing on the perceptions he has of the knowledge the other actor possesses. Actors in a Transactive Memory system divide their cognitive work load, by passing on knowledge that they do not need to someone who they think can benefit from it and they ask for knowledge from others who they think have the knowledge they need. Social Exchange theory's main mechanism for explaining knowledge sharing is that people create, maintain and dissolve knowledge sharing ties based on the knowledge they possess and need and the access they have to alternative knowledge sources. So when an actor thinks another actor can offer him knowledge and that he can offer the other actor knowledge in return, the actor is more likely to approach the other actor for knowledge sharing. The value that the actors ascribe to the other actor's resources has a considerable effect on how the actors share knowledge. The reasoning provided by Proximity theory is that two actors form a knowledge sharing tie based on whether they are 'proximate/close' in the sense that actors are more likely to share knowledge with the other if they have more in common.

All three theories attempt to explain how actors form ties by the attributes their relations have. As can be seen in the conceptual model presented in chapter 1, this is exactly the focus of our study as we explore how the variables in the relational context affect the way the actors share knowledge. Because the three theories are based on different underlying mechanisms, it can be expected that the ideas on how the enablers affect knowledge sharing are also different. Below, we discuss the propositions that follow from Transactive Memory theory, Social Exchange theory, and Proximity theory concerning the effects of the enablers on the knowledge sharing characteristics. The propositions are discussed separately for each property of knowledge sharing. Starting with reciprocity, we will discuss how the expertise overlap will affect reciprocity following Transactive Memory theory, Social Exchange theory, and Proximity.

2.3.1 The proposed effects of the enablers on reciprocity

The effect of expertise overlap on reciprocity

Transactive Memory theory assumes that a team works as a Transactive Memory System: everyone is an expert in his own area, and these experts depend on each other's knowledge for completing their tasks. Transactive Memory systems becomes more efficient as knowledge becomes more differentiated and less redundant among the individuals in the system (Palazzolo, 2005). Knowledge differentiation is the extent to which transactive memory system members are experts in areas that other people are not (Wegner, 1987). When there is no or a small overlap in expertise, the differentiation is large. This means that the team members will need each other's expertise and approach each other for the topics they themselves are no expert on, but the other is. So having no or a smaller overlap in expertise would lead to mutual and asymmetrical knowledge sharing. When there is a large overlap in expertise, Transactive Memory theory would say the team members are less likely to share knowledge, since they would assume all of them have the same knowledge anyway. Thus Transactive Memory theory proposes expertise overlap to have a negative effect on the reciprocity of knowledge sharing.

Social Exchange theory explains the forming of ties by the demand and supply of resources; in the case of knowledge sharing a team member is likely to share knowledge with someone who can offer him the knowledge needed and to whom he can offer knowledge in return. Thus, in the case of knowledge being shared, both team members involved must have to offer each other knowledge of value. Knowledge that has most value is the knowledge not possessed; there has to be a discrepancy in knowledge (Akgun et al., 2005; Hollingshead, 2000; Moreland, Argote, & Krishnan, 1996). When there is no expertise overlap, the discrepancy in knowledge is highest and it will be most valuable for team members to share knowledge. In that case their knowledge sharing is more likely to be reciprocal. The larger the overlap in expertise, the smaller the discrepancy in knowledge.

Consequently, the knowledge they can offer each other becomes less valuable. In situations like these, knowledge sharing ties are more likely to be absent (a null tie) or asymmetrical at the most. Social Exchange theory therefore proposes a negative effect of expertise overlap on the reciprocity of knowledge sharing.

From *Proximity theory* we expect the opposite. Being a form of homophily-theory, Proximity theory is based on the notion that the more the team members have in common, the closer they are and the more likely they are to form ties. The larger the expertise overlap, the closer the team members are in their thought worlds, because they for example are used to the same professional language and the same way of thinking. Cognitive proximity is also a term used to describe this type of closeness (Nooteboom, 2000). Several authors have pleaded for cognitive closeness as facilitating communication and knowledge sharing and absorption (Dougherty, 1992; Nooteboom, 2000). Proximity theory would therefore suppose that as the expertise overlap becomes larger, the team members are more likely to share knowledge (either mutually or asymmetrically).

The effect of co-location on reciprocity

Transactive Memory theory would argue that for a transactive memory system to function, people need accurate representations of who has what knowledge. When team members are co-located, it is easier for them to learn about who has what knowledge; directory updating is facilitated. Other authors (Moreland, 1999; Wegner, 1987) add that the representations of who has what expertise are acquired gradually and informally and are hardly documented explicitly and, therefore, can remain unrecognized by remote group members. Research on transactive memory systems has also shown that dating couples who worked face-to-face retrieved acquired knowledge more effectively than dating couples that worked via a computer conference system that only supported text-based communication (Hollingshead, 1998b). This would suggest that in a situation where the team members are co-located, and therefore have more opportunity to interact face-to-face, information retrieval and information allocation is also facilitated. Studies on virtual teams support these arguments, showing that co-location increases the shared understanding of contextual knowledge, helping members to directly observe and share experiences (Jarvenpaa & Staples, 2000). Overall it becomes easier for the team members to make full use of each other's expertise and approach each other for knowledge allocation and retrieval, which makes them more likely to use each other's knowledge mutually. To sum up, Transactive Memory theory expects co-location to have a positive effect on the reciprocity of knowledge sharing.

From a *Social Exchange theory* point of view, it is also proposed that co-location has a positive effect on reciprocity. Cramton (2001) for instance found that dispersed teams lacked mutual knowledge of their members' resources, causing miscommunication, misattribution of intents, and ineffective collaboration between members. When not co-located, the team member may not be familiar with the knowledge the other has to offer or he may not see alternatives. In this case, knowledge sharing ties are more likely to be absent or asymmetrical. When team members are located in the same building, it is easier for them to learn what knowledge the other has to offer. As research on social exchange shows, these individual beliefs about knowledge ownership are related to the sharing of knowledge (Festinger, Schachter, & Back, 1950). It enables the team members to engage in knowledge sharing ties that are likely to be reciprocal. Social Exchange theory proposes a positive effect of co-location on the reciprocity of knowledge sharing.

Proximity theory is originally based on the work of Festinger et al (1950) who found that physical closeness facilitates communication because people are more likely to meet and interact. Related research studying the relation between physical proximity and communication (Brandon & Hollingshead, 2004) came to the same conclusion: when people are physically close their communication is facilitated. A common physical location offers them the opportunity to meet. Translated to knowledge sharing within the context of instrument consortia, proximity theory would suggest that when team members are not co-located, this would make them more likely to not share knowledge, to have null ties. When the team members in these consortia work in the same location, they are more likely to share knowledge with each other (either mutually or asymmetrically). A positive effect on reciprocity is therefore expected from co-location.

The effect of involvement in multiple projects on reciprocity

Following *Transactive Memory theory*, for a transactive memory system to function properly, people need accurate representations of the knowledge of the team members in the system. The accuracy of expertise recognition is the extent to which team members in the network accurately perceive what knowledge other team members possess (Rau, 2000, in: Palazzolo et al, 2006). When both team members in a dyad are involved in this one consortium. their expertise recognition can be quite accurate, facilitating the information allocation and retrieval. This makes them more likely to know to whom they should pass on knowledge, from whom they can retrieve knowledge, but also to whom not to pass on knowledge and who not to approach when confronted with a specific problem. Their knowledge sharing is therefore more likely to be mutual and less likely to be null or asymmetrical. When team members are not only partly involved in the consortium but also work on other projects, their expertise recognition is likely to be less accurate than for the team members who are involved in this one project. Participation of team members in multiple projects also has an advantage, for these team members are also part of other transactive memory systems. Being involved in multiple projects broadens a team member’s perspective, and he may learn how to apply his expertise in different situations. This means the person involved in another project becomes more expert. So while expert recognition is harder for the team members involved in multiple projects, at the same time these team members become more expert through being part of another transactive memory system. In a situation where one team member is involved in multiple projects and the other team member is not, the one working fulltime could approach the one involved in multiple projects for new expertise. At the same time the team member involved in multiple projects could approach the other for staying up-to-date on the tasks in the consortium. A dyad where one is involved in multiple projects and the other is not, is therefore expected to result in reciprocal knowledge sharing. When two team members are both involved in multiple projects, they both become more expert, but at the same time their priorities shift between projects and the time to share knowledge is restricted for both. This leads to both team members being very selective in their knowledge sharing; they only approach the persons who they think have the crucial knowledge, leading to more null and asymmetrical ties. Summing up, Transactive Memory theory expects the involvement of one team member on multiple projects to be positive for reciprocity, and the involvement of both team members in multiple projects to have a negative effect on the reciprocity of their knowledge sharing.

Several authors in *Social Exchange theory* pose that exchange takes place if the team members believe that the exchange provides them with more value than the other options open to them do (Uehara, 1990). Therefore, according to Social Exchange theory, knowledge sharing depends on the alternative sources of knowledge open to the team members; “the alternatives will determine the limits within which the rate of exchange falls” (Heath, 1976 in Uehara, 1990: p.532). When both team members are working solely within the consortium, the number of alternative sources for knowledge is similar for both, resulting in a great likelihood for reciprocal knowledge sharing ties. In situations where team members are involved in multiple projects, they have a higher chance of finding alternative knowledge sources. When one of the team members is involved in another project but the other team member is not, the one working in multiple projects would have more alternative sources. Their relation is then unbalanced, and this increases the chance they do not share knowledge or share knowledge asymmetrically. In a dyad where both team members are involved in multiple projects, circumstances are similar for both, and this is expected to result in reciprocal knowledge sharing ties. To summarize, Social Exchange theory proposes a negative effect on reciprocity when one team member is involved in multiple projects. The situation where both team members are involved in outside projects is expected to positively influence the reciprocity of knowledge sharing.

Following the arguments of *Proximity theory*, involvement in multiple projects leads to more distance. First, being involved in multiple projects means that team members acquire different experiences as they are part of other groups of people. Second, being involved in multiple projects can also implicate that one changes locations, which causes physical distance. Where both team members are involved in this one consortium, they would be close and Proximity theory would expect greater likelihood for reciprocal knowledge sharing. In situations where one team member is involved in multiple projects and the other is not, the team members are less proximate than they would be if they would both be involved in this one consortium. Because they would be less proximate, they would also be less likely to find each other for knowledge. Therefore, their knowledge sharing is more likely to be null or asymmetrical. This would be the same for the situation where one of the two or both are involved in multiple projects. So from the perspective of Proximity theory the involvement of team members in multiple projects is expected to have a negative effect on the reciprocity of their knowledge sharing.

The effect of task dependency on reciprocity

Transactive Memory theory is based on the notion of cognitive dependence. Team members try to lower their cognitive work load by distributing it across team members in the Transactive memory system. By dividing the cognitive work load, cognitive dependencies are created and where team members perceive dependency on each other's knowledge, they are likely to share knowledge. Cognitive interdependence is necessary for the development of a transactive memory; it is not group membership itself but the interdependence that comes along with group membership that stimulates the development of a transactive memory system (Hollingshead, 1998a; Moreland, 1999; Wegner et al., 1991). Interdependency indicates that people are interdependent in the sense that a team member's actions have an impact on other team members' outcomes (Emerson, 1962). In work situations, and certainly in Instrument consortia, the cognitive interdependency between team members is mainly caused by task dependencies, particularly when one team member's output is another team member's input (Thompson, 1967). Thus, when team members perceive they are task dependent, they are cognitively interdependent and more likely to approach each other for knowledge allocation and retrieval. This means that at the dyadic level team members who do not perceive any task dependency are unlikely to share knowledge. When the team members do perceive task dependency, they are likely to share knowledge mutually or asymmetrically. Thus, Transactive Memory theory proposes task dependency to positively influence the reciprocity of knowledge sharing.

Following *Social Exchange theory*, the exchange of resources is related to the extent to which team members are dependent on each other for resources. As Emerson (1972) argues, the dependence of team member B on team member A is (1) directly proportional to B's motivational investment in resources owned by A, and (2) inversely proportional to the availability of those resources outside of the A-B relation. When there is no task dependency, Social Exchange theory would argue that the team members attach less value to the knowledge the other has and therefore they would be more likely to share knowledge asymmetrically or not at all. In the situation that A and B are task dependent, the number of alternative sources for that particular knowledge is very small or non-existent, for they

Propositions for reciprocity									
Explanatory variables (enablers)	Social theory								
	Transactive Memory theory			Social Exchange theory			Proximity theory		
	M	A	N	M	A	N	M	A	N
Expertise overlap	-	+	+	-	+	+	+	+	-
Co-location	+	-	+	+	-	+	+	+	-
Involvement in multiple									
projects: one actor	+	+	-	-	+	+	-	+	+
both actors	-	+	+	+	-	-	-	+	+
Task dependency	+	+	-	+	-	-	+	+	-

M = mutual knowledge sharing
A = asymmetric knowledge sharing
N = no knowledge sharing
+ : theory proposes a positive effect of the enabler on reciprocity
- : theory proposes a negative effect of the enabler on reciprocity
How to read this table: For example, Transactive Memory theory expects expertise overlap to negatively influence mutual knowledge sharing.
Table 2-2: Propositions for reciprocity

specifically need each other's input for their tasks. In that case the team members attach great value to each other's knowledge and this makes them more likely to share knowledge mutually. Therefore Social Exchange also proposes a positive effect of task dependency on the reciprocity of knowledge sharing.

Proximity theory would also argue that there is a positive effect of task dependency on the reciprocity of knowledge sharing ties. Proximity theory defines task dependency as a form of organizational proximity. Even though the definitions of organizational proximity differ, they agree on the notion that organizational proximity would facilitate interaction between people. Task dependencies create organizational proximity and this makes people more likely to share knowledge with each other. Where there is no task dependency relation, they are less close and thereby their knowledge sharing is more likely to be null or asymmetrical. This means that Proximity theory expects task dependency to have a positive effect on reciprocity.

The different expectations based on the three social theories concerning the effects of the variables on the reciprocity of knowledge sharing are summarized in table 2-2.

2.3.2 The proposed effects of the enablers on frequency

The effect of expertise overlap on frequency

As discussed under reciprocity, differentiation is crucial for the functioning of a *Transactive Memory* system as the system becomes more effective and efficient as each team member becomes more expert in his own area. If there is no overlap in expertise the transactive memory system would function effectively, and team members are likely to be aware of needing each other's knowledge for task completion. This would lead the team members to share knowledge frequently. Nickerson (1999) has argued that when people are knowledgeable across multiple areas of expertise, they assume that others are also experts in multiple areas of expertise. Consequently, they assume that they are self-sufficient and others are too. The greater the expertise overlap between two team members, the more they assume to be self-sufficient and assume the other is too. This would lead to less frequent knowledge sharing between the team members. To summarize, Transactive Memory theory proposes a negative effect for expertise overlap on the frequency of knowledge sharing.

Focusing on the resources the team members have, *Social Exchange theory* would argue that people tend to seek others who can offer them knowledge and to whom they can offer knowledge. As mentioned, people offer each other knowledge of the most value when there is a discrepancy in their knowledge (Jarvenpaa et al., 2000). When there is no expertise overlap, or the overlap is small, the team members can both offer each other valuable knowledge. People prefer these types of relations; and, therefore, they are more likely to engage more frequently in these knowledge sharing relations than in relations where the expertise overlap is larger and the value they can offer each other is smaller. Thus following the arguments of Social Exchange theory, as the overlap in expertise increases the team members are likely to share knowledge less frequently.

The previous section on reciprocity argued that *Proximity theory* regards people with a large overlap in expertise more proximate than people with no or a small overlap in expertise. Team members prefer to engage in relations with others who are similar or proximate to them. Knowledge sharing is one such relation, so a larger overlap in expertise would be expected to cause the team members to share knowledge more frequently.

The effect of co-location on frequency

Transactive Memory theory would suggest a positive effect for co-location on the frequency of knowledge sharing ties. The arguments mentioned for the effect of co-location on reciprocity of knowledge also play a role in the effect of co-location on frequency. When co-located, the processes in the transactive memory system are facilitated (Akgun et al., 2005;

Hollingshead, 2000; Moreland et al., 1996). It not only becomes easier to recognize expertise, but also to approach others in the system for knowledge allocation and knowledge retrieval. Furthermore, as a number of authors mention, being co-located means that team members meet more often and develop collective knowledge of 'how to get things done around here', which facilitates knowledge sharing (Collins, 1983; Granovetter, 1985; Kogut et al., 1992). These arguments lead to the proposition that co-location leads to more frequent knowledge sharing.

The arguments for *Social Exchange theory* are more or less similar to that of Transactive Memory theory. From the perspective of Social Exchange theory, co-location makes it easier for team members to learn about the knowledge other team members have to offer. They become aware of alternative sources for knowledge but also they get to learn who has valuable knowledge. At the same time they are also able to identify their own position. (Emerson, 1962). Thus, the team members are better be able to identify who can offer them valuable knowledge and to whom they can offer valuable knowledge. Consequently, they can make better choices about who they want to share knowledge with. The ties they prefer are balanced ties (Nahapiet et al., 1998) so when they can make better choices about whom to share knowledge with, they are likely to engage more frequently in knowledge sharing ties, which will mostly be the balanced ones. Thus from the Social Exchange theory point of view, co-location is expected to have a positive effect on the frequency of knowledge sharing.

The reasoning from the perspective of *Proximity theory* is quite straightforward, as co-location is in fact physical proximity. A lot of research in Proximity theory is concerned with the effect of physical proximity on the frequency of interaction. As argued, being proximate increases the likelihood that people share knowledge, because the team members have more opportunities for spontaneous and planned interaction (Kiesler & Cummings, 2002; Newcomb, 1961). Thus, from a Proximity-theory perspective, being co-located means that the team members are physically proximate, and this leads the team members to share knowledge more frequently.

The effect of involvement in multiple projects on frequency

Transactive Memory theory would argue that when people are involved in multiple projects, they not only have less time for expert recognition, their perceptions of others' expertise may also be less accurate. Perceptions of each other's' expertise can come from different sources, such as shared experiences and previous conversations (Hollingshead, 1998a; Wegner et al., 1991). When people are working full time in the consortium they are likely to have more shared experiences and previous conversations than when one or both are also involved in projects outside the consortium. Therefore when one or both are involved in multiple projects, their perceptions of each other's expertise are likely to be less accurate than they would have been when both were involved in the consortium only. When involved in multiple projects, they not only have less insight into who has which expertise, they also simply have less time to allocate and retrieve knowledge. At the same time, if team members are also involved in multiple projects they are also part of other transactive memory systems. Knowledge allocation and retrieval with others becomes easier as they learn to share knowledge with people from other areas of expertise. So participating in multiple projects is expected to cause members to share knowledge less frequently, also because the team members need less time to share knowledge. This concerns the situation where one of the team members is involved in multiple projects as well as the situation where both team members are involved in multiple projects.

When team members are involved in multiple projects, *Social Exchange theory* would argue that the chance that they have alternative options for knowledge sources is greater. As argued in the section on reciprocity, how and whether the team members engage in knowledge sharing relations depends on the availability of alternative knowledge sources. When both team members are involved in this one consortium they not only have about the same range of alternative sources for knowledge, they also learn more about each other's knowledge. This makes them likely to share knowledge frequently. Where only one of them is involved in multiple projects, this person is better able to identify different sources of knowledge. The team member involved in this one consortium is likely to have less alternative knowledge sources, which makes the relation unbalanced and the team members are therefore likely to share knowledge less frequently. The involvement of one team member in multiple projects is therefore expected to have a negative effect on the frequency of knowledge sharing. When two team members are both involved in multiple projects, the opportunities of finding alternative knowledge sources is equal for both. This makes their exchange position more equal; therefore, a positive effect is expected for the strength of knowledge sharing ties.

From the perspective of *Proximity theory*, the involvement of team members in projects outside the consortium leads them to be less proximate. They share less project-specific experiences, they might work in different locations and when persons are involved in multiple projects they are involved in different project environments surrounded by different persons, working on different tasks. In this perspective, in a dyad where one or both team members is/ are involved in multiple projects, the team members are less proximate and this is likely to lower their frequency of knowledge sharing.

The effect of task dependency on frequency

As argued, cognitive dependency is central to the *theory of Transactive Memory* systems. Cognitive dependency exists when people perceive they are dependent on each other's knowledge for the execution of their tasks (Hollingshead, 1998a). Cognitive dependency is most likely when the group task is complex, non-routine, and requires a high degree of coordination

Propositions for frequency

Explanatory variables (enablers)		Social theory		
		Transactive Memory theory	Social Exchange theory	Proximity theory
Expertise overlap		-	-	-
Co-location		+	+	+
Involvement in multiple				
Projects:	one actor	-	-	-
	both actors	-	+	-
Task dependency		+	+	+

+ theory proposes a positive effect of the enabler on frequency
- theory proposes a negative effect of the enabler on frequency
How to read this table: For example, Transactive Memory theory expects a negative effect of expertise overlap on the frequency of knowledge sharing.

Table 2-3: Propositions for frequency

between group members (Levine & Moreland, 1999 in: Brandon & Hollingshead, 2004). In instrument consortia, where there is task dependency between team members, tasks become more complex, and need coordination, which causes the team members to be cognitive dependent. Where cognitive dependency is perceived, people are likely to share knowledge more frequently. Thus from the perspective of Transactive Memory theory, it is likely that where task dependency is perceived, people will share knowledge more frequently than when there is no task dependency.
As stated before, the central notion in *Social Exchange theory* is that people prefer to share knowledge with others who can offer them knowledge of value, and who they can offer knowledge in return. When there is a task dependency tie between two team members, the output of one team member constitutes input for the other and the other way around, as they need to coordinate their tasks. This means that they both have valuable knowledge to offer each other for the completion of their tasks. This increases the likelihood that they share knowledge more frequently. Therefore, from a social exchange perspective we expect that if there is a dependency relation between the team members in a dyad, they are likely to share knowledge more frequently than when there is no task dependency.

From the perspective of *Proximity theory*, it is also expected that task dependency and the frequency of knowledge sharing are positively related. As discussed above, task dependencies create a form of organizational closeness. This closeness makes the team members likely to share knowledge more frequently. That means that if there is a dependency relation between team members, they are likely to share knowledge more often than if there is no task dependency between them; task dependency has a positive effect on frequency.

It is safe to say that there are differences between SE, Proximity, and Transactive Memory theory in the effects they propose of the variables on the frequency of knowledge sharing. The expected effects are summarized in table 2-3.

2.3.3 The proposed effects of the enablers on multiplexity

The effect of expertise overlap on multiplexity

Transactive Memory theory assumes that groups of team members function as transactive memory systems. Knowledge differentiation is used as a measure for the development of a transactive memory system. Individuals accept responsibility for different knowledge areas (Wegner et al., 1991). The transactive memory system is most efficient when each team member in the system has his own area of expertise (Hollingshead, 1998a). That means that in situations where team members have no or just a small overlap in expertise, they are most efficient in processing information and knowledge. After all, when team members need certain knowledge when working on their tasks they can approach another team member who is an expert in that area. With this expert there is more knowledge to share because the expert knows much more about the specific topic than does the non-expert. Therefore, as the differences in areas of expertise become larger, knowledge sharing becomes more focused, with more knowledge to allocate to and retrieve from other team members. As the expertise overlap is larger the team members all have broader expertise that is less deep. This is expected to lead to less thick knowledge being shared, i.e. a lower multiplexity of knowledge sharing.

Social Exchange theory emphasizes the role of demand and supply of knowledge to explain knowledge sharing; a team member is likely to share knowledge with someone who can offer him/her the knowledge needed and whom he can offer knowledge in return. Social Exchange theory stresses that knowledge for the team members has most value if it is knowledge they themselves do not possess (Dougherty, 1992). The greater the difference in expertise, the more the team members can offer each other. This means that if the overlap is very small or nil, team members are not only more likely to share knowledge, but also to share knowledge about different topics. If on the other hand, the overlap is larger and they have less knowledge to offer to each other, their knowledge sharing is likely to be less thick or absent.

Proximity theory emphasizes that expertise overlap refers to the number of areas of expertise the team members have in common. The more areas of expertise the team members have in common, the more similar they are. Also, the overlap in expertise may lead the team members to be cognitive proximate, which means they are more similar in worlds of thought (Jarvenpaa et al., 2000). When team members are closer, their knowledge sharing is likely to be richer. So from this perspective the argument would be that the larger the overlap in expertise, the more multiplex the knowledge sharing tie is.

The effect of co-location on multiplexity

Transactive Memory theory argues that when team members are co-located they often share the same relations and are exposed to the same external information. They specialize further and cognitively divide their workload (Hollingshead, 2000; Wegner et al., 1991). They also become more efficient in processing knowledge, and their knowledge sharing is expected to be richer. This argument is supported by Stasser and William (1987) who argue that knowledge that is shared locally is unlikely to be shared by dispersed group members who have not already interacted extensively and is therefore less likely to be discussed by a dispersed group. To summarize, from the perspective of Transactive Memory theory, being co-located is expected to have a positive effect on the multiplexity of the knowledge shared.

Under the *Social Exchange theory* knowledge sharing is based on how dependent the team members are on each other's knowledge. This dependence is linked to the motivational investment in each other's knowledge and to the availability of the knowledge from alternative sources (Emerson, 1972). When team members are co-located they are better able to identify who has what knowledge and who are the alternative knowledge sources. Because they are better able to see substitutes, they are likely to not make themselves dependent on just one or two persons for knowledge, but instead spread these dependencies and share knowledge with different persons on different topics. Therefore, being co-located is expected to have a negative effect on the number of types of knowledge that is shared between two team members.

From the perspective of *Proximity theory*, co-location means that the team members are physically proximate. Proximity promotes the readiness of interaction, and consequently people have the opportunity to discover each other's commonalities (Newcomb, 1961). Translated to the context of knowledge sharing, this means that co-location makes people more likely to interact and share knowledge and by interacting these people get to know more about each other and find more similarities between them. This makes them likely to also share knowledge about other things. For example, when people working on the same floor meet each other at the coffee machine and start talking, they get to know more about what the other is working on or what the other person's interests are. This makes them more likely to start sharing knowledge. Thus, Proximity theory argues that when people are co-located, this increases the likelihood of them sharing multiple contents of knowledge.

The effect of involvement in multiple projects on multiplexity

From the perspective of *Transactive Memory theory*, a person involved in multiple projects is also involved in other transactive memory systems. This makes this person more likely to develop knowledge in other areas of expertise. Additionally they learn to apply their expertise in other settings. They bring this expertise to their team so that other team members can retrieve this knowledge and benefit from it. This makes it more likely that the multiplexity of the knowledge shared increases. Thus in situations where one or two team members are involved in multiple projects, the Transactive Memory theory would propose proposes that this has a positive effect on the multiplexity of knowledge sharing.

From the perspective of *Social Exchange theory*, the involvement of team members in projects outside the consortium increases the probability of finding alternative knowledge sources. When two team members are involved on the same project, they are more dependent on each other for knowledge because there are less alternatives and also they learn more about the value of the knowledge they can offer each other. This leads to thicker knowledge being shared. Team members who are involved in multiple projects have more opportunities to spread their knowledge sharing across multiple relations. For each individual case they can decide who is the best knowledge source for that situation. As a consequence their knowledge sharing is less multiplex. In cases where one is involved in multiple projects but the other is not, there is a greater chance of an unbalanced situation as the team member involved in multiple projects has more alternative sources than the other. In this situation, knowledge sharing is also likely to be less multiplex.

In the perspective of *Proximity theory*, involvement in multiple projects is likely to make team members less close as they have less in common. The team members involved in multiple projects have to divide their time over multiple projects. They have less time and opportunity to develop a shared language and other commonalities. Additionally, their physical proximity might also decrease because the projects they are working on might differ in location. This may cause people to shift from locations, thereby decreasing physical proximity. When people are less close, the multiplexity of the knowledge shared between them is likely to become less.

The effect of task dependency on multiplexity

We already discussed that *Transactive Memory theory* sees task dependencies as an important source for cognitive dependencies. Leading to cognitive dependencies, task dependencies stimulate the development of Transactive Memory systems. It motivates team members to become more expert in their own domain as they accept responsibility for a certain area of expertise (Wegner, 1987). This eventually results in the team members sharing thicker knowledge because they need each other’s knowledge for

Propositions for multiplexity			
Explanatory variables (enablers)	Social theory		
	Transactive Memory theory	Social Exchange theory	Proximity theory
Expertise overlap	-	-	+
Co-location	+	-	+
Involvement in multiple			
projects: one actor	+	-	-
both actors	+	-	-
Task dependency	+	+	+

+ theory proposes a positive effect of the enabler on multiplexity
- theory proposes a negative effect of the enabler on multiplexity
How to read this table: For example, Transactive Memory theory expects a negative effect of expertise overlap on the multiplexity of knowledge sharing.
Table 2-4: Propositions for multiplexity

task completion. So from the Transactive Memory point of view, task dependencies cause the team members to share thicker knowledge.

According to *Social Exchange theory*, when two team members' tasks are interdependent, they need each other's knowledge for the execution of their tasks. For this knowledge they are entirely dependent on each other because they exclusively hold that task-specific knowledge. People prefer these types of balanced relations, where both team members have to offer each other knowledge of equal value. So when team members are task dependent on each other, their knowledge is very valuable for each other, which makes them more likely to share knowledge (Dow, Bobrinsky, Pallaschke, Spada, & Warhaut, 2006). Additionally, their motivation to engage in these knowledge sharing ties is high (for the relations are balanced), so there is a greater probability that they will share multiple content-types of knowledge.

We have already argued above that following *Proximity theory*, task dependency leads to a form of organizational proximity. Being more proximate makes the team members not only more likely to share knowledge more reciprocally or more often, but also to share thicker knowledge. Proximity theory would argue that people share more contents of knowledge when being proximate. Therefore, dependencies are positive for the multiplexity of knowledge shared.

The propositions for multiplexity of knowledge sharing as deducted from the theories are summarized and represented in table 2-4.

2.4 Summary

This chapter started with a search for social theories that are likely to explain how and why people share knowledge. A multi-theory approach was argued for, because it is likely that multiple mechanisms underlie knowledge sharing behavior of the team members in instrument consortia. Three theories were selected for explaining knowledge sharing in instrument consortia; Transactive Memory theory, Social Exchange theory, and Proximity theory. Transactive Memory theory explains knowledge sharing ties by team members sharing knowledge to reduce their cognitive workload and basing their knowledge sharing on the perceptions they have of the other team member's knowledge. From the perspective of Social Exchange theory, team members share knowledge with other team members based on the knowledge and attributes they possess and the knowledge the other team member has and needs. The explanation Proximity theory offers for two team members forming a knowledge sharing tie is whether they are 'proximate/close' in the sense that they are more likely to share knowledge when they have more in common. These three social theories offer general explanations for explaining knowledge sharing dyads, but they have not been applied to the specific context of this research: knowledge sharing in instrument consortia.

The context of knowledge sharing in instrument consortia was translated into four enablers expected to have an effect on the way people in the instrument consortia share knowledge. The way people share knowledge is reflected in the knowledge sharing characteristics reciprocity, frequency, and multiplexity. Subsequently, from the perspective of each social theory it was reasoned how the enablers would affect the knowledge sharing characteristics and for each theory propositions were formulated regarding these effects.

The propositions are summarized in table 2-5. The columns indicate the enablers, the rows the explained knowledge sharing characteristics, grouped for each social theory. For example, in table 2-5 we see that the involvement of both team members in multiple projects is expected to have a positive effect on the frequency following Social Exchange theory. For some effects the theories offer complementing or overlapping propositions; for other effects they are contradictory. This indicates that it may indeed be the case that multiple mechanisms simultaneously shape knowledge sharing. The empirical part of this study evaluates the explanatory value of the theories.

Theoretical propositions intra-team knowledge sharing							
			Explanatory variables				
Social theory	**Explained characteristic**		Expertise overlap	Co-location	Involvement in multiple projects one actor	both actors	Task dependency
Transactive Memory theory	Reciprocity	M	-	+	+	-	+
		A	+	-	+	+	+
		N	+	+	-	+	-
	Frequency		-	+	-	-	+
	Multiplexity		-	+	+	+	+
Social Exchange theory	Reciprocity	M	-	+	-	+	+
		A	+	-	+	-	-
		N	+	+	+	-	-
	Frequency		-	+	-	+	+
	Multiplexity		-	-	-	-	+
Proximity theory	Reciprocity	M	+	+	-	-	+
		A	+	+	+	+	+
		N	-	-	+	+	-
	Frequency		+	+	-	-	+
	Multiplexity		+	+	-	-	+

M = mutual knowledge sharing, A= asymmetrical knowledge sharing, N=null tie (no knowledge sharing)
+ theory proposes a positive effect of the enabler on the knowledge sharing characteristic
- theory proposes a negative effect of the enabler on the knowledge sharing characteristic
How to read this table: For example, Transactive Memory theory expects a negative effect of expertise overlap on the occurrence of mutual knowledge sharing.

Table 2-5: Overview theoretical propositions for intra-team knowledge sharing

Chapter 3

Empirical research design

3 Empirical research design

3.1 Introduction

The previous chapter set up a framework of theories on how enablers affect the way the team members share knowledge. To explore whether these effects actually take place in instrument consortia, an empirical study was conducted. A comparison of the relations between enablers and knowledge sharing characteristics found through the empirical study to the propositions formulated not only gives us an insight into how the team members share knowledge, but also teaches us which theories explain knowledge sharing in the specific context of instrument consortia. This chapter describes the design of this empirical study. Chapters 4 and 5 present and discuss the findings.

The empirical study was conducted by studying two instrument consortia. This chapter starts by describing the specific field in which the empirical study is conducted and presents the two consortia studied. As indicated in the conceptual model (introduced in chapter 1), two levels are discerned at which knowledge sharing takes place: the intra-team level and the inter-team level. However, the propositions on how enablers influence knowledge sharing were formulated for the intra-team level. By gathering and studying data at both the intra– and inter team level we gain insight into knowledge sharing at both levels. For each level a different method of data gathering is used, mainly because the populations of the two levels are fairly different. Section 3.3 discusses the empirical study at the intra-team level, for which a quantitative method was used. Section 3.4 discusses and explains the empirical study at the inter-team level, for which qualitative methods were used. For each level it is explained which data were necessary, how the data were collected, and how the data were processed and analyzed.

3.2 Field of study: instrument consortia

The empirical study is conducted in the field of space science. Within this specific field of science, instruments are developed for observations in and of the universe. Over the past few decades, it has become impossible for institutes to develop these instruments on their own. Not only are the costs and financial risks too high, but the range of areas of expertise involved is too large for one institute to possess. This has set in motion a trend of institutes forming consortia which increasingly become larger, consisting of many institutes from different countries. These collaborations were formed so that participating institutes have the opportunity to utilize each other's advanced facilities. With the founding of the European Space Agency (ESA) in 1973 (Monge et al., 2003) it became much easier to set up NPD projects with multiple partners from multiple countries. Since then the number of international collaborations has been growing. We refer to these collaborations as instrument consortia. Not only have the consortia grown in size since the 70s, they have also had to deal with increasing technical complexity. Compared to a few decades ago, instruments now cost a lot more and rely on expertise in many different areas. The different areas of expertise include astronomy, mechanical engineering, optical engineering, electrical engineering, and software. Overall, the instrument consortia are good examples of NPD consortia for they consist of many partners, involve high costs and risks and most of all, their objective is to develop complex new products.

Within the field of space science two instrument consortia were studied. In these instrument consortia multiple organizations situated in different countries co-design and co-develop new instruments for conducting measurements in space. Because the goal of the empirical study is to measure knowledge sharing both within teams and between teams, it was preferable to find consortia with both levels present. Additionally, we wanted to include teams in highly comparable environments. Both consortia are part of larger projects (programs). Unfortunately, we were not allowed to study the entire programs as this would substantially intervene in the consortia. It would also be impossible to include the complete programs in this thesis due to the amount of work this would involve. We therefore opted for studying one consortium within each program. These consortia are representative for the other consortia in these programs. Both consortia conduct new product development projects developing measurement instruments. For confidentiality reasons, the consortia were given fictive names: project Space and project Ground.

Project Space covers the development of one of three instruments to be placed on a satellite. It is part of a larger project, which is one of the cornerstone missions in ESA's Horizon 2000 program. There is one prime contractor, and subcontractors covering all 15 ESA member nations. Also parties in the United States are involved in the mission. Including the spacecraft, its scientific payload, the launch, and the operations, the costs of the mission total some 1,000 million Euros.

Project Ground is also part of a larger program. The program was to initially cover the construction of an antenna-network to function as one large telescope. This gave the program an astronomical background. However, the program was then changed to a more generic Wide Area Sensor Network. Functions for geographical research and studies in precise agriculture were incorporated. Then the program was split up into two main branches: a scientific branch and a technical R&D branch. Teams with expertise in astronomy, geophysics, agriculture and ICT in the scientific branch cooperate to solve the scientific issues related to the program. In the R&D branch the Wide Area Sensor Network is developed and built by subcontractors. Project Space covers the development of the network of antennas and the measurement instruments for the astronomy part. We chose to study project Ground because it is very comparable to project Space in that they both develop highly complex technical instruments for astronomical measurements, have long durations, highs costs and involve many teams from different organizations. Some key aspects of these consortia are presented in table 3-1, from which it is obvious how very similar they are.

More extensive descriptions on the instruments developed in these projects are presented below. Additionally, we give more general information on the projects and describe their organizations.

Project Space

The objective of project Space is to develop and build an instrument to be installed on a satellite and use it for astrophysical observations. With the help of infrared and sub-millimeter rays, this satellite will take a closer look at the formation of stars and planets. Additionally, it aims to give more insight into the so-called 'Dark Age' of the universe; the period during which the first galaxies formed. The satellite will be better and bigger than its predecessors, due to increasing science demands and technical possibilities. Besides the instrument we focus on, there will be two other instruments on board the satellite. The instrument project Space builds will receive signals from distant star constellations and interstellar gas clouds. It has to be built for extreme conditions, a vacuum and a temperature up to with temperatures as low as 4K/-269°C or 10K/-263°C, which is close to the absolute zero (-273°C). The satellite is scheduled for launch in 2009. A rocket will send it to 1.5 million km from Earth to have a clear and undisturbed view of the universe. This place is further away from Earth than any astrophysics mission has been up to now. The minimal lifespan of the satellite and its instruments will be three years. The estimated costs for the instrument developed are around 150 million Euros.

The project was initiated when a group of international partners wrote a proposal, which was submitted to and approved by ESA. It followed years of technological research. Following ESA's approval, more partners had to be found. Partners were chosen for different reasons, but generally they had to bring specific expertise to the project, and of course funding. The total project duration is about 15 years.

The organization of project Space is typical for instrument consortia. The organization chart is added in appendix 1. A special role is played by astronomy scientists who set up and maintain the criteria to be met by instrument. This team represents the 'clients' (astronomers) who use the instrument for measurements once it is launched in space. The project organization is very functionally based, because once the instrument is designed, it is split up in different functional parts that make up the subsystems. Within these subsystems the parts are further subdivided and assigned to teams as tasks, developing and building the different parts. When all the teams have built their parts, the parts are assembled and have to function together as one instrument. At the time our data collection took place, project Space was in its developmental phase. At the time of collecting the data, approximately 200 persons from 12 countries were working on project Space. During the design and developmental phases, ESA carried out reviews to keep up to date with the status of the project, to signal problems and bottlenecks in the process, and to see whether quality criteria were met.

Characteristics of project Space and project Ground		
Characteristics	Project Space	Project Ground
Objective	Develop highly technical measurement instrument for space (space based)	Develop highly technical measurement instrument for space (space based)
Domain	Field of space science	Field of space science
Project duration	15 years	10 years
Estimated costs	150 mln Euros	148 mln Euros
Number of teams	29 teams	23 teams

Table 3-1: Characteristics of project Space and project Ground

Project Ground

The second project involved in the empirical study aims to build a sensitive radio telescope. This radio telescope is developed for detecting objects over the entire past history of the cosmos. It can detect signals that are a thousand, million or even billion years away. The objective is to design a completely new type of radio telescope, which is based on phased array technology and that uses an innovative network design. It will be the first in a new generation of software radio telescopes, and the first that allows the measuring of the entire low frequency region of the radio spectrum (from 10 to 250 MHz, around the FM band). This telescope exists of thousands of simple antennas, spread over an area of about 150 km in diameter and linked by very fast fiberglass data transport cables. Very high energetic cosmos rays will be detected to observe the first Milky Way systems. This radio telescope is developed in collaboration with the 'industry'. Industry is a term which is used to indicate that these organizations are outside the institutes which conduct astronomy research but belong to the business sector. In the case of project Ground, collaboration with the industry is beneficial, because the future technology requirements of radio astronomy run almost parallel to those of telecommunications and computer networking industries. It should be fully operational in 2009. The costs of this project are estimated around 100 million Euro. An additional 48 million Euro is necessary for research on the development of techniques for the instrument. In the case of project Ground, its 'customers' are not just astronomers. Other small instruments can also be attached to the antennas, such as seismic sensors or detectors for agricultural science. This is why other groups including geophysics, a farming cooperation, a weather institute, and universities are also included in the development of the instrument.

Within project Ground each partner is responsible for its own part of the program, but they cooperate on design and scientific aspects. A foundation has been established for the design and development of the instrument with a board of four directors, charged with project management. We conducted our data collection in the design and development phase. At the time of data collections, around 86 people were working in 23 teams. The project organization is also very functional. For the organization chart, please see appendix 2. As in project Space, a team of scientists in project Ground is assigned to represent the interests of the scientists who use the instrument when it is up and running.

3.3 Empirical study at the intra-team level

Studying knowledge sharing at the intra-team level covers how team members (in sets of two) share knowledge and how the characteristics of their dyads influence the way they share knowledge. In this section, we start by describing the data necessary for testing the propositions, how the data was gathered and how the data was processed and analyzed. The actual findings and interpretation of the findings are presented in chapter 4.

3.3.1 Data required

In instrument consortia knowledge is distributed as people bring different parts of knowledge to the projects, enabling the project as a whole to accomplish the overall task of developing a new product. As a result interaction is necessary in the form of knowledge sharing within and between teams in the consortia. The focus in this thesis lies on these interactions of knowledge sharing. In our research, a network perspective was adopted to study knowledge sharing interactions enabling us to represent the relational data of knowledge sharing dyads and to explore the nature and properties of those relations (Dougherty, 1992). Additionally, as argued in chapter 1, the network perspective can be applied to different kinds of actors, making it possible to study knowledge sharing both within teams as well as between teams. Also, the network perspective allows for the use of multiple theories. As pointed out, the focus is on dyadic knowledge sharing: pairs of two team members of two teams sharing knowledge one-on-one. Our approach to studying knowledge sharing is a multiple theoretical approach. Chapter 2 discusses the three social theories providing theoretical mechanisms explaining how actors share knowledge and how the enablers influence this knowledge sharing. These theories are Transactive Memory theory, Social Exchange theory, and Proximity theory.

Monge and Contractor (2003) identify the following elements of networks: agents, the attributes of their relation, their rules of interaction, and characteristics that emerge from these rules. In table 3-2, these elements are translated to our study at the intra-team level. They represent the concepts central in this thesis at the intra-team level (see the conceptual model in chapter 1). To gain an insight into knowledge sharing within teams in instrument consortia, we needed data on all of the concepts in table 3-2 and their relations, so it can be explored which propositions apply and which do not. How the data on the concepts were gathered is described below.

Research concepts		
Elements/ concepts	Intra-team level	Inter-team level
Agents	Team members	Teams
Attributes	Expertise overlap Co-location Task dependency Involvement in multiple projects	Expertise overlap Co-location Task dependency
Rules of interaction	Mechanisms derive from: Transactive Memory theory Social Exchange theory Proximity theory	Mechanisms derive from: Transactive Memory theory Social Exchange theory Proximity theory
Emergent structure	Knowledge sharing characteristics: Reciprocity Frequency Multiplexity	Knowledge sharing characteristics: Reciprocity Frequency Multiplexity

Table 3-2: Research concepts

3.3.2 Data collection for the intra-team level

The objective of the empirical study is to explore the effects of the enablers on the knowledge sharing characteristics between team members. Chapter 2 formulates propositions for these effects. By gathering and analyzing data at the intra-team level, we wanted to see whether these propositions were supported or not. Using a quantitative method is appropriate for this for it allows us to explore the effects and test hypotheses. Questionnaires were used to gather data. Using questionnaires enabled us to gather a large range of data on the whole population. The population in the instrument consortia was not only large but also spread over the world. The questionnaires were sent to other countries and continents. Before further explaining how the questionnaire was conducted, we will discuss how the necessary data were translated to measures in the questionnaires.

The aim of the empirical study is to study the effects of enablers on the knowledge sharing characteristics. The knowledge sharing characteristics are therefore seen as dependent variables and the (dyadic) attributes are defined as explanatory variables. How the concepts from table 3-2 were translated into measurable constructs is discussed below.

Dependent variables: the knowledge sharing characteristics

To collect data on knowledge sharing, the respondents were asked to indicate the team members with whom they shared knowledge and how often they shared knowledge with these team members. This was done in a way common to gathering network data. The questionnaire set out a full

roster of team members for each team. We presented the lists of team member names to the team leaders. A blank space at the bottom of each list could be used by team members to add names of team members in case of incorrect lists of team members or changes in the team's composition. As a result, data was obtained in a form of dyadic knowledge sharing relations from each team member to his fellow team members. The relations were assigned different values for their strength; daily, weekly, monthly, or less than once a month/ never.
The questionnaire distinguishes four types of knowledge content, based on a distinction between procedural and declarative knowledge. Procedural knowledge is goal-oriented knowledge to execute tasks. Declarative knowledge is factual or experiential knowledge distinguishing:
(1) Know-who: knowledge of the persons in the project, for example knowing that person A is located in building B and has knowledge in a domain C.
(2) Know-why: knowledge of why things are done, background knowledge of the project, for example knowing the goal at the start of the project, but also the current status of the project, et cetera.
(3) Know-what: content-related knowledge of facts, models, specifications, et cetera.
Within procedural knowledge, we discern:
(4) Know-how: knowledge of how to do things, knowledge of procedures, processes, and expertise in how to do things.

For NPD projects, people are part of a team and have tasks to execute. These four types are included to be able to measure the multiplexity of knowledge sharing (the number of contents the team members share knowledge of). The reciprocity and frequency of knowledge sharing are based on the sharing of know-how. We analyzed the models of reciprocity and frequency for all four knowledge types, but the overall findings were similar. Know-how is the goal-oriented knowledge used to execute tasks and, because we are mainly interested in the knowledge people in the consortia use for carrying out their tasks, the choice was made to base the models of reciprocity and frequency on the sharing of know-how. Based on the knowledge sharing data the knowledge sharing characteristics were computed. The exact measures for the knowledge sharing characteristics are described below.

Reciprocity of knowledge sharing
Reciprocity expresses the directionality of knowledge sharing; the degree to which there is two-way knowledge sharing. A knowledge sharing dyad can be *null*, *asymmetric* or *mutual*. A null tie exists when no knowledge is shared between two team members. An asymmetrical tie between two team members refers to a knowledge sharing tie, where team member A approaches B, but B does not approach A for knowledge sharing. Knowledge sharing is mutual when there is a knowledge sharing tie from team member A to B and a tie from B to A. Our empirical study did not distinguish between the intensity of the knowledge sharing when considering the reciprocity of ties. This meant that we only considered whether they both indicated to share knowledge with each other without considering a possible

difference in frequency. Thus if one team member indicated to have weekly knowledge sharing and the other monthly, their relation was still mutual because both indicated to have a knowledge sharing relation with the other. As the minimal frequency measured was monthly, the values team member *i* and team member *j* assigned to their knowledge sharing were first dichotomized to either monthly (1) or not (0). After dichotomizing, the values of *i* and *j* were added up, resulting in three possible states for the dyad (D) of *i* and *j*:

- D*ij*=(0,0) Null dyad
- D*ij*=(1,0) or D*ij*=(0,1) Asymmetric dyad
- D*ij*=(1,1) Mutual dyad

(based on Wasserman & Faust, 1994).

Frequency of knowledge sharing

The strength of the knowledge sharing between two team members is represented by the frequency of knowledge sharing; how often do team member A and team member B share knowledge? Four values of frequency were measured: daily, weekly, monthly, less than monthly/never. It is not uncommon for respondents to assign different values to their relations. We opted to take the maximum of the values both team members assigned to their knowledge sharing interaction, because in the example above there is weekly knowledge sharing between *i* and *j*, regardless of the direction of knowledge sharing.

Multiplexity of knowledge sharing

As common in social network analysis, multiplexity is used to study the overlap between multiple networks, in this case knowledge networks.

As regards contents this means that we study the overlap between networks that concern different types of knowledge. This is the way we constructed the measure for multiplexity. Four content types of knowledge were distinguished: know-how, know what, know-who, and know-why. The extent to which these different contents of knowledge in ties overlap is denoted by multiplexity.

Respondents indicated the frequency of knowledge sharing with their team members for all four contents of knowledge. Similar to the reciprocity of knowledge sharing, for multiplexity of knowledge sharing we disregarded the indicated frequency and are merely interested in whether or not a particular content of knowledge is shared or not. Again the values were also dichotomized to being shared at least monthly. This resulted in a score for each type of content denoting whether it was shared (at least monthly) in the dyad (1) or not (0). The sum of these scores indicated the number of types of knowledge shared in the dyad, representing the multiplexity.

Explanatory variables: enablers

Expertise overlap

Together with key persons in both projects, a list was drawn up of areas of expertise present in the projects. In the questionnaire, the respondents were asked to indicate for each area of expertise whether it was their specialization or not. At the bottom of the list, a category 'other' was added where respondent could fill in their specialization if this had been missed in the list. The full list of specializations can be found in the questionnaire in appendix 3. For each dyad, the number of overlapping areas of expertise was scored.

Co-location
The team leaders were asked to provide us with lists of their team members and the addresses of their work place. This was necessary for sending the questionnaires to them, but also provided us with information on the locations where the respondents worked. Based on this information, for each dyad it was scored whether the team members reside in the same location (1), or in different locations (0).

Involvement in multiple projects
The questionnaire asked respondents to indicate whether they were involved in other projects outside the focal project. From these data, it was possible to score for each dyad whether respondents were involved in one project (0), one of them was involved in a project outside the consortium (1), or both were involved in multiple projects (2). To be able to use these categories in analyses, the categories of one being involved in multiple projects or of both being involved in multiple projects were translated into dummies (involvement1 respectively involvement2), where the reference category was that they were both involved in this one project.

Task dependency
Each team member was asked to indicate whether he and the team member in question needed mutual exchange of work outputs throughout the course of their work (1) or not (0). The task dependency relations were symmetrized by taking the maximum scores.

After translating the concepts to measures, the questionnaire was drawn up. The matrices concerning knowledge sharing with other team members were personalized to include participation in multiple teams. The basic questionnaire scheme is set out in appendix 3. Before sending the questionnaire to the members of project Space and project Ground, presentations on our research were given in both projects to create more support within the projects and, thereby, positively influence response rates. Shortly after giving the presentations, the questionnaires were handed out or sent to the project members. The questionnaire was sent to all team members of project Space and project Ground in 2005/2006, together with an answer envelope. After the initial distribution of the questionnaires, non-respondents received follow-up emails and telephone calls. Table 3-3 shows the response rates for the questionnaire.

Response rates questionnaire		
Project	Team leaders	Team members
Project Space	73.1 percent	39.4 percent
Project Ground	78.3 percent	43.1 percent

Table 3-3: Response rates questionnaire

3.3.3 Data processing and analysis

After receiving the questionnaires, they were coded to ensure the anonymity of the respondents. This was necessary because the questionnaires could not be filled out anonymously; they had to be personalized so that the respondents could see the names of their team members in the questionnaire. After coding the questionnaires, they were entered into a database and the original paper versions of the questionnaires were destroyed. Before discussing the analyses conducted, the data set is described.

In the projects 261 persons from 48 teams directly involved in NPD activities were asked to fill out the questionnaire. For more background information about the population, additional information about the respondents' age, education, and tenure in the project was gathered. The age of the team members varied from 24 to 67 years with an average of 42 years. As the tasks in the instrument consortia are very complex and space science requires much specialization, we had expected to find highly educated people. This was indeed the case. The largest part of the persons (66 percent) has an academic degree or higher. The time they had been part of the project varied between 1 and 11 years, with an average of 5 years.

For the explanatory and dependent variables included in the study, the descriptives are shown in table 3-4. Table 3-4 for example shows that the average value for reciprocity is 0.67. To give a better idea of how each category of the dependent variables are present in the population, figure 3-1 is included. As figure 3-1a shows, the largest part of the team members share knowledge mutually. Concerning the frequency of knowledge sharing, each category is about evenly represented in the data set. There are slightly more team members sharing knowledge weekly and daily than monthly and less than monthly/never (see figure 3-1b). When sets of team members share knowledge, it is mostly not just one content they share. As can be seen in figure 3-1c, in most dyads 4 contents of knowledge are shared.

Table 3-4 also shows descriptives for the explanatory variables. The mean value for co-location is 0.73, which means that in more than half of the dyads the team members are co-located. There is also quite a part of the dyads where one of the team members is involved in projects outside the consortium. In almost 20 percent of the dyads, the team members are both involved in projects outside the consortium.

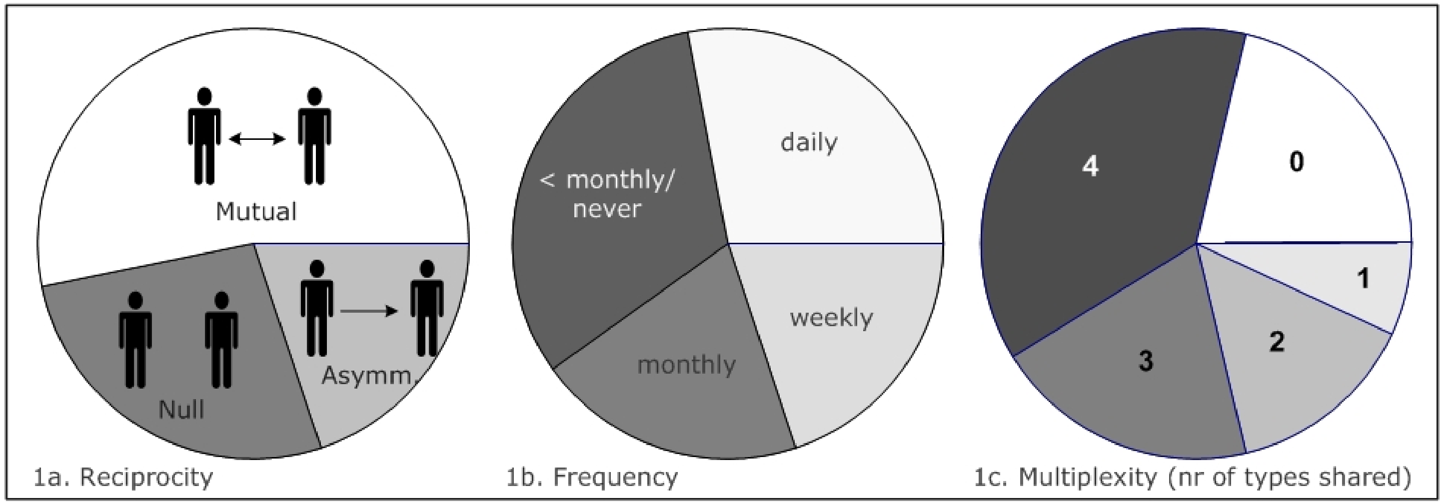

Figure 3-1: Knowledge sharing within teams in instrument consortia

Descriptives’

	Variable	Mean	S.d.	Min.	Max.	1	2	3	4	5	6	7
1	Reciprocity	.67	.79	0	2							
2	Frequency	2.32	1.09	1	4	0.78**						
3	Multiplexity	2.45	1.56	0	4	-0.79**	-0.82**					
4	Expertise overlap’’	0	.61	-.55	2.45	-0.14**	-0.03	0.11*				
5	Co-location	.73	.45	0	1	-0.24**	0.31**	0.25**	-0.10			
6	1 involved in multiple projects	.40	.49	0	1	0.23**	0.21**	-0.20**	0.07	-0.15**		
7	Both involved multiple projects	.19	.40	0	1	-0.04	-0.05	0.09	0.09	0.02	-0.40**	
8	Task dependency	.73	.45	0	1	-0.45**	-0.44**	0.42**	0.06	0.03	-0.02	-0.05

’ n= 357 (dyads). Two-tailed tests are reported.
’’ expertise overlap is grand mean centered (GM=.55)
** p<0.05, ** p<0.01*

Table 3-4: Descriptives intra-team data

Finally the table shows that the mean value for task dependency is 0.71. This indicates that in almost three out of four dyads the team members perceive their tasks to be dependent on each other.

To explore the effects of the enablers on the knowledge sharing characteristics, statistical analyses were conducted. In general, regression analysis fits the testing of the hypotheses like the propositions formulated in this thesis, for it is an appropriate method to investigate the interactions among various variables. In this research, the focus is on knowledge sharing at the dyadic level, where knowledge is shared between two team members. However, the team members are embedded in teams and this makes the data nested. This causes the observations within the teams not being independent[1]. In analyzing the data at the intra-team level, it should be recognized that the dyads within the same team are all exposed to the same stimuli, which might make them likely to be more similar to one another than dyads in other groups. In a regression analysis it is assumed that (1) the random errors are independent, that (2) they are normally distributed, and (3) have constant variance. As Bryk and Raudenbush (1992) note, in this situation the assumption of independent random errors is violated because the random error component within nested data will include a group level random error which causes the observations within groups to be dependent. Additionally, the assumption of constant variance is violated because the group level random error is likely to vary across groups. For these reasons, the choice is made to use a multilevel regression analysis so that the team level is accounted for.

To analyze the relations of the enablers and the different knowledge sharing characteristics, 3 models were formulated; one for each knowledge sharing characteristic. In table 3-5, the constructs used in the data analysis at the intra-team level are summarized, together with their values and measurement scales. As the table shows, reciprocity of knowledge sharing is a multinomial dependent variable. A multinomial logistic multilevel regression was therefore used for analyzing reciprocity. Because frequency is an ordinal dependent variable, an ordinal logistic multilevel regression was used. The model for multiplexity was analyzed using a 'regular' multilevel regression. For the actual analysis of the models, the statistical HLM6 program was used. Restricted Maximum Likelihood was used for estimation, for this should lead to better estimates, especially because the number of teams was relatively small (Bryk & Raudenbush, 1992; Hox, 2002).

The explanatory variables at the dyadic level included in the models are expertise overlap, co-location, involvement in multiple projects, and

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[1] Principally, the teams are also nested in projects, but because data was collected in two projects which were very alike, not much variation was expected between the two projects. Moreover, the number of projects was too small to include it as an additional nesting level in the statistical analysis.

task dependency. To make the interpretation of the results easier, we opted to center expertise overlap (grand mean). For co-location, involvement in multiple projects, and task dependency, centering would not make the interpretation easier. Moreover, they all have natural and meaningful null values.

At the team level, no explanatory variables were included, because the reason to include the team level is solely to account for the embeddedness of the dyads within teams. We did not include variables at the team level in our framework of theories because it is not in the scope of this study to explore which variables at the team level might have explanatory value for the knowledge sharing dyads within the teams. Therefore, the team level effect was taken into account by including an intercept at the team level. Additionally, no specific effects were defined on the slopes of the variables at the dyadic level. Chapter 4 discusses the models more extensively, together with their results and interpretation.

3.4 Empirical study at the inter-team level

In the empirical study of knowledge sharing at the inter-team level, the focus is on how teams (in sets of two) share knowledge and how the characteristics of their dyads influence the way they share knowledge. This section discusses the data necessary for the empirical study at the inter-team level, the data collection and the processing and analysis of the data.

3.4.1 Data required for the inter-team level

The objective of the empirical study at the inter-team level is to explore to what extent the effects of enablers on knowledge sharing between teams are similar to the effects within the teams. Moreover, the objective is to explore to what extent there is similarity in mechanisms explaining the knowledge sharing within and between teams. The propositions formulated in chapter 2 were concerned with the intra-team level and not with the inter-team level. The empirical findings within teams were therefore taken as the starting point for the data collection for knowledge sharing between teams. To gain insights into knowledge sharing between teams and how it is different or similar to knowledge sharing within teams, we needed to gather data on the relations of the enablers of the teams to the knowledge sharing characteristics between teams as well as data on the rules of interaction shaping these relations (see table 3-2). As argued in the description of the conceptual model, the enabler involvement in multiple projects is not included at the inter-team level. How these data at the inter-team level were gathered is described in the following.

Measurement constructs		
Constructs	**Values**	**Measurement**
Properties of knowledge sharing (dependent variables):		
- Reciprocity	0= null tie 1= asymmetrical tie 2= mutual tie	Multinomial
- Frequency	1=daily 2=weekly 3=monthly 4=less than monthly/ never	Ordinal
- Multiplexity	{0,1,2,3,4}	Ratio
Enablers (independent variables):		
- Expertise overlap	{0, …}	Ratio
- Co-location	0= not collocated 1= collocated	Binomial
- Involvement in multiple projects	2 dummy variables: Involvement of one team member in multiple project: 0=no 1=yes Involvement of both team members in multiple project(s) 0=no 1=yes	binomial binomial
- Task dependency	0 = no task dependency 1 = task dependency	Binomial

Table 3-5: Measurement constructs

3.4.2 Data collection

As mentioned, no explicit propositions are formulated for knowledge sharing at the inter-team level. Therefore, the empirical findings at the intra-team level for studying knowledge sharing at the inter-team level are used as a starting point. The emphasis is on exploring knowledge sharing between teams. For this purpose, a qualitative method is most suitable since this gives more in-depth information on how teams share knowledge, how the enablers are related to knowledge sharing characteristics, and the relevance of the mechanisms as described by Transactive Memory theory, Social Exchange theory, and Proximity and to what extent they actually play a role in knowledge sharing between teams.

The main method used in gathering data at the inter-team level is conducting interviews. At the start of the empirical study interviews were conducted to gain information on the issues that played a role in the consortia concerning knowledge sharing. These explorative interviews were held with 15 team leaders in project Space and 19 team leaders in project Ground. One of the results was a network of inter-team interaction. It was very difficult for the team leaders to have an overview of these relations, therefore, it was used as a starting point for further study. We mainly used more structured and extensive interviews with key persons in the project to get more insight into the knowledge sharing relations between the teams and the influences of the enablers. More specifically, these interviews focus on how expertise overlap, collocation, and task dependency of teams affect the frequency, reciprocity, and multiplexity of the knowledge sharing between teams and what the underlying mechanisms are. Since there were no previous research reports available on this subject, a new interview schedule was designed for this study based on the information requirements. Appendix 4 shows the information requirement table. The interviews are structured in three layers. It starts with open questions in the first layer and ends with closed questions in the third layer. The notion behind this is that by starting with open-ended questions, the respondents are encouraged to think openly and talk freely about their own experiences. In their answers, the interviewees most of the times did not include all the aspects for which we needed information. The second layer provided more closed questions on the aspects for which we needed information. For example, if a respondent did not mention the effect of co-location, more closed questions were posed about this relation. The questions in the third layer focused on the answers provided by asking questions like "*Why do you think…?*". By using this interview design, all relevant data was asked, making the interviews comparable. Appendix 5 sets out the interview scheme, with the structure and questions of the interview.

The project leaders of both consortia participated in the interviews; they were selected for their helicopter view of the projects and insights into inter-team knowledge sharing. Additionally, for each consortium a middle manager was selected with an insight into the knowledge sharing between teams from a lower level perspective. All interviews were conducted on a one-to-one basis, between researcher and respondent. Because respondents usually express themselves better in their native language, the interviews were conducted in Dutch. The duration of the interviews was between 60 and 80 minutes. In addition to the focused interviews with the project leaders and managers, we conducted observations during meetings.

3.4.3 Data processing and analysis

The interviews produced a rich amount of data, which was analyzed systematically following Miles and Huberman (1994). In preparing the qualitative analysis a code list was set up. Text-analysis matrices were also drawn up in advance to be able to compare the answers given by the respondents at a later stage. With permission from the respondents, the interviews were digitally recorded. The actual analysis and processing of the data started by listening to the digital voice recordings and transcribing the interviews. After the transcription, each interview was printed and the text fragments/ lines were coded according to the four main topics; (1) reciprocity of knowledge sharing, (2) frequency of knowledge sharing, (3) multiplexity of knowledge sharing and (4) the management of knowledge sharing. Because some of the text fragments referred to more than one topic, in most cases multiple copies of the transcript were numerically coded. For each main topic a question file was produced. Subsequently, based on the codes, the transcripts were cut up into relevant sections and allocated to the appropriate topic file. By doing so, all the responses to the four main topics were assembled. To make the data more manageable, the quotations in each question file were further analyzed and broken down into a number of sub-categories and subheadings. The analyses matrices were filled with the relevant data. A careful selection was then made of the data relevant for each cell of the matrix. These decisions were made based on the table of information requirements, the context in which statements were made, and the degree to which the respondents emphasized it. Starting point for the final analysis was the findings of the quantitative study within the teams. The last step in analyzing the interview data was comparing the categorized interview data to the findings from the questionnaires within the teams. The original transcripts were also included to make sure that answers were seen within their context. During the analysis and interpretation process the data was actively searched and checked for reasons why conclusions should not be trusted, and particular attention was paid to exceptions to findings. The conclusions were verified as the analysis proceeded. The results of the qualitative study on knowledge sharing between teams are presented and discussed in chapter 5.

3.5 Summary

This chapter described the empirical design of this research. A distinction between the intra-team level and the inter-team level knowledge sharing was made in the research questions central to our research, and the empirical testing also was different for both levels. Therefore, the presentation and discussion of the empirical results will be done separately. The results for knowledge sharing at the intra-team level are described and discussed in chapter four, the results for the inter-team level are discussed in chapter five.

Chapter 4

Results: knowledge sharing at the intra-team level.

4 Results: knowledge sharing at the intra-team level

4.1 Introduction

This chapter presents and discusses the empirical results for dyadic knowledge sharing at the intra-team level. Data on knowledge sharing between team members was gathered through questionnaires and analyzed by multilevel regression analyses.

Chapter 2 discussed the effects of four enablers on the direction, frequency and multiplexity of knowledge sharing and formulated propositions. Using multilevel regression analysis, a model was built for each knowledge sharing characteristic. The effects of the enablers on the knowledge sharing characteristics were then analyzed from the empirical data. This chapter presents these models. The results of the analysis are discussed separately for each knowledge sharing characteristic. The models for reciprocity, frequency, and multiplexity are discussed in sections 4.2, 4.3, and 4.4. Each section starts with a description of the model for the property concerned. Subsequently, the statistical results are presented, interpreted, and compared to the propositions formulated in the framework of theories. The empirical results also have theoretical implications. Which theory best explains the effects of the enablers and the knowledge sharing characteristics self is discussed in section 4.5.

4.2 Reciprocity

4.2.1 Description of the model

Reciprocity represents the degree to which there is two-way knowledge sharing. The reciprocity of knowledge sharing relations is indicated by three states; people can share knowledge mutually, asymmetrically, or not at all. In the model for reciprocity, reciprocity is the dependent variable and expertise overlap, co-location, involvement in multiple projects, and task dependency are the explanatory variables. Because reciprocity is a categorical dependent variable, the multinomial logit link function is used in the multilevel regression. In our statistical model, M denotes the possible categories of the outcome variable reciprocity. The response, R, takes on the value of m with probability Prob(R=m). In the case of reciprocity, there are three categories, where:

m=1, for a mutual tie
m=2, for an asymmetrical tie
m=3, for a null tie

and:
$\Pr ob(R_{ij} = 1) = \varphi_{1ij}$
$\Pr ob(R_{ij} = 2) = \varphi_{2ij}$
$\Pr ob(R_{ij} = 3) = \varphi_{3ij} = 1 - \varphi_{1ij} - \varphi_{2ij}$
φ_{1ij} denotes the probability of dyad *i* in team *j* falling into category 1.

As argued, the multinomial logit link function is used. For *M*=3 there are two sets of level-1 (the dyad-level) and level-2 (the team level) equations:
The level-1 link function is:

$$\eta_{mij} = \ln\left(\frac{\varphi_{mij}}{\varphi_{Mij}}\right)$$

Category *M* is the reference category. For reciprocity this is the category for null ties, so the reference category denotes the relations where no knowledge is shared. This means that when *m*=1, η_{1ij} denotes the log odds of a set of team members *i* in team *j* sharing knowledge mutually relative to them not sharing knowledge. For reciprocity there are three categories, therefore there are two equations; an equation modeling the probability of the team member sharing knowledge mutually relative to not sharing knowledge (equation 1) and an equation modeling the probability of the team members sharing knowledge one-way relative to them not sharing knowledge (equation 2).
The pair of logits at the dyadic level is modeled as a function of the enablers:

$$\eta_{1ij} = \beta_{0(1)} + \beta_{1j(1)}EXP + \beta_{2j(1)}CO + \beta_{3j(1)}INV\_1 + \beta_{4j(1)}INV\_2 + \beta_{5j(1)}TD \qquad (1)$$
$$\eta_{2ij} = \beta_{0(2)} + \beta_{1j(2)}EXP + \beta_{2j(2)}CO + \beta_{3j(2)}INV\_1 + \beta_{4j(2)}INV\_2 + \beta_{5j(2)}TD \qquad (2)$$

Where:
EXP= expertise overlap
CO= co-location between *i* and *j*
INV_1= either *i* or *j* is involved in multiple projects
INV_2= both *i* and *j* are involved in multiple projects
TD= task dependency between *i* and *j*
() refers to the equation concerned

For the team level (level-2), only a random intercept is modeled, thus:

$$\beta_{0(1)j} = \gamma_{00(1)} + u_{0(1)j}$$
$$\beta_{0(2)j} = \gamma_{00(2)} + u_{0(2)j}$$
$$\beta_{q(m)j} = \gamma_{q0(m)j}$$
$q = 1,\ldots,5$
$m = 1,2$

Therefore the full model is:

$$\eta_{ij} = \gamma_{00(1)} + \gamma_{10(1)}EXP_{ij} + \gamma_{20(1)}COLOC_{ij} + \gamma_{30(1)}INV\_1_{ij} + \gamma_{40(1)}INV\_2_{ij} + \gamma_{50(1)}TD_{ij} + \gamma_{00(2)} + \gamma_{10(2)}EXP_{ij} + \gamma_{20(2)}COLOC_{ij} + \gamma_{30(2)}INV\_1_{ij} + \gamma_{40(2)}INV\_2_{ij} + \gamma_{50(2)}TD_{ij} + \upsilon_{oj(1)} + \upsilon_{0j(2)} \quad (3)$$

4.2.2 Results

The intra-class correlation (ICC) measures the proportion of the variance explained by the grouping structure in the population (Hox, 2002). In other words, the ICC is the proportion of team level variance compared to the total variance. The ICC can be calculated by running a model without including the explanatory variables. This so-called 'null model' (or 'intercept-only model') only incorporates the intercepts. The null model gives an insight into the distribution of the variance by estimating how much of the variance resides at the dyadic level (σ_e^2) and how much at the team level (σ_{u0}^2). Using the null model, the ICC can be calculated by the equation:

$$\text{ICC} = \frac{\sigma^2\upsilon 0}{\sigma^2\upsilon 0 + \sigma^2 e}$$

Table 4-1 sets out the results of the null model and the full model for reciprocity. The estimate of the variance at the dyadic level ($\sigma^2 e$) has a value of 1.00. In logistic multilevel regressions, this value is just a scale factor. The variance for a standard logistic distribution is $\pi^2/3 \approx 3.29$. Thus, the ICC for the model of the reciprocity being mutual is:
$\rho_1 = \frac{4.69}{4.69 + 3.29} = 0.59$, indicating that 59 percent of the total variance in this model for mutual knowledge sharing can be explained by variation at the team level. For the knowledge sharing being asymmetrical compared to null, $\rho_2 = 0.28$, indicating that 28 percent of the variance in this model resides at the team level. From this, we can conclude that whether or not two team members share knowledge mutually depends to a considerable extent on the team they belong to, but still also for a large part (41 percent) on the characteristics of their dyad. In the case of the team members sharing knowledge asymmetrically rather than not at all, this depends for the largest part on the enablers and less (28 percent) on their team membership.

After running the null model, the explanatory variables were included and the full model was analyzed. In the models where the knowledge sharing is mutual ($Y = 2$) the intercept is the expected log odds of the team members sharing knowledge mutually relative to the team members not sharing knowledge. For the model where knowledge sharing is asymmetrical ($Y = 1$), the intercept reflects the log odds of the team members having one-way knowledge sharing relative to them not sharing knowledge. For two team members who have an average expertise overlap, who are not co-located, who are not involved in multiple projects, and have no task dependency, the estimated expected log odds for sharing knowledge mutually is -1.15, corresponding to an odds ratio of 0.32. This means that these team members are 0.32 times as likely to share knowledge mutually compared to not sharing knowledge at all. In other words, they are three times more likely to not share knowledge than to do so mutually. The same team members have 1.15 times the odds of having one-way knowledge sharing as opposed to not sharing knowledge at all. Translating these odds into probabilities, the probability that team members in these dyads do not share knowledge is 41 percent, the probability that they share knowledge asymmetrically is 47 percent, and the probability they share knowledge mutually is 12 percent.

The findings indicate that only the involvement of one team member in multiple projects has a negative effect on mutual knowledge sharing. Expertise overlap, co-location and task dependency on the other hand all positively affect mutual knowledge sharing as compared to no knowledge sharing at all. For asymmetrical knowledge sharing, the involvement of one or both team members in multiple projects has a negative effect. However, task dependency, expertise overlap, and co-location considerably increase the probability that team members share knowledge one-way as opposed to them not sharing knowledge. In the model, the odds ratios indicate the size of the effects of the explanatory variables on the direction of knowledge sharing.

Task dependency has the largest effect on both mutual and asymmetrical knowledge sharing. Keeping the other variables constant, creating task dependency between team members means that the odds of sharing knowledge mutually increase substantially. The team members are 38 times more likely to share knowledge mutually than to not share knowledge. At the same time, the probability that the team members share knowledge asymmetrically increases seven times compared to them not sharing knowledge at all. From this, it can be concluded that when task dependency is created between two team members, the probability that they will share knowledge (either mutually or asymmetrically) is much higher than that they will not share knowledge. The results also show that the effects of task dependency, co-location, and expertise overlap are larger for mutual knowledge sharing than for asymmetrical knowledge sharing.

The model can be used to calculate the probabilities of dyads falling in one of the three categories. Five profiles were formulated to facilitate the interpretation of the results. The profiles are examples of situations to illustrate the effects of the enablers on the direction of knowledge sharing.

Results for reciprocity’

	Intercept only model				Final model					
	Model Y=mutual		Model Y=asymmetric		Model Y=mutual			Model Y= asymmetric		
Fixed part predictor	Coeff.	Odds ratio	Coeff.	Odds ratio	Coeff.		Odds ratio	Coeff.		Odds ratio
Intercept	-0.28 (0.40)	0.76	0.78**(0.23)	2.17	-1.15	(0.79)	0.32	0.14	(0.60)	1.15
Expertise overlap					1.47**	(0.41)	4.34	0.93**	(0.37)	2.52
Co-location					1.25*	(0.58)	3.50	0.51	(0.48)	1.66
Involvement_1					-1.19**	(0.51)	0.41	-0.86*	(0.45)	0.42
Involvement_2					0.24	(0.70)	1.27	-0.13	(0.61)	0.88
Task dependency					3.64**	(0.50)	38.25	1.94**	(0.44)	7.01
Random part:										
σ^2_e	1		1		1			1		
σ^2_{u0}	4.69		1.30		5.08			1.85		

’ n= 357 (dyads). Unstandardized coefficients are shown (standard errors in parentheses). Two-tailed tests are reported. Reference category: no knowledge sharing.

*   p<0.05

** p<0.01

Table 4-1: The results for reciprocity

The first profile represents the 'average' situation; dyads where the team members have an average expertise overlap, where they are co-located, not involved in multiple projects, and are task dependent. The second profile shows what happens when the team members in these dyads are not co-located. The third profile illustrates what happens to the dyads in the average situation when there is no task dependency. The fourth profile shows the effect of co-location and expertise overlap, in order to explore whether co-location and an above average overlap in expertise substitute for task dependency. When two team members are both involved in multiple projects, they are less likely to be co-located. In the fifth profile we show what happens when they are task dependent.
For each of these profiles, the probabilities of falling in the different categories are calculated. These are shown in table 4-2. Looking at the profiles and the probabilities for the mutual, asymmetrical and null ties, it is noticed that the probability of the team members sharing knowledge mutually is highest in the first profile, which represents the average situation. The large effect of task dependency on mutual knowledge sharing is also illustrated when comparing profile one and three. Profile one and

Profiles for reciprocity

Profiles			Reciprocity		
			Prob (mutual)	Prob (asymm)	Prob (null)
1	expertise overlap: co-located: multiple projects: task dependent:	avg* yes no yes	0.75	0.24	0.02
2	expertise overlap: co-located: multiple projects: task dependent:	avg no no yes	0.57	0.38	0.05
3	expertise overlap: co-located: multiple projects: task dependent:	avg yes no no	0.27	0.48	0.25
4	expertise overlap: co-located: multiple projects: task dependent:	> avg** yes no no	0.59	0.38	0.03
5	expertise overlap: co-located: multiple projects: task dependent:	avg no both yes	0.66	0.30	0.04

* *avg: avg stands for average.*
*** > avg = the mean value + 2· standard deviation.*
Table 4-2: Profiles for reciprocity

three concern the same set of team members, but where in the first profile the team members are task dependent, in profile three they are not. The probability that knowledge is shared mutually then drops to 0.27 while the probability of the team members sharing no knowledge rises from 0.02 to 0.25. Compared to the other profiles, this is the highest probability that the team members will not share knowledge. This is a clear indication of the strength of the effect of task dependency on knowledge sharing. When comparing the first and the fifth situation, it seems that when team members are not co-located, involvement in multiple projects can somewhat compensate because profile five shows that involving both team members in multiple projects makes them more likely to share knowledge mutually. For profile two and profile four, the probabilities of sharing knowledge mutually or asymmetrically are almost equal. This means that being co-located and having an above average overlap in expertise creates the same probability of team members sharing knowledge as being task dependent. However, the probability of the team members not sharing knowledge is also highest in this situation. A comparison of profile two and five reveals the effect of involvement in multiple projects. Both represent a situation where two team members have an average overlap in expertise, are task dependent, but not co-located. Where in the second profile both team members are not involved in projects outside the consortium, in the fifth profile they are. Noticeably, when they are both involved in multiple projects the probability of them sharing knowledge mutually increases somewhat. At the same time, the probability of them sharing knowledge asymmetrically drops somewhat, while the probability of them not sharing knowledge stays almost equal. In situation three, team members have the highest probability of sharing knowledge asymmetrically. In this situation, the team members are neither task dependent nor involved in multiple projects, but they are co-located and have an average overlap in expertise. To explain these results, we return to the explanations as provided by the social theories.

4.2.3 Comparing the findings to the propositions

Three social theories were discussed, offering explanations for knowledge sharing and proposing effects for the influence of enablers on the reciprocity of knowledge sharing. The proposed effects for the enablers on reciprocity are shown in table 2.2. Comparing the relations found through the analyses to these propositions, we found that certain aspects of the theories were not supported, while other propositions were affirmed. Table 4-3 shows where the propositions of the social theories are affirmed and where they are not supported. For *expertise overlap*, the results show positive effects on mutual and asymmetrical knowledge sharing. The effects of expertise overlap are also considerable relative to the other variables. When team members have a larger overlap of expertise, they are more likely to share knowledge asymmetrically or mutually than to share no knowledge at all.

Comparison of propositions and empirical findings for reciprocity

Explanatory variable	Social theories											
	Transactive Memory theory			Social Exchange theory			Proximity theory			Empirical findings		
	M	A	N	M	A	N	M	A	N	M	A	N
Expertise overlap	X	√	X	X	√	X	√	√	√	+	+	-
Co-location	√	X	X	√	X	X	√	√	√	+	+	-
Involvement in multiple projects:												
One actor	X	X	X	√	X	√	√	X	√	-	-	+
Both actors	X	X	X	√	√	√	X	X	X	+	-	-
Task dependency	√	√	√	√	X	√	√	√	√	+	+	-

M=mutual knowledge sharing
A= asymmetrical knowledge sharing
N= null tie (no knowledge sharing)
√ : the proposition of the theory is in line with the empirical findings
X : the proposition of the theory is not supported by the empirical findings
-: the findings indicate that the enabler negatively affects reciprocity
+: the findings indicate that the enabler positively affects reciprocity

Table 4-3: Comparison of the theoretical propositions and the empirical findings for reciprocity

The arguments of Transactive Memory theory and Social Exchange theory for the effect of expertise overlap on the direction of knowledge sharing are quite overlapping. Transactive Memory states that knowledge sharing is most efficient when knowledge is differentiated; when team members have a small or no overlap in expertise, they are more likely to share knowledge. In other words, as the overlap in expertise increases, the need for the professionals to share knowledge diminishes. Social Exchange theory states that there needs to be a discrepancy in knowledge to make the knowledge sharing valuable for the team members. When there is an overlap in knowledge, team members see less value in sharing knowledge because they have less to offer each other. The empirical findings do not support the arguments of Transactive Memory theory and Social Exchange theory. On the other hand, Proximity theory states that team members who are (cognitively) proximate are more likely to share knowledge. When there is a small or no overlap in expertise they are likely to not share knowledge. This argument is supported by the findings. Team members in instrument consortia prefer to approach team members with whom they have an overlap in expertise. It is likely that they feel that they share the same language, background and mental models with these team members (they are cognitively proximate).

The results for *co-location* show that co-location is positively related to both mutual knowledge sharing and asymmetrical knowledge sharing. Comparing the propositions of the theories to the empirical findings, we found that the three theories all propose that team members who are co-located are more likely to share knowledge mutually. Transactive Memory theory states that co-location causes the team members to recognize each other's expertise more accurately. Because they have better insight into each other's knowledge, they share knowledge more mutually. This is quite similar to the reasoning of Social Exchange theory, which proposes that when team members are co-located, it is easier for them to learn what expertise the other has to offer. Additionally, Social Exchange theory states that co-located team members are better able to recognize their position in the whole and the alternative knowledge sources. This also leads the team members to share knowledge mutually. These arguments were supported by the empirical findings. However, for the effects of co-location on asymmetrical knowledge sharing and the absence of knowledge sharing, the line of reasoning of Transactive Memory theory and Social Exchange theory does not appear to hold. Besides co-location leading to more mutual knowledge sharing, both theories also state that it leads to more team members not sharing knowledge. When team members have better insight into each other's expertise, they can also make better decisions about who they should not approach for knowledge. This leads to more relations where no knowledge is shared and to fewer relations where knowledge is shared asymmetrically. These propositions are not supported by the empirical findings. Instead, we find that co-location not only has a positive effect on mutual knowledge sharing, it also causes team members to share knowledge in one direction more. At the same time co-located team members have fewer null ties. The empirical findings thereby support the propositions of Proximity theory. Proximity theory stated that when team members are co-located, they are more likely to meet and interact causing them to share knowledge both mutually and asymmetrically. This is in line with the empirical results for the instrument consortia.

For *involvement in multiple projects*, the results show that when one team member is involved in projects outside the consortium and the other is not, they are less likely to share knowledge. However, when both team members are involved in projects outside the consortium the opposite is found; the results show that these team members are more likely to share knowledge mutually and less likely to share knowledge asymmetrically or not at all. Comparing these findings to the propositions, we found that none of the propositions of Transactive Memory theory are supported by the data. Transactive Memory theory states that when one team member is involved in multiple projects, team members need each other's expertise. The one involved in another project needs the other to stay up-to-date on the consortium, and the one working fulltime in the consortium needs the other for new knowledge and experiences gained in the outside project. In the situation where both team members are involved in multiple projects, Transactive Memory theory states that they have less insight into each other's expertise and also become more selective in their information retrieval, leading to more null and asymmetrical ties. This line of reasoning for the involvement of team members in projects outside the consortium does not find support for the instrument consortia studied. The propositions of Proximity theory are only partly supported by the empirical findings. Proximity theory states that the involvement of both team members makes them less close and therefore leads to less (mutual and asymmetrical) knowledge sharing. Nevertheless, the empirical findings indicate different effects. For the involvement of one team member in projects outside the consortium, the explanation of Proximity is supported, but for the involvement of both team members in multiple projects it is not. The mechanisms proposed by Social Exchange theory explain the effects of involvement in multiple projects better, as five out of six propositions are in line with the results. The explanation Social Exchange theory provides is that when one or both of the team members are involved in multiple projects, their alternative sources for knowledge are likely to play a role in whether they share knowledge mutually or not. When a team member is involved in a project outside the consortium, he has access to alternative knowledge sources. At the same time this person has less relevant knowledge to offer the team members who work fulltime on the consortium and has less insight into the knowledge other team members have. This makes team members less likely to share knowledge with the team members who work fulltime on the consortium. At the same time they are more likely to share knowledge (mutually) with the team members who work in multiple projects. These arguments are supported by the empirical data.

As the results show, the enabler that has the largest effect on the reciprocity of knowledge sharing is *task dependency*. Two team members are most likely to share knowledge when they perceive task dependency between them. This is not particularly surprising as the team members of instrument consortia find themselves in a very task-oriented environment.

Furthermore, we focused on measuring know-how, a type of knowledge used for solving problems and executing tasks. In formulating propositions for the effect of task dependency on the direction of knowledge sharing, the three theories were quite overlapping and complementary. Social Exchange theory states that when team members are task dependent, it implies that they are dependent on each other’s knowledge. This makes them likely to engage in mutual knowledge sharing. This explanation very much resembles the reasoning of Transactive Memory theory. Transactive Memory theory also links task dependency to cognitive dependency by stating that when the team members are task dependent they need each other’s knowledge. This explanation is very likely to be the case in the instrument consortia: team members have to execute their tasks and engage in knowledge sharing with team members whose input they need for the completion of their tasks. The explanation of Proximity theory is complementary to the reasoning of Transactive Memory theory and Social Exchange theory. Proximity theory regards task dependency as a form of organizational proximity, which implies that when two team members are task dependent, they are more proximate and, therefore, more likely to share knowledge (either mutually or asymmetrically). As the results show, the argumentation of all three theories is supported. There is one exception: the effect of task dependency on asymmetrical knowledge sharing as proposed by Social Exchange theory. The other two theories just state that the probability increases that team members share knowledge when they are task dependent, either asymmetrically or mutually. Social Exchange theory is based on the principle of reciprocity and states that team members prefer mutual knowledge sharing. When there is task dependency between two team members they need each other’s knowledge. In the view of Social Exchange theory this makes them less likely to have asymmetrical knowledge sharing. However, the empirical data show the opposite effect; the tendency of team members to prefer mutual relationships does not seem to hold for the effect of task dependency on the direction of knowledge sharing.

4.3 Frequency

4.3.1 Description of the model

In the model for frequency the explanatory variables are expertise overlap, co-location, involvement in multiple projects and task dependency. The dependent variable is frequency, which has four possible values: daily, weekly, monthly, and less than monthly/never. Frequency is an ordinal variable, and therefore an ordinal multilevel regression is most appropriate. The ordinal multilevel regression uses cumulative probabilities, making the assumption of proportional odds. The assumption underlying the proportional odds model is that the explanatory variables affect the odds ratio in the same way for every category of the explanatory variable. This implies that, for example, expertise overlap should have a similar association with each successive cumulative odd. Before using the ordinal multilevel regression, this assumption was checked by analyzing the model in a multinomial multilevel analysis. The directions of the coefficients are similar for the categories of frequency, from which we can conclude the assumption of proportional odds is supported. Therefore, an ordinal multilevel regression model is used for frequency.

An ordinal multilevel regression uses a logit link function. This makes the type of model for frequency somewhat similar to the type of model used for reciprocity. In the model for frequency, *M* denotes the possible categories of the outcome variable, in this case frequency. The response, R, takes on the value of *m* with probability Prob(R=*m*). In the case of frequency, there are four categories, where:

m=1, for daily knowledge sharing
m=2, for weekly knowledge sharing
m=3, for monthly knowledge sharing
m=4, for less than monthly or no knowledge sharing

The difference with the model for reciprocity is that an ordinal multilevel model uses cumulative probabilities. The probabilities in the ordinal model are formulated as follows:

$$\Pr ob(Y_{1ij} = 1) = \Pr ob(R_{ij} = 1) = \varphi_{1ij}$$
$$\Pr ob(Y_{2ij} = 1) = \Pr ob(R_{ij} = 1) + \Pr ob(R_{ij} = 2) = \varphi_{2ij}$$
$$\Pr ob(Y_{3ij} = 1) = \Pr ob(R_{ij} = 1) + \Pr ob(R_{ij} = 2) + \Pr ob(R_{ij} = 3) = \varphi_{3ij}$$
$$\Pr ob(Y_{4ij} = 1) = \Pr ob(R_{ij} = 1) + \Pr ob(R_{ij} = 2) + \Pr ob(R_{ij} = 3) + \Pr ob(R_{ij} = 4) = \varphi_{4ij}$$

For the ordinal model, all the odds take the following form:

$$\eta_{mij} = \frac{\Pr ob(score \le j)}{\Pr ob(score > j)}$$

So when *m*=1(daily knowledge sharing), η_{1ij} denotes the log odds of dyad *i* in team *j* sharing knowledge on a daily basis relative to sharing knowledge less frequently. The last category (the frequency is less than monthly or never) does not have an odds associated with it, since the probability for scoring up to and including the last score is 1.

The ordinal multilevel model works with threshold values. These are values that do not depend on the values of the explanatory variables, but they are like an intercept in a linear regression, except that each logit has its own. They can be used in calculations of predicted values, like in calculation of the probabilities for the profiles we use to interpret the results. The logits at the dyadic level are modeled as a function of the enablers:

$$\eta_{1ij} = \beta_{0(1)} + \beta_{1j(1)}EXP + \beta_{2j(1)}CO + \beta_{3j(1)}INV\_1 + \beta_{4j(1)}INV\_2 + \beta_{5j(1)}TD \quad (4)$$

$$\eta_{2ij} = \beta_{0(2)} + \beta_{1j(2)}EXP + \beta_{2j(2)}CO + \beta_{3j(2)}INV\_1 + \beta_{4j(2)}INV\_2 + \beta_{5j(2)}TD + \delta_2 \quad (5)$$

$$\eta_{3ij} = \beta_{0(3)} + \beta_{1j(3)}EXP + \beta_{2j(3)}CO + \beta_{3j(3)}INV\_1 + \beta_{4j(3)}INV\_2 + \beta_{5j(3)}TD + \delta_2 + \delta_3 \quad (6)$$

Where:
EXP=expertise overlap
CO=co-location
INV_1= either *i* or *j* is involved in multiple projects
INV_2= both *i* and *j* are involved in multiple projects
TD=task dependency

For the team level (level-2), only a random effect is modeled:

$$\beta_{0(1)} = \gamma_{00(1)} + u_{0(1)}$$

$$\beta_{0(1)} = \gamma_{q0(m)}$$

$$q = 1,\ldots,5$$

The final model for frequency is formalized as follows:

$$\eta_{ij} = \gamma_{00} + \gamma_{10}EXP_{ij} + \gamma_{20}COLOC_{ij} + \gamma_{30}INV\_1_{ij} + \gamma_{40}INV\_2_{ij} + \gamma_{50}TD_{ij} + \delta 2 + \delta 3 + u_{0j} \quad (7)$$

With:
δ_2 = threshold for weekly knowledge sharing
δ_3 = threshold for monthly knowledge sharing

4.3.2 Results

Like the model for reciprocity, the model for frequency is analyzed using HLM6. Table 4-4 sets out the results for frequency. For frequency, the analyses start with running the null model. The ICC is calculated based on the null model. As a logit link function is used, we use the variance for a standard logistic distribution ($\pi^2 / 3 \approx 3.29$). The ICC for frequency is: $\rho = 0.37$. This indicates that the frequency with which team members in a dyad share knowledge depends for 37 percent on the team in which the dyad is situated and for the largest part (63 percent) on the enablers.

After running the intercept-only model, the full model is analyzed. The intercept and threshold values and corresponding odds ratios indicate that for a dyad where the overlap in expertise is average, where the team members are not co-located, not involved in multiple projects, and not task dependent, the odds of sharing knowledge daily as opposed to sharing knowledge less often is very low (0.01). The same team members are 8.75 times as likely to share knowledge at least weekly as likely to sharing knowledge less than weekly. The odds for at least monthly knowledge sharing as opposed to less than monthly or not at all are 52.80.

The interpretation of the coefficients of the explanatory variables is somewhat different from multinomial or linear models. The findings indicate that the coefficients for all explanatory variables are positive. In ordinal multilevel regression a positive coefficient for a dichotomous variable means that the higher scores are more likely for the first category. In our case the first category is daily knowledge sharing. The positive coefficients for these

Results for frequency'				
	Intercept only model		Final model	
Fixed part predictor:	Coeff.	Odds ratio	Coeff.	Odds ratio
Intercept	-1.64** (0.25)	0.19	-4.49** (0.54)	0.01
Expertise overlap			0.32* (0.19)	1.37
Co-location			1.57** (0.32)	4.81
Involvement1			0.01 (0.27)	1.01
Involvement2			0.92* (0.39)	2.50
Task dependency			2.10** (0.26)	8.75
Threshold 2	1.54** (0.09)	4.64	2.17** (0.18)	8.75
Threshold 3	2.83** (0.12)	16.90	3.97** (0.26)	52.80
Random part:				
σ^2_e	1		1	
σ^2_{u0}	1.95		2.69	

' n= 357 (dyads). Unstandardized coefficients are shown (standard errors in parentheses). Two-tailed tests are reported.
** p<0.05*
*** p<0.01*
Table 4-4: The results for frequency

variables indicate that when team members are for example task dependent, the probability that they share knowledge daily increases the most. For continuous variables, a positive coefficient implies that when the value of the variable increases, the likelihood of larger scores increases. Expertise overlap is the only continuous explanatory variable. The positive coefficient for expertise overlap means that when the expertise overlap between team members increases, it becomes more likely that they share knowledge more frequently. Comparing the enablers, we found that task dependency has the largest effect on the frequency of knowledge sharing. However, the effect of co-location is also quite large. For frequency, the probabilities of falling into one of the categories were also calculated for the five profiles. The results are presented in table 4-5.

The table shows that in the average situation (profile one), the probability is highest that team members will share knowledge on a daily or weekly basis. The role of co-location becomes clear in profile two. It presents the same situation, except the team members are not co-located. It shows that when the team members are not co-located, the probability that they share knowledge daily drops to 0.08, while the probability that they share knowledge monthly rises from 0.16 to 0.38. Thus, team members who have average overlap in expertise, and are not involved in

Profiles for frequency

Profiles			Frequency			
			Prob (daily)	Prob (weekly)	Prob (monthly)	Prob(less than monthly/never
1	expertise overlap: co-located: multiple projects: task dependent:	avg* yes no yes	0.31	0.49	0.16	0.04
2	expertise overlap: co-located: multiple projects: task dependent:	avg no no yes	0.08	0.36	0.38	0.17
3	expertise overlap: co-located: multiple projects: task dependent:	avg yes no no	0.05	0.27	0.42	0.26
4	expertise overlap: co-located: multiple projects: task dependent:	> avg** yes no no	0.09	0.37	0.38	0.16
5	expertise overlap: co-located: multiple projects: task dependent:	avg no both yes	0.19	0.48	0.26	0.08

** avg: avg stands for average. The variable 'expertise overlap' is grand mean centered, which means that the mean is taken as the average value.*
*** > avg = the mean value + two times the standard deviation.*
Table 4-5: The profiles for frequency

multiple projects and have task dependency are more likely to share knowledge weekly or monthly when not co-located. If these team members would be co-located, it is highly likely that they share knowledge more often.

The third profile illustrates the large effect of task dependency. If the team members are not task dependent, the probability is highest that they share knowledge monthly or less than monthly/never, even when co-located. The effect of expertise overlap on the frequency of knowledge sharing is shown in the fourth profile. Certainly when compared to profile three, which represents the same situation where team members are co-located, are not task dependent, and not involved in multiple projects. Where in profile three the team members have an average overlap in expertise, in profile four they have an above average overlap. Comparing the two situations, we found that when the team members have an above average overlap in expertise, the probability that they share knowledge weekly increases from 0.27 to 0.37. At the same time, the probability that they share knowledge less than monthly or never decreases from 0.26 to 0.16. The effect of involvement of team members in multiple projects is positive. This is demonstrated in profile five. When comparing profile five to profile two, it is illustrated that the probability of the team members sharing knowledge daily rises from 0.08 to 0.19. The probability of the team members sharing knowledge weekly also increases (from 0.36 to 0.48). At the same time, the probability of the team members sharing knowledge monthly or less than monthly/never drops. However, when comparing profile one and five, we find that the probability of the team members sharing knowledge weekly is similar for both situations.

4.3.3 Comparing the propositions to the empirical findings

The propositions formulated for frequency of knowledge sharing are presented in section 2.2.2, and summarized in table 2-3. Table 4-6 presents a comparison for the empirical findings and the propositions of Transactive Memory theory, Social Exchange theory, and Proximity theory.

Expertise overlap is positively related to the frequency of knowledge sharing. From the three social theories, only the proposition of Proximity theory is in line with this result for expertise overlap. Both Transactive Memory theory and Social Exchange theory state that when there is an overlap in expertise, the team members share knowledge less frequently. The reasons Transactive Memory theory and Social Exchange theory both provide are that when team members have an overlap they can benefit less from each other's knowledge. Proximity theory, on the other hand, states that team members prefer to share knowledge with team members who are proximate to them. This implies that when team members have an overlap in expertise, this makes them more proximate and therefore more likely to share knowledge more frequently. Since this proposition is supported by the empirical findings, the explanation Proximity theory offers for the

Comparison of propositions and empirical findings for frequency

Explanatory variable (enablers)		Social theory			
		Transactive Memory	Social Exchange	Proximity	Empirical findings
Expertise overlap		X	X	√	+
Co-location		√	√	√	+
Involvement in multiple					
projects:	one actor	X	X	X	=/+
	both actors	X	√	X	+
Task dependency		√	√	√	+

√ : the proposition of the theory is in line with the empirical findings
X : the proposition of the theory is not supported by the empirical findings
-: the findings indicate that the enabler negatively affects frequency
+: the findings indicate that the enabler positively affects frequency

Table 4-6: Comparison of the theoretical propositions and the empirical findings for frequency relation between expertise overlap and frequency of knowledge sharing is most plausible. In other words, team members indeed appear to share knowledge more frequently with those team members they perceive to be closest in thinking.

When team members are *co-located* they are also more likely to share knowledge more frequently. Mainly for daily knowledge sharing, co-location makes a difference. This positive relation is predicted by all three theories. Social Exchange theory states that when team members know what expertise the others have, they know better what the other has to offer and what they can offer the other. Transactive Memory theory states that when people are co-located, this enables their directory updating so they have a more complete insight into the knowledge other team members have. Thus, the arguments of Social Exchange and Transactive Memory theory are quite similar as both theories state that when team members are co-located they have a better insight into what the other team members know and, therefore, they are likely to share knowledge more frequently. Proximity theory argues that when the team members are physically proximate, they are more likely to meet and share knowledge. For the theories all have equal predictive value as regards the effect of co-location on the frequency of knowledge sharing. Both the insight into other team members' knowledge and the higher probability of meeting probably explain the positive effect co-location has on the frequency of knowledge sharing. When a team member realizes he needs input from someone else, he will first look if someone in his neighborhood is present whom he can approach for the knowledge he needs.

For the *involvement* of one team member in multiple projects we found almost no effect on the frequency of knowledge sharing. However, for the involvement of both team members in multiple projects a surprisingly substantial effect is found for the frequency of knowledge sharing. Only the proposition of Social Exchange theory is in line with the positive relation found for involvement of both on the knowledge sharing frequency. Transactive Memory theory and Proximity theory both propose a negative effect on frequency of knowledge sharing. Transactive Memory theory proposes a negative effect from the notion that involvement in multiple projects makes the expertise recognition less accurate and causes the team members to have less time for knowledge retrieval and allocation. Proximity theory‘s explanation is that involvement in multiple projects makes the team members less proximate in the sense that, for example, they are less organizationally close and less physically proximate. The empirical findings do not support these propositions; therefore, they are not likely to explain the effect of involvement in multiple projects on the frequency of knowledge sharing. The proposition Social Exchange theory provides, is supported by the findings. Social Exchange theory states that when team members are involved in projects outside the consortium, this increases their probability of finding alternative knowledge sources. When both team members are involved in multiple projects this means they have equal positions and a balanced relationship. Also, they gain experiences outside the consortium, bringing new knowledge to the project. This makes them more likely to share knowledge more frequently. This argument is a suitable explanation as it is supported by the empirical findings.

Task dependency is found to have a very strong positive effect on the frequency of knowledge sharing between team members. The propositions of all three social theories are consistent with these positive relations. Transactive Memory theory and Social Exchange both state that when there is task dependency between team members they need each other's knowledge, resulting in more frequent knowledge sharing. The Proximity theory provides a highly complementary explanation. Proximity theory simply states that when there is task dependency between team members they are organizationally close. This closeness makes them share knowledge more frequently. This means that the positive effect of task dependency can both be explained by the team members needing each other's knowledge as well as the perceived organizational closeness.

Overall for the enablers, it seems that different mechanisms simultaneously play a role in their effects on how frequent team members share knowledge. For expertise overlap it is mainly proximity theory providing an explanation. For involvement in multiple projects the propositions of Social Exchange theory are most consistent with the findings, whereas for co-location and task dependency it is probably a combination of different mechanisms that plays a role in affecting the frequency of knowledge sharing.

1.1 Multiplexity

4.3.4 Description of the model

Multiplexity is defined as the number of knowledge contents shared. Four categories of content are defined for knowledge: know-how, know-what, know-who, and know-why. Because multiplexity is a ratio variable, a 'regular' multilevel regression model is used for analyzing the effects of the enablers on multiplexity. For the dyadic level (level-1), the model is:

$$\text{Multiplexity} = \beta_0 + \beta_1 EXP + \beta_2 CO + \beta_3 INV\_1 + \beta_4 INV\_2 + \beta_5 TD + u_0 + r \qquad (8)$$

Where:
EXP= expertise overlap
CO= co-location
INV_1= either *i* or *j* is involved in multiple projects
INV_2= both *i* and *j* are involved in multiple projects
TD= task dependency

For the team level, again only a random effect is included in the model:

$$\beta_0 = \gamma_{00} + u_0$$

$$\beta_{qj} = \gamma_{q0}$$

$q = 1,...,5$

The full model is denoted as:
Multiplexity=

$$\gamma_{00} + \gamma_{10}EXP + \gamma_{20}CO + \gamma_{30}INV\_1 + \gamma_{40}INV\_2 + \gamma_{50}TD + u_0 + r \quad (9)$$

4.3.5 Results

The results for the model for multiplexity are shown in table 4-7. Like the previous models for reciprocity and frequency, we start the analyses by running a null model. From the null model, the ICC is calculated. The ICC for the multiplexity-model indicates that 28 percent of the variance is explained by variables at the team level. This means that the variance in the number of knowledge contents shared in a dyad mostly (72 percent) depends on the characteristics of that dyad.

Results for multiplexity′

	Intercept only model		Full model	
Fixed part predictor:	Coeff.		Coeff.	
Intercept	2.33**	(0.16)	0.90**	(0.26)
Expertise overlap			0.38**	(0.11)
Co-location			0.59**	(0.19)
Involvement_1			0.04**	(0.16)
Involvement_2			0.80	(0.22)
Task dependency			1.28**	(0.14)
Random part:				
σ^2_e	2.06		1.32	
σ^2_{u0}	0.82		0.63	
Deviance	3257		1163	

′ n= 357 (dyads). Unstandardized coefficients are shown (standard errors in parentheses). Two-tailed tests are reported.
** $p<0.05$*
*** $p<0.01$*

Table 4-7: The intercept-only model and full model for multiplexity

After running the null model, the explanatory variables are included and the full model is analyzed. Because an ordinary multilevel model is used, deviance is calculated for both the null model and full model. Deviance is minus twice the log of the likelihood for models fitted by maximum likelihood. Its value indicates how well the model fits the data. The deviance of the null model and the full model can be used to compare their fit statistically. This test is based on the difference between deviance statistics, which has a chi-square distribution with degrees of freedom equal to the difference in number of parameters estimated in the models being compared. Table 4-7 shows that after adding the five enablers, the deviance drops considerably (from 3257 to 1163), so that the chi square is: $\acute{\chi}$=2094, with a degrees of freedom (df) of 6. The *p*-value is 0.000, implicating that the fit of the model for multiplexity is improved statistically significant when adding the enablers.

The intercept shows that when in a dyad the expertise overlap is average, the team members are not co-located, not involved in multiple projects, nor task dependent. They are expected to share about one type (0.9) of knowledge content. The results also show that all of the explanatory variables have a positive effect on the number of knowledge-content shared. Please note that the effect of the involvement of both team members in multiple projects is not statistically significant. Most strongly related to the number of knowledge contents shared is task dependency. The expected values for each of the five profiles are calculated for multiplexity. They are presented in table 4-8. As the table shows, team members share 2.56 types of knowledge-content in the average situation (profile one). However, when they are not task dependent this drops to 1.49 types of content shared. The effects of having an expertise overlap are illustrated when comparing the third and the fourth profile. When team members have an average expertise overlap, they are expected to share 1.49 types of knowledge content, but if the overlap in expertise is above average this increases to 2.17 types. When the team members are not task dependent and not involved in multiple projects, but they are co-located, the overlap in expertise can make the difference between them sharing one or two contents of knowledge. The comparison of profile two and five illustrates that being involved in multiple projects has a positive effect on the number of knowledge types shared.

4.3.6 Comparing the propositions to the empirical findings

The propositions formulated for the multiplexity of knowledge sharing are presented in section 2.2.3 and summarized in table 2-4. Table 4-9 shows the comparison of the propositions derived from the theories with the empirical findings.

Expertise overlap is found to be positively related to the number of contents of knowledge shared. The arguments of Transactive Memory theory and Social Exchange theory are to a large extent overlapping. Both theories state that when team members have an overlap in expertise they have less knowledge to offer each other, leading to less thick knowledge sharing. This notion is not supported by the empirical findings. The propositions of Proximity theory on the other hand are supported by the data. The positive effect of expertise overlap, therefore, is better explained by the mechanism Proximity theory proposes. In other words, when team members share areas of expertise they have more in common, and this makes them more likely to share multiple contents of knowledge.

A somewhat stronger positive effect on multiplexity is found for *co-location*. This implies that the explanation of Social Exchange theory for the effect of collocation on the number of knowledge contents shared does not seem to hold in the context of instrument consortia. Social Exchange theory proposes that when team members are co-located, they are better able to identify who has what knowledge and whether there are alternative knowledge sources. This makes them spread their knowledge sharing across different sources, which makes their knowledge sharing less multiplex. The opposite effect is found in the empirical data. Both the propositions from Transactive Memory theory and Proximity theory are consistent with the findings. Transactive Memory theory states that when team members are co-located, their cognitive workload is further divided and their Transactive Memory System becomes more efficient in processing knowledge as they

Profiles for multiplexity

Profiles			Multiplexity
1	expertise overlap: co-located: multiple projects: task dependent:	avg* yes no yes	2.56
2	expertise overlap: co-located: multiple projects: task dependent:	avg no no yes	2.18
3	expertise overlap: co-located: multiple projects: task dependent:	avg yes no no	1.49
4	expertise overlap: co-located: multiple projects: task dependent:	> avg** yes no no	2.17
5	expertise overlap: co-located: multiple projects: task dependent:	avg no both yes	2.98

** avg: avg stands for average. The variable 'expertise overlap' is grand mean centered, which means that the mean is taken as the average value.*
*** > avg = the mean value + two times the standard deviation.*

Table 4-8: The profiles for multiplexity become further specialized. Team members become more dependent on each other's expertise and their knowledge sharing becomes more multiplex. Proximity theory states that co-location increases the probability of the team members meeting and having more in common. This makes them more likely to share multiple contents of knowledge. The arguments of Transactive Memory theory and Proximity theory are complementary as they do not rule out one another. In the instrument consortia, when team members are co-located their expertise recognition and knowledge processing is easier than when they have to work together over a distance. Moreover, it seems logical that when team members are co-located they meet each other during lunch and at other social events, increasing the likelihood that they engage in informal conversations. This allows them to get to know more about each other's knowledge than if they had not been co-located.

Involvement in multiple projects is also found to be positively related to the multiplexity of knowledge shared. The propositions of Proximity and Social Exchange theory are not supported. Proximity theory states that being involved in projects outside the consortium causes the team members to have less time and opportunities to develop a shared language and discover commonalities. Consequently, the team members are less likely to share knowledge of multiple contents. Social Exchange theory expects involvement in multiple projects to increase the probability of finding alternative sources for knowledge. The team members can then decide for each situation who is the best source for the knowledge they need and spread their knowledge sharing across different people. This would lead to less multiplex knowledge sharing. However, instead of the negative relation as expected by Proximity theory and Social Exchange theory, we find a positive relation. In other words, when one or both team members are

Comparison of propositions and empirical findings for multiplexity

Explanatory variable (enablers)	Social theory			
	Transactive Memory	Social Exchange	Proximity	Empirical findings
Expertise overlap	X	X	√	+
Co-location	√	X	√	+
Involvement in multiple				
projects: one actor	√	X	X	+
both actors	√	X	X	+
Task dependency	√	√	√	+

√ : the proposition of the theory is in line with the empirical findings
X : the proposition of the theory is not supported by the empirical findings
-: the findings indicate that the enabler negatively affects multiplexity
+: the findings indicate that the enabler positively affects multiplexity

Table 4-9: Comparison of the theoretical propositions and the empirical findings for multiplexity involved in multiple projects, they tend to share multiple contents of knowledge. This positive effect is in line with the proposition of Transactive Memory theory. Transactive Memory theory describes a twofold effect of involvement in multiple projects. On the one hand, involvement in multiple projects could lead to less multiplex knowledge sharing because it becomes more difficult for the team members to find the right people for knowledge allocation and retrieval. This argument is not supported. On the other hand, Transactive Memory theory states that involvement in multiple projects could lead to more multiplex knowledge sharing because team members who are involved in multiple projects gain new expertise outside the consortium. They bring in new expertise gained outside of the consortium and are, therefore, more likely to share multiple contents of knowledge with others.

Like in the models for reciprocity and frequency, *task dependency* is the main explanatory variable for the number of knowledge contents shared between team members. All three theories propose this positive effect of task dependency on multiplexity of knowledge sharing. The explanations provided by Transactive Memory theory and Social Exchange theory for the positive effect of task dependency are quite overlapping. Both theories explain that when two team members are task dependent, they need each other's knowledge for conducting their tasks. This means they have more knowledge to share, making their knowledge sharing more multiplex. The explanation of Proximity theory is complementary to that of Transactive Memory theory and Social Exchange theory. The argument of Proximity theory is that when team members are task dependent, they are organizationally proximate. They have this relation in common and, therefore, are more likely to share multiple knowledge contents. The propositions of all three theories are in line with the empirical results. This means that team members who are task dependent share multiple types of knowledge, because they need each other's knowledge and have more commonalities than team members who are not task dependent.

4.3.7 Summary of the findings

The first part of this chapter described the empirical results for the effects of the enablers on knowledge sharing within teams. Task dependency was found to be the strongest enabler for all knowledge sharing characteristics. By creating task dependencies between team members, the probability of them sharing knowledge, sharing knowledge more frequently and sharing multiple types of knowledge are increased.

The probability that team members share knowledge (mutually) is also increased when team members have an overlap in expertise and when they are co-located. The involvement of team members in other teams is found not to have a real impact on the direction of knowledge sharing between team members. As mentioned, task dependencies are most facilitating for the frequency of knowledge sharing between team members.

Comparison propositions to empirical findings at the intra-team level							
Social theory:	Explained characteristic:		Expertise overlap	Co-location	Involvement in mult. proj.		Task dependency
Transactive Memory	Reciprocity	M	X	√	X	X	√
		A	√	X	X	X	√
		N	X	X	X	X	√
	Frequency		X	√	X	X	√
	Multiplexity		X	√	√	√	√
Social Exchange	Reciprocity	M	X	√	√	√	√
		A	√	X	X	√	X
		N	X	X	√	√	√
	Frequency		X	√	X	√	√
	Multiplexity		X	X	X	X	√
Proximity	Reciprocity	M	√	√	√	X	√
		A	√	√	X	X	√
		N	√	√	√	X	√
	Frequency		√	√	X	X	√
	Multiplexity		√	√	X	X	√

√ : the proposition of the theory is in line with the empirical findings
X : the proposition of the theory is not supported by the empirical findings
Table 4-10: Overview of the theoretical propositions compared to the empirical findings

A second enabler we found to increase the probability team members share knowledge more often was co-location. For the involvement in projects outside the consortium, the findings indicate that when two team members are both involved in multiple projects, the frequency of their knowledge sharing is also likely to be higher than when they are involved in this one project. Finally, having expertise overlap is found to be facilitating the frequency of knowledge sharing between two team members, although this enabler was found to have the smallest effect compared to the other enablers.

For multiplexity, task dependency is the strongest enabler. Co-location and expertise overlap also stimulate team members to share knowledge of multiple content types. The involvement of team members in multiple projects barely has an effect on the number of content types shared between team members.

4.4 Explanatory strength of the theories

The empirical study aimed to explore the effects of the enablers on the knowledge sharing characteristics, of which the results are described above. The second intention was to explore which mechanisms in the theories best explain the effects of the enablers on the knowledge sharing characteristics by adopting a multi-theory perspective in which (competitive) theories are compared. This is the focus of this section. In this section Transactive Memory theory, Social Exchange theory, and Proximity theory are compared as to which theory best explains the effects found in the empirical study.

Table 4-10 shows which of the propositions of the three theories are supported by our empirical study of knowledge sharing between team members and which are not. For example, the table shows that the propositions of Transactive Memory theory for the effect of expertise overlap on reciprocity are not supported for mutual knowledge sharing and null ties. However they are supported for asymmetrical knowledge sharing. By comparing the theories vertically, in the columns of table 4-10, insight is gained into which theory explains the role of the specific enabler well and which does not. This comparison is made in section 4.5.1. By comparing the theories horizontally in the rows of table 4-10, an evaluation is made of knowledge sharing characteristics and how well a theory overall explains knowledge sharing in the instrument consortia. This comparison is made in section 4.5.2. This section discusses for each of the knowledge sharing characteristics which of the theories best explains the effects.

4.4.1 Explanatory strength of the theories for the effects of the enablers

Expertise overlap

Proximity theory proposes the effect of expertise overlap on knowledge sharing the best by far. Transactive Memory theory and Social Exchange theory each have only one proposition supported by the empirical data. The question is why Social Exchange theory and Transactive Memory theory deal so poorly with the effects of expertise overlap. In the dataset, 51 percent of the dyads show no overlap in expertise, 43 percent one area of expertise and only six percent more than one area of expertise. This means that the size of the overlap is irrelevant – what matters is whether the overlap is present or not. When there is an overlap in expertise, team members are more likely to share knowledge, share it more frequently and share multiple types of knowledge, than when there is no overlap. An explanation may be that team members work on tasks that require highly specialized knowledge. If they come across issues they cannot solve individually, they need the specialized knowledge from others who are specialists in their same area of expertise. This means that for conducting their tasks team members often need knowledge of (approximately) their own area of expertise.

Transactive Memory theory and Social Exchange theory both emphasize that to make knowledge sharing perceived as being useful, there has to be a discrepancy in knowledge. This argument appears to be not supported. However, we do not want to completely rule out the mechanisms of Transactive Memory theory and Social Exchange theory. Why would team members turn to colleagues who have the same knowledge as they have? Perhaps the differences in knowledge are much more subtle and at a lower level. In these instrument consortia each team is selected for the task based on his expertise. When a team member needs knowledge for executing his task, it is likely that he approaches someone within the same area of expertise. He may assume that only people in this area of expertise can help find a solution, which may very well be the case. Although this person has knowledge in the same area of expertise, he might have different experience or specific knowledge in this area. Therefore, they can reach synergy by discussing the problem together. So the differences in knowledge can also be within areas of expertise, for example, on specific subjects or in seniority. Between the areas of expertise (as we measured expertise overlap), the differences are perceived as quite large. This makes team members look for others who find themselves in similar area(s) of expertise. Within the areas of expertise, where the differences are relatively smaller, the mechanisms of Social Exchange and Transactive Memory are likely to play a role.

Co-location

As regards co-location, the Proximity theory has the most accurate propositions. Social Exchange theory and Transactive Memory theory only support some propositions. This seems logical as the Proximity theory is based on research relating physical proximity to more frequent communication. Apparently, this mechanism also shapes knowledge sharing within teams of the instrument consortia. Not only are the team members likely to share knowledge more frequently, they are also more likely to share knowledge mutually and on multiple contents. Transactive Memory generally agrees with this as it states that physical proximity facilitates all three processes found in Transactive Memory systems. Social Exchange theory very poorly explains the effects of co-location, which may be explained by the market mechanism that is central to Social Exchange theory. This market mechanism centres on the notion that the discrepancy in knowledge between the team members is particularly important. When team members are co-located, they have more knowledge in common as they share project specific experience. They are also better able to identify alternative knowledge sources. However, for the team members in the instrument consortia who are already quite diverse in their expertise (see the previous section on expertise overlap), this project specific expertise is likely to be important for it creates a basis for sharing knowledge.

Involvement in multiple projects

Social Exchange theory best explains the effects involvement in multiple projects has on the three knowledge sharing characteristics. Transactive Memory theory on the other hand only poorly explains the effect of involvement in multiple projects on knowledge sharing within teams.

Social Exchange theory and Proximity theory explain the effects for the involvement of one team member in multiple projects equally well. However, for the involvement of both team members in multiple projects the propositions of Social Exchange theory are almost completely supported, whereas for Proximity none of the propositions is affirmed. Both team members being involved in projects outside the consortium is a situation where the closeness of both varies with the time they spend on the other project. When working in multiple projects, it is likely that they are not proximate in terms of physical closeness, but at these times they are probably also not task dependent, and find themselves in a different social setting. Conversely, at times they do work for the consortium, their closeness is high. In the data we found that in 74 percent of the dyads where both team members are involved in multiple projects there is co-location, and in 65 percent of these dyads there is task dependency. These are two forms of proximity, which are the same for dyads where none or one of the team members is involved in multiple projects. In this varying situation, Proximity theory does not explain the effects well. It focuses on the issue that when working on the other project they are less proximate, whereas the high proximity when working for the consortium probably has more impact. As the Social Exchange theory explained the involvement of both in multiple projects very well, it is plausible that the number of alternative knowledge sources plays a role in knowledge sharing in these dyads. When team members are involved in multiple projects, the probability that they have alternative sources of knowledge at their disposal is higher than when they work in the one consortium. When one of the team members is involved in multiple projects, the relationship becomes unbalanced in the sense that this team member has more alternative sources for knowledge than the other. Social Exchange theory states team members prefer balanced relations, and therefore expects a negative effect on the reciprocity and frequency of knowledge sharing. The empirical findings indeed show this negative effect on reciprocity, but not on how frequent the team members share knowledge. When both team members are involved in multiple projects, their probability of finding alternative knowledge sources is similar. Following Social Exchange theory, this leads to more mutual and more frequent knowledge sharing. This expectation is in line with the empirical findings. However, the propositions of Social Exchange theory for the effect of involvement in multiple projects on the multiplexity of knowledge sharing do not hold. For the effect of involvement in multiple projects on multiplexity, it is only the propositions of Transactive Memory theory that are in line with the empirical findings.

The propositions of Transactive Memory theory for the effects of involvement in multiple projects are two-fold. On the one hand, by being involved in multiple projects, team members acquire new knowledge which they bring to the consortium. This is in line with the empirical findings in that the number of knowledge contents shared between team members increases when one or both team members are involved in multiple projects. On the other hand, Transactive Memory theory's states that when team members are involved in multiple projects, they have less accurate expertise recognition and they have less time for knowledge allocation and knowledge retrieval. This argument is not supported by the empirical findings. Apparently, even when involved in multiple projects, the time the team members spend together in the consortium is likely to be sufficient to get a good idea about each other's knowledge.

Task dependency

Almost all propositions for the effects of task dependency on knowledge sharing characteristics are supported by the empirical findings. This indicates that all three theories are valuable for predicting the effect of task dependency on knowledge sharing within teams in instrument consortia. Even though all three theories propose different theoretical mechanisms, they predict the same effects of task dependency. The explanation may be that the mechanisms the theories propose for the effects of task dependency are highly complementary. Transactive Memory theory states that task dependencies lead to cognitive dependencies, which stimulate the development of Transactive Memory systems where people need each other's knowledge and therefore share knowledge mutually, frequently, and on multiple content types. Following Social Exchange theory task dependency also leads to team members needing each other's knowledge, but with an emphasis on the value each team member's knowledge has for the other team members. The view of Proximity theory is complementary as the Proximity theory states that task dependency is a form of organizational closeness; when two team members are task dependent, they are more proximate which makes them more likely to share knowledge asymmetrically, mutually, more frequently and on multiple contents. Thus, even though the Transactive Memory theory, Social Exchange theory, and Proximity theory emphasize different aspects, their basic ideas and ensuring propositions about the effect of task dependency on knowledge sharing are very similar.

We can conclude that the effects of expertise overlap and co-location are most correctly proposed by Proximity theory. It is likely that mainly the mechanisms of closeness underlie these effects rather than mechanisms of discrepancy in knowledge as proposed by Transactive Memory theory and Social Exchange theory. The effect of involvement in multiple projects is best explained by Social Exchange theory; the availability of alternative knowledge sources seems to shape knowledge sharing when one or both team members are involved in projects outside the consortium. For task dependency we found that Transactive Memory theory, Social Exchange theory and Proximity theory all explain its effects on knowledge sharing within teams. Here multiple mechanisms, which are to some extent complementary and to some extent overlapping, play a role in shaping the effect of task dependency on knowledge sharing within teams.

4.4.2 Explanatory strength of the theories for the knowledge sharing characteristics

Reciprocity

Comparing the three theories on the extent to which they successfully explain reciprocity, we found that for Transactive Memory few propositions are supported. Social Exchange theory explains reciprocity somewhat better, however Proximity theory by far best explains reciprocity. Apparently, closeness is a mechanism that strongly shapes the direction of knowledge sharing between team members. Transactive Memory theory centres on the notion that individuals in a team each have different specializations and by sharing knowledge they all have access to the specialist knowledge present within the team. This implies that team members approach others who they perceive to have different expertise. Social Exchange theory is based on a similar notion. Social Exchange theory states that individuals prefer knowledge sharing with others who have different knowledge to offer and to whom they can offer knowledge in return. Transactive Memory theory and Social Exchange theory therefore have overlapping assumptions on the direction of knowledge sharing. However, the findings indicate that the mechanism of closeness as proposed by Proximity theory are more likely to shape the direction of knowledge sharing between team members in the instrument consortia. It seems that when team members are confronted with a problem, they do not approach team members with different expertise from them and do not engage in mutual knowledge sharing as expected. Instead they approach team members who are physically, organizationally, and cognitively close. An explanation may be that team members in these highly multidisciplinary projects find it easier to share knowledge with team members who think like them and who are easily accessible to (i.e. are physically close).

Frequency

For frequency the empirical results indicate that all three theories to some extent explain how frequently team members share knowledge with each other. Of the five effects proposed by each theory, two were supported for Transactive Memory and three for Social Exchange theory and Proximity theory. Even though the three social theories incorporate different mechanisms, they propose similar effects for some of the effects of the enablers on frequency of knowledge sharing. The explanations provided by Transactive Memory theory and Social Exchange theory are clearly overlapping. Both theories for instance argue that when team members are co-located they have better insight into each other's knowledge and therefore they have better insight into the knowledge they can offer each other. When the team members perceive a need for knowledge this means they can better identify whom to approach for knowledge sharing. Proximity theory proposes a complementary mechanism. Team members who are co-located have more opportunities to have (spontaneous or planned) interaction: co-location increases the likelihood team members share knowledge. The notion of Proximity theory is very compatible with the notion of Transactive Memory theory and Social Exchange theory; it is plausible that when people are co-located they meet in the hallways, during coffee-breaks and during lunch, et cetera. Thereby they have a higher probability of interacting. Aside from this interaction, the probability of the team members sharing knowledge is also increased because they learn about each other's expertise.

For the involvement of *one* team member in multiple projects, Transactive Memory theory, Social Exchange theory ans Proximity theory have similar propositions for the frequency of knowledge sharing. The theories provide different but complementary explanations. Transactive

Memory theory suggests that the involvement of one team member in multiple projects is negative for frequency. Transactive Memory theory states that when a team member is not working fulltime on the project, it becomes more difficult for him/her to identify the expertise the other team members in the consortium have. This complicates knowledge allocation and retrieval. Social Exchange theory focuses on the alternative sources for knowledge, which are higher for the team member who is involved in multiple projects than for the team member solely involved in the consortium. As a consequence the positions of the team members are unequal, making knowledge sharing less attractive. Additionally, the team member with alternative sources is able to spread his knowledge sharing over a number of sources. Thereby the frequency of knowledge sharing decreases. Proximity theory proposes a negative effect for involvement in multiple projects of one team member because the team members are less close in terms of physical location and share less project specific experience. However, none of the three theories propositions are supported by the empirical data as the results show a small positive effect instead of a negative effect. The propositions of Transactive Memory theory and Proximity theory for the involvement of *both* team members in multiple projects are similar to the propositions for the involvement of *one* team member in multiple projects. These propositions are not supported by the empirical findings as well. Social Exchange theory does propose a positive effect of the involvement of both team members on the frequency of their knowledge sharing. The explanation Social Exchange theory provides for this positive effect is that when both team members are involved in multiple projects, they both have equal positions in terms of alternative sources for knowledge. As team members prefer equal relationships, this makes them likely to share knowledge more frequently with each other.

Multiplexity

As table 4-10 shows, Social Exchange theory does not explain the multiplexity of knowledge sharing between team members very well. Proximity theory explains the effects better, only it does not completely capture the effects of involvement in multiple projects. Situations where team members are involved in multiple projects are in particular situations where the closeness of team members is very low. Transactive Memory theory seems to provide the best explanation for the knowledge contents shared between team members. Even though Social Exchange theory and Transactive Memory theory propose overlapping mechanisms, the theories are quite different in explaining the contents of knowledge shared. Social Exchange theory argues that people prefer to have alternative sources for knowledge so they are less dependent on one source so they are able to spread their knowledge sharing over a number of sources. This would imply that in these situations knowledge sharing is focused and that the multiplexity of the knowledge sharing relations is low. The empirical findigs do not support this line of reasoning. Opposite to Social Exchange theory, Transactive Memory theory states that in an optimal situation team members share multiple content types of knowledge with each other. The optimal situation Transactive Memory theory describes is where expertise is differentiated among the team members. Each team member is expert in a certain area on all types of knowledge (know-why, know-how, know-who, and know-what). When a team member needs knowledge he will approach the appropriate expert and share knowledge of multiple content types within this area of expertise. The empirical findings support this mechanism. Besides the mechanism of Transactive Memory that shapes the multiplexity of knowledge sharing between team members, the mechanism of Proximity theory also seems to play a role.

4.4.3 Summary and the search for new theory

In the previous we concluded that Proximity theory best explains the effects of expertise overlap and co-location on knowledge sharing in instrument consortia. The effects of involvement in multiple projects are best explained by Social Exchange theory. For task dependency, the effects are predicted by all three social theories. Figure 4-1A sets out a graphical illustration of which theories best explain the effects of the enablers. Figure 4-1A shows that expertise overlap and co-location are best explained by Proximity theory, and that the effect of task dependency on knowledge sharing is explained by both Proximity theory, Social Exchange theory, and Transactive Memory theory.

The finding that Proximity theory best explains the effects of expertise overlap and co-location seems logical. Proximity theory assumes that individuals who are physically or cognitively close are attracted to each other. Proximity theory is based on research conforming this assumption. In our study these effects of closeness are likewise confirmed for the context of instrument consortia.

More surprisingly we found that not Proximity theory but Social Exchange theory best explains the effect of team members being involved in multiple projects. The involvement of team members in projects outside the consortium is a situation in which the basic closeness of persons is very low or varies. It seems that in these situations Proximity theory explains knowledge sharing poorly. Social Exchange theory differs from the other two theories in that it emphasizes the positions of the team members towards each other. One of the main assumptions Social Exchange theory makes is that individuals prefer balanced situations where they have equal positions. Being involved in projects outside the consortium is in particular a situation were positions of team members shift. In that sense it is not surprising that Social Exchange theory best explains the effects of involvement in multiple projects on the way people in the consortia share knowledge.

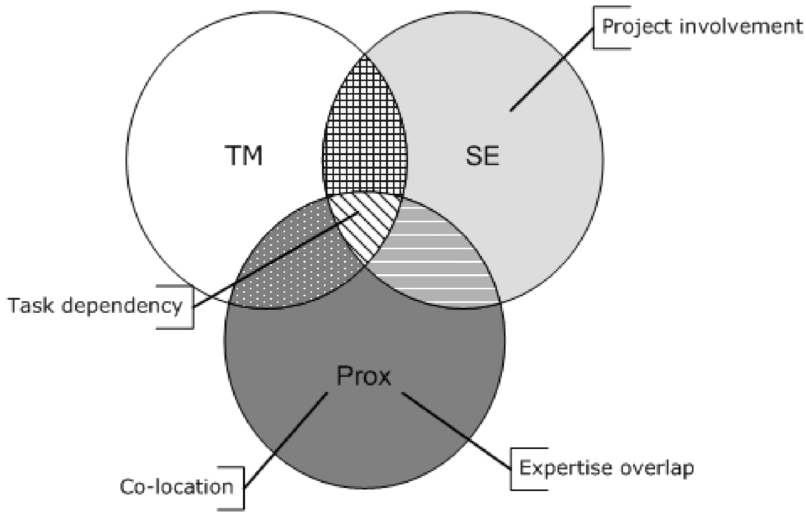
To summarize, we conclude that Proximity theory mainly explains effects very well in situations where the basic closeness between team members is relatively high.

The effects of task dependency on knowledge sharing characteristics between team members in the consortia are explained by all three theories. The three theories each comprise different mechanisms, but propose similar effects. It is possible that multiple mechanisms underlie the strong enabling effect of task dependency of knowledge sharing between team members. Another possibility is, for instance, that only the mechanism of Social Exchange theory makes team members who are task dependent share knowledge more reciprocally, more often and on multiple content types. In that case it may be plausible that Transactive Memory theory also explains the effects of task dependency because the mechanisms of these two theories are to a high extent overlapping for task dependency. It could be a coincidence that Proximity theory's propositions are supported as Proximity theory offers a different explanation only the predicted effect is the similar to that of Transactive Memory theory and Social Exchange theory. We have to conclude that our empirical study at the intra-team level is not suitable for answering this question.

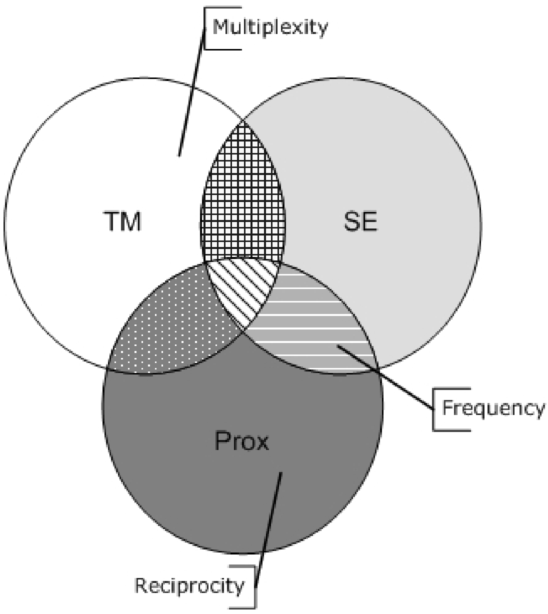
A relevant question is: was the choice of theories the best choice to be made for explaining the effects of the enablers on knowledge sharing between team members? Looking at figure 4-1 we have reservations about this, because the effects of the enablers can almost be fully explained by including Social Exchange theory and Proximity theory. Transactive Memory theory could have been excluded at least for explaining the effects of the enablers. We did not expect this as Transactive Memory theory is pre-eminently a theory that explains knowledge sharing in situations where individuals are experts in different areas of expertise. On the other hand, a condition for the mechanisms of Transactive Memory theory to work is that the individuals have accurate knowledge about what others know. The insufficiency of this knowledge can be a reason for the small role the mechanisms of Transactive Memory theory play in the instrument consortia.

We also compared the theories on their affirmed propositions for the knowledge sharing characteristics. Figure 4-1b illustrates the theoretical findings from this perspective. This comparison shows that Proximity theory best explains the reciprocity of knowledge sharing within teams in instrument consortia. This indicates that team members mainly approach each other on the basis of who is most proximate to them. On forehand we expected Social Exchange theory to be best predicting reciprocity, because one of the premises of Social Exchange theory is that people exchange resources based on their expectation to get resources in return. This is in fact the central notion of reciprocity (Blau, 1964a). Because Proximity theory best explains reciprocity of knowledge sharing, a plausible explanation is that there is mutual knowledge sharing because the team members are co-located. Asymmetrical knowledge sharing could indicate that if one team member really needs specialist knowledge he approaches the team members he knows to have it. This means that when a team member needs specialist knowledge he will not approach the team member who is closest. Instead he approaches the team member who has that specific knowledge. For less critical knowledge, it is easier to share knowledge with team members who he meets on a daily basis.

We found the frequency of knowledge sharing within teams is best explained by Social Exchange theory and Proximity theory. A combination of exchange mechanisms and closeness mechanisms explains how often team members share knowledge. This supports the explanation we suggested for the explanatory strengths of the theories for reciprocity. We expected that it



A: explanatory value in explaining the effects of the dyadic attributes



B: explanatory value in explaining the aspects of knowledge sharing

TM: Transactive Memory theory
SE: Social Exchange theory
Prox: Proximity theory

Figure 4-1: Explanatory value of the theories is a combination of mechanisms that predicts the frequency of knowledge shared between team members. It is not plausible that team members only share knowledge very frequently with others who for example are close. Or that team members only share knowledge frequently with others in equal positions. For critical problems or specialistic knowledge a team member is likely to share knowledge with the team member who has the most appropriate knowledge that he does not have and not just with the team members who are proximate.

For multiplexity, we found that Proximity theory and Transactive Memory theory have the most supported propositions. This implies that the multiplexity of knowledge shared between team members is mainly shaped by mechanisms of closeness and by the perceptions they have about each other's knowledge. On the one hand, it is striking that multiplexity is best predicted by Transactive Memory theory since in explaining the effects of the enablers on knowledge sharing not many of Transactive Memory theory's propositions are supported. On the other hand, it is to be expected as Transactive Memory theory is particularly a theory that focuses on the content of knowledge shared. Transactive Memory theory evolves around the notion that each individual is expert in a specific area. It stresses that a team member (in a transactive memory system) approach a team member in the transactive memory system who they think has expertise they need. The expert has to explain more to the team member who is not expert, than he would need to explain experts in his own areas of expertise. In knowledge sharing within a transactive memory system the team members are likely to share knowledge of at least two types of knowledge, because they are explaining something to persons who are not experts on the subject. If only Proximity theory had been included for explaining the multiplexity of knowledge sharing between team members, most of the effects would have been predicted except for the effects of involvement in multiple projects. The propositions of Transactive Memory theory for multiplexity were also almost all supported by the data except for the effect of expertise overlap. Using Transactive Memory theory has added value as it explains the effects of involvement in multiple projects on the multiplexity of knowledge sharing between team members whereas the other theories are not able to explain these effects.

To summarize, in explaining the effects of the enablers Transactive Memory theory could have been left out. In explaining knowledge sharing characteristics Transactive Memory theory should be included as the empirical findings indicate that Transactive Memory theory has added value in explaining the multiplexity of knowledge shared between team members.

For further theoretical development the question is whether it is possible to form one unifying theory that explains knowledge sharing in instrument consortia. Because there is a quite clear dividing line between the theories in their abilities to explain the knowledge sharing characteristics, this can be used as a starting point for a new theory. A combination of Proximity theory and Social Exchange theory best explains the reciprocity and frequency of knowledge sharing in dyads of team members. A combination of Proximity and Transactive Memory theory best explains the multiplexity of knowledge sharing between team members.

A condition for unifying the theories in a new theory is that their foundations are not in conflict. In selecting the theories for our study a number of criteria were used. The theories have these criteria in common; they can be applied at the dyadic level, both within as well as between teams, their focus is on (existing) relations, and they have a static view on the relations. As to the basic mechanisms of the theories, their arguments are sometimes contradicting. The theories mainly contradict in their propositions covering the effects of expertise overlap and co-location. Proximity theory's propositions on these effects were affirmed, whereas we found almost no support for the propositions of Transactive Memory theory and Social Exchange. The findings indicate that under some conditions one theory makes better predictions than the other theories. When team members are task dependent, all three theories explain knowledge sharing. However, when team members are co-located and/or have an overlap in expertise - a situation where the team members are highly proximate - Proximity theory best explains knowledge sharing between the team members. When proximity is particularly low, where one or both team members are involved in projects outside the consortium for instance, the mechanisms proposed by Social Exchange best explain knowledge sharing. Then Proximity theory does not have much explanatory power anymore.

An initiative to formulate a new theory to explain knowledge sharing in instrument consortia would look something like this: when it is critical, specialist knowledge that a team member needs he approaches a team member who has the required specialist knowledge regardless of how proximate this team member is to him. If he needs the knowledge he will try to get it from the team member perceived to be most expert. If it is less specific knowledge the team member needs, he will acquire this from team members who are most close. In situations where the basic proximity is low, team members will still make the effort of finding the knowledge they need. This mechanism shapes the direction and frequency of knowledge sharing between team members. Multiplexity of knowledge sharing is explained by a similar mechanism; a team member shares multiple contents of knowledge with others who he considers to be expert. Team members are better able to identify who has which expertise when they are co-located. However, even in situations where overall proximity is low and expertise recognition may not be very accurate, they will still turn to team members who they perceive to be experts in the areas in which they need knowledge.

Chapter 5

Results: knowledge sharing at the inter-team level.

5 Results: knowledge sharing at the inter-team level

5.1 Introduction

In the research design we argued that knowledge sharing should take place at two levels minimum; within the teams and between teams. Within the teams team members have to collaborate to complete their team task, which in most cases is the part they are developing. Knowledge sharing between teams takes place because the different parts the teams are developing have to be integrated into one new product. In case of the instrument consortia the teams together have to integrate their parts into one measurement instrument. The previous chapter explored knowledge sharing at the intra-team level. We discussed the effects of enablers on the reciprocity, frequency, and multiplexity of knowledge sharing between team members. This chapter discusses knowledge sharing between teams. The focus is on how teams share knowledge and how the enablers influence their knowledge sharing. More specifically, the objective of the empirical study at the inter-team level is two-fold. The first purpose is to explore to which extent the effects of enablers on knowledge sharing between teams are different from the effects found within the teams. The second intention is to explore whether there is a difference in mechanisms explaining the knowledge sharing within teams and between teams.

In chapter 3 we indicated that the empirical study at the inter-team level was conducted using qualitative methods. The main method of gathering data was conducting interviews. At the beginning of the empirical research exploratory interviews with team leaders were conducted to gain more information on the issues that played in the consortia concerning knowledge sharing. These exploratory interviews were held with fifteen team leaders in project Space and nineteen team leaders in project Ground. One of the results of these interviews was a network of inter-team interaction. It proved to be very difficult for the team leaders to indicate these relations. Therefore this network was used as a starting point for further study. We conducted more focused interviews with key persons on how expertise overlap, task dependency, co-location, and involvement in multiple projects affect the direction, strength, and multiplexity of knowledge sharing between teams and on the underlying mechanisms. For each consortium we interviewed the project leader and a middle manager. These respondents were selected because of their helicopter view over the projects and their insight into knowledge sharing between teams in their projects. In addition to the interviews, we observed the interaction between teams by attending meetings and talking to people in the consortia.

This chapter presents the findings for the empirical study on knowledge sharing between teams. It starts by giving a more detailed description on how the projects are organized and what their method of working is. Findings of the empirical study of knowledge between teams are described for each knowledge sharing characteristic in the subsequent sections. Section 5.3, 5.4 and 5.5 respectively discuss the findings for the reciprocity of knowledge sharing, the frequency of knowledge sharing and the multiplexity of knowledge sharing. Each section is split up in two parts. The first part of each section compares the effects of enablers on knowledge sharing between teams to the effects they have within teams. The second part focuses on the mechanisms explaining the knowledge sharing between teams and whether these are different from the mechanisms explaining knowledge sharing within teams. This chapter concludes by summarizing and discussing the findings at the inter-team level.

5.1.1 Detailed descriptions of method of work in the instrument consortia

In chapter three the projects were already briefly discussed. To give a better idea on the method of working in the projects, the organization structures, the phases in the projects and the work structures that underlie the communication processes are described in more detail.

In appendices 1 and 2 the organization charts of project Ground and project Space are shown. The organization charts visualize three layers of management and teams in both projects; (1) the system level, (2) the subsystem level, and (3) the institute/work packages.

The *system level* takes responsibility for the effectiveness of the project, the coherence in the project, the final integration of the parts and verification of the instrument. The system level in project Space consists of the project management team, the project office, the system engineering team, the Assembly, Integration & Verification team (AIV), and the Product Assurance/Quality Assurance team (PA). In project Space the Principal Investigator (PI), co-PI's, the Project scientist, the Project manager, and the project Space steering committee form the management of the consortium. The Principal Investigator (PI) is the formal point of contact with ESA and the chairman of the project Space steering committee. The PI is authorized to make decisions regarding performance-, cost-and schedule changes in consultation with the project Space steering committee and has the independent authority to accredit the final instrument together with ESA. Together with the co-PI's, the project scientist and the project manager he forms the PI team which is the top level government body. The project manager reports to the PI. The project management team supports the project manager. Their task is to ensure coherent and consistent instrument development and interface control, adequate calibration of the instrument and the establishment of the Instrument Control Centre (ICC).

At the highest organization level of project Ground the top level government body is an independent International Steering Committee. This committee is assigned the tasks of reviewing the effectiveness of the cooperation within and between the research groups, reviewing the research programs, and reviewing the progress on the research infrastructure. Project Ground is split up in two parts; a part where the scientific research is conducted and a part where the instrument is designed and developed. The focus in our study is not on the research part but on the part of the project where the actual design and development of the instrument takes place. This is done in the so-called Infrastructure part of the project Ground organization. The system level in the Infrastructure part of project Ground consists of the Infrastructure Procurement Committee, the project management team, the project office and the System Engineering group. The Infrastructure Procurement Committee reports to the International Steering Committee for the design and development of the instrument. The system level of this part further consists of the project management, the system design and engineering team and project control team. Their task is similar to the system level in project Space: they ensure coherent and consistent instrument development and interface control, adequate calibration of the instrument, and implementation of the instrument. In other words, in both projects the system level is responsible for the coordination between project control, system engineering, testing and calibration at the subsystem level. The system engineering team has an important role in both projects. The system engineers have to ensure that the performance of the instrument is compliant with the scientific objectives and the operational and spacecraft requirements. Their task is to manage the engineering process in such a way that this objective is reached within the schedule constraints.

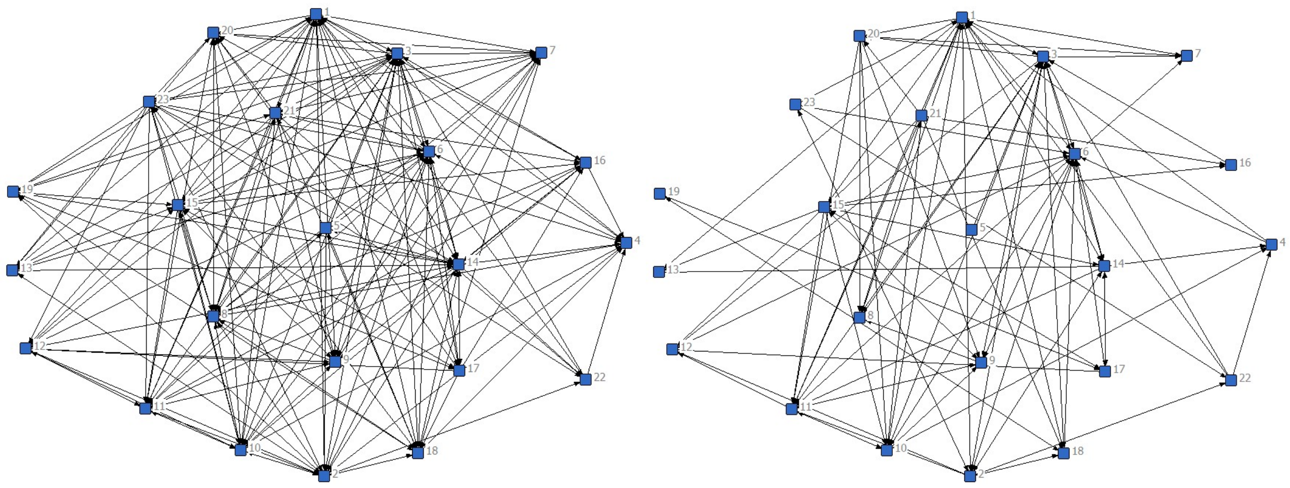
At the *subsystem level* the instruments are decomposed in subsystems. In project Space the instrument is decomposed in seven subsystems; the Focal Plane, the Local Oscillator, the High Frequency Subsystem, the Wide Band Spectrometer, the High Resolution Spectrometer, the Instrument Control Unit, and the Instrument Control Centre. In project Ground the instrument is decomposed in four subsystems: Station System, Central Systems, Post Processing, and Test & Integration. The subsystem teams are responsible for the design, development, production, verification, calibration, and delivery of the relevant subsystem. They report to the system level. In project Space the High Frequency subsystem is an exception in this, it reports as a subsystem (i.e. directly to the system level), but their deliveries are at the institute level, to be incorporated in the units and assemblies.

The lowest level in project Space is the *institute level*, which in project Ground is referred to as *work package level.* At this level the subsystems are further decomposed into building blocks. These building blocks are assigned to teams. At the institute level or work package level there are team leaders, who are responsible for the organization and management of the realization of the associated unit within the constraints defined by he agreed specifications, the interfaces, the schedule, and the resources available.

In terms of the processes taking place, the project activities have a structured character. In both projects teams work towards pre-planned review milestones. These reviews are related to the phases distinguished in the projects. The projects differ in the type of instrument they make. Project Space develops a space-based instrument and project Ground develops a ground-based instrument. In both projects three phases of development are discerned, however because of the difference in type of instrument these phases differ. In project Space phases distinguished are: Development model, Qualification model, and Flight model. Project Ground discerns the phases: Preliminary design phase, Detailed design phase, and the Main manufacturing phase. The milestones/reviews are linked to these phases. Project Ground for instance has a Preliminary Design Review, a Critical Design Review, et cetera.

In the project plans of both projects some guidelines are stated for communication. There appears to be quite a difference between the projects in the sense that for project Space the communication principles and structure is laid down very specific and detailed for the different levels and teams, whereas for project Ground this is only generally described in terms of aims/objectives. For example, the project plan for project Space states that communication principles are that: "*all formal exchange of information and in particular regarding all project baselines and changes therein, reporting progress, cost and schedule shall go through managers*". The project plan shows communication matrices for communication between the subsystem and system level and for communication between the subsystem and institute level. These are based on the consortium structure. The project plan also sets out the underlying principle for communication : "*the principle of free communication exchange between all functional parts at all three levels with the obligation to report proposed changes to the appropriate formal responsible for authorization prior to acting on these changes*". In the matrices contact persons for different functions in all the subsystems and at the system level are formally appointed. Key contact persons have been assigned to each subsystem at the unit level to promote contact with subsystems. Responsibilities of these key persons are technical monitoring and evaluation, attending meetings and reviews, functioning as a soundboard and support and signalling issues to the project management. The project plan provides schedules for meetings, for instance the meetings with ESA are all set up. For these meetings as well as for the meetings within project Space directions are given concerning the objectives, the composition, chairman, the frequency of the meetings. Even formats for meetings are given. For example it is stated that: "*All meetings shall have an agenda, to be drawn up by the party responsible for organizing the meeting*". The contents of the minutes of meetings are formally determined. For the whole consortium consortium meetings are organized. These meetings always take three days. They mostly include a progress and management meeting, discussions of system- and instrument issues, discussions of main Assembly, Integration & Test aspects, and meetings focused on science and calibration issues.

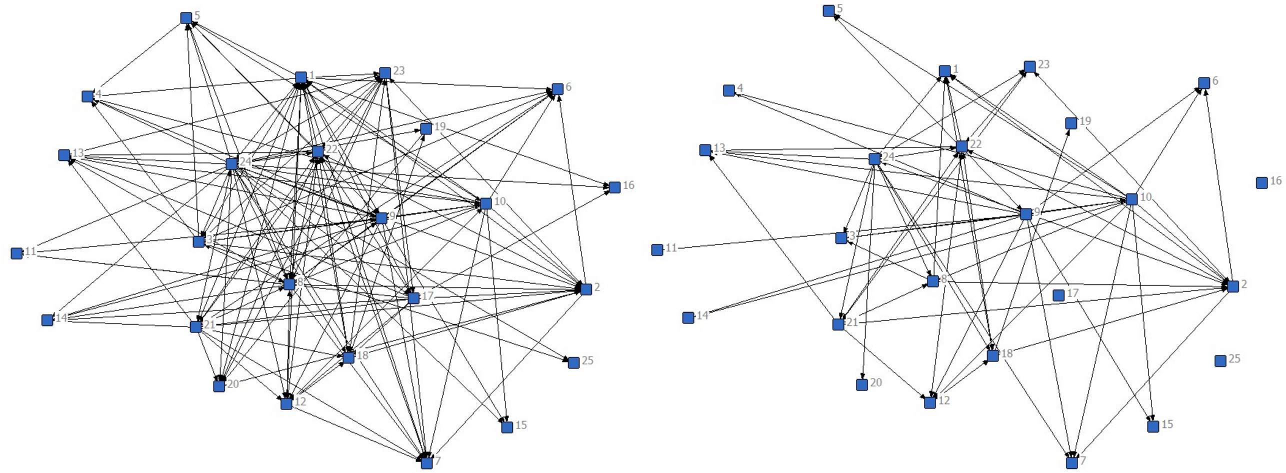
The project plan for project Ground does not discuss a communication plan in such detail. In the documents accessible for this study such guidelines were not found. A plausible reason for this may be that this is felt less necessary because not that many parties are involved as are involved in project Space and that the development activities mainly take place at one organization. It is likely that communication guidelines of the organization apply to the consortium.



At least monthly interaction between teams

At least weekly interaction between teams

Figure 5-1: Interaction networks project Ground



At least monthly interaction between teams | At least weekly interaction between teams

Figure 5-2: Interaction networks project Space

From the interviews held with the team leaders we derived networks of interaction between teams. Figure 5-2 shows the plots for project Ground, figure 5-3 shows the plots for project Space. The team leaders indicated that it was very difficult for them to identify the relations because they do not have a complete overview of al the relations. The team leaders indicated that in some cases they know which team members have interaction with other teams, it is however impossible for them to estimate whether this interaction is knowledge sharing or other communication, like personal conversations. The networks do not provide detail information on the dyads between the teams to be able to make statements on the effects of the enablers on the knowledge sharing characteristics. Therefore we used the network plots as a starting point for further study and we conducted more focused interviews with key persons who had a helicopter view on interaction patterns between teams.

Results of the complete qualitative study at the inter-team level are described below.

5.1.2 The effects of the enablers on the reciprocity of knowledge sharing

Findings for the effects of the enablers on the reciprocity of knowledge sharing within teams are repeated in table 5-1.

Findings for reciprocity at the intra-team level

Explanatory variables (enablers)		Reciprocity M	A	N
Expertise overlap		-	+	+
Co-location		+	-	+
Involvement in multiple				
projects:	one actor	+	+	-
	both actors	-	+	+
Task dependency		+	+	-

M= mutual knowledge sharing, A= asymmetric knowledge sharing,
N= no knowledge sharing
-: the findings indicate that the enabler negatively affects reciprocity
+: the findings indicate that the enabler positively affects reciprocity

Table 5-1: Empirical findings for reciprocity of knowledge sharing within teams

Task dependency

Within teams we found that task dependency had by far the largest effect on the reciprocity of knowledge sharing. Between teams we expect task dependency to have a similar strong effect on the reciprocity of knowledge sharing. Task dependencies in these projects are often related to interfaces. Between teams, the interfaces cause teams to share knowledge. Teams for example have to share knowledge of how the parts they make physically fit together. Moreover they have to share knowledge when things in their part are altered, because changes in one part may have consequences for other parts.

In the instrument consortia we observed that task dependency is indeed a main enabler for knowledge sharing between teams. Project leaders and managers indicated this strong effect of task dependency on knowledge sharing between teams. Three of them describe the effect as very strong. One of the respondents formulated: *"Yes, that is the most important trigger of the need to know something. In general in this project, I think, is the need for something the most important cause leading to knowledge sharing".* Not only is it a cause to share knowledge, also task dependent teams tend to share knowledge more mutually. One of the project leaders gave an example of two teams working within the same subsystem. Both teams developed a part of the subsystem: "*Within the subsystem X, between team A and team B knowledge sharing went very well. They approached each other for knowledge. They made arrangements like team A will make this and team B will make that and gives it to team A. That all went very well."*

However, the interviewees noticed that task dependencies not always lead to mutual knowledge sharing. This also depends on how the teams experience this task dependency. Task dependency can be perceived to be one-way, thereby leading to asymmetrical knowledge sharing; "*Task dependency should make knowledge sharing more bilateral, but if you feel that you are doing things and others need to adapt to that, then it works unilatera*l".

When no task dependency is perceived teams tend to not share knowledge. As one of the project leaders stated: *"… if there is no functional contact, no interface, both parties can feel they do not have to share knowledge at all, so they won't."* A case mentioned by the interviewees from project Space was that of two teams working in the same subsystem. These teams each developed a part, using the same signal. Each time they were at a consortium meeting they were surprised by what the other team had done. Because the teams had problems in their communication the project management tried to make their tasks dependent. The project leader siad: *"There was a fight of the worst kind. At a certain point I told them I did not want to receive those kinds of emails anymore. Then we separated them functionally and now there is no need to share knowledge anymore."*

To summarize, the strong positive effect of task dependency found within teams is also found between teams. Task dependency between teams is seen as a main enabler for teams to share knowledge. In most cases it leads to mutual knowledge sharing, although it depends on the perception teams have of task dependencies. If there is no task dependency, the teams tend to not share knowledge.

Expertise overlap

Within teams we found expertise overlap leads to more mutual and asymmetrical knowledge sharing and to less team members not sharing knowledge. We expect this to be somewhat similar for knowledge sharing between teams because between teams there are most likely more differences in expertise. When members of two teams do have an overlap in expertise we would expect them to be more likely to share knowledge.

However, this positive effect for expertise overlap is not completely supported for the inter-team level. On the one hand, the interviewees argue that expertise overlap does have a facilitating effect for knowledge sharing between teams. One of the managers argued that expertise overlap leads to more mutual knowledge sharing. Also in the other interviewees' statements we found evidence that expertise overlap is indeed related to sharing knowledge mutually. One reason offered is that certain fields of expertise are "*a small world, and a close world*" where most experts know each other and some of the experts even know each other for years. For example, experts have already worked together in other international space projects and met during conferences. Another reason offered for the positive effect of expertise overlap is that teams share a language which makes the knowledge sharing easier. One of the respondents explicitly linked it to the type of projects. He states that in a project where a broad spectrum of disciplines is present people tend to search similar others: "…t*he hardware-people go talk to the hardware-people and the software-people with the software-people and they find each other weird*".

On the other hand, we found arguments indicating that expertise overlap leads to teams not sharing knowledge. We asked the project leaders and managers to give examples of situations where sets of teams do not share knowledge. The examples given all concern dyads of teams with a large overlap in expertise. These situations stood out to the project leaders and managers because these teams were actually carried out (almost) similar tasks without reaching synergy by using each other. This made the development process very inefficient. One of the project leaders mentioned the 'not invented here syndrome' being the cause of this. By using the term 'not invented here syndrome' he refers to the culture of teams not using already existing products or knowledge because of its different origin. In the example the interviewee described two teams were working on one part of the instrument. He described that both teams did not want to use each other's knowledge, because "*they thought the other was not doing relevant things and they just wanted to do their own things*".

The interviewed managers indicated that the opposite of expertise overlap, a difference in expertise may also cause teams to mutually share knowledge. One manager stressed that when people from different teams have dissimilar worlds of thought they can learn a lot from each other and they feel the need to share knowledge mutually; "*Yes, that will make them share knowledge mutually. (…) someone who has to implement something, or someone who does something on the supercomputer. If you place them* *together, they can learn from each other*". The respondents gave examples of teams that had different expertise and shared knowledge mutually. One described a situation where one team was working on the placement of antenna's and one team was concerned with the nature development in that particular region. Although there is no direct task dependency between these teams in developing the instrument, the teams wanted to learn from each other so the placement of the antenna's could be done in a right way. The interviewee described: "*There is not really a necessity to share knowledge, because you could also say 'these are our rules and you just have to accept it'. That is possible and then you write some pages on the conditions. That would have been possible, but we see it as an iterative process. We all have ideas on how the instrument should be developed and placed, so we try to come to a common decision making and to make the best of it. We even try to build shared knowledge by each contributing their own parameters.*" In this case a difference between expertise leads to mutual knowledge sharing.

To summarize, we conclude that the effect of expertise overlap highly depends on the situation. In most cases expertise overlap will facilitate knowledge sharing between teams. However there is the risk of the teams not sharing knowledge if the team members have doubts about the other teams expertise and are not willing to the other's knowledge. At the same time, no overlap in expertise can also lead to knowledge sharing if both teams see value in each other's knowledge. The interview data support that the professionals in the consortia find it easier to adopt knowledge from others who are expert in a different area than they are. They are more reluctant or critical towards other professionals who are expert in a similar area. In this sense the effect of expertise overlap between teams is different from the effect within teams.

Co-location

We found that co-location within teams increased the probability of team members sharing knowledge. For knowledge sharing between teams we expect co-location to have a similar positive effect. This means we should find support that co-located teams share knowledge more mutually than physically dispersed teams. Although we expect that the effect between teams is smaller because the physical dispersion between teams is much higher than within teams.

In both projects we indeed found evidence that co-location is positively related to knowledge sharing. The respondents all share the opinion that co-location facilitates knowledge sharing. However, the interviewees do have different ideas on the strength of the effect of co-location. The interviewees from project Ground indicated that co-location has a strong effect on the direction of knowledge sharing. One of them formulated: "*It helps enormously. If you are isolated at an island, you have to make an effort to communicate knowledge. Whilst if you are co-located in a building, in principle you have to make an effort not to share knowledge with each other*". This was also supported by statements of team leaders in this project. Most teams were located in location z, but some teams were located elsewhere. For example one team leader said: "*(…) so one team* *was for instance team A. That was sometimes a bit hard because the people were not here, because they are mostly in location x. That makes life a bit hard. That sometimes meant that they did things on their own and they didn't know that what we have made, set up, that they could use that."* Relating the issue of co-location to the specific nature of the instrument consortia, one of the interviewees stated that: "*If they are already cognitively distant and you separate them physically, they will each go into their own world…The direction you get when they are physically close is by far less divergent than when teams are in different physical locations*". It seems that the effect of co-location may enlarge the effect of not having expertise overlap.

In project Space the interviewees agree that co-location may facilitate knowledge sharing. As one of them formulates: "*Well, if there had been co-location of course it would have gone better*". However, both respondents claim that the positive effect of co-location on asymmetric and mutual knowledge sharing is not very strong. One of the respondents stated that the effect of co-location also depends on whether there is task dependency. His words are: "*Co-location only works when there is task dependency… Any team will contact another team when they feel it is necessary, even when the other team is at the other side of the world*". The difference in the perceived strength of the effect of co-location between project Ground and project Space attracts the attention because this is exactly where the two projects differ. Teams within project Ground are less physically dispersed than teams within project Space. It is striking to find that in project Ground - where the teams are less dispersed - the effect of co-location is perceived as high. Whereas in project Space co-location is seen as less important, while physical dispersion is high between the teams within this project. An explanation may be that members of project Space accept that they do not really have a choice, accept the situation and find other ways to work together over a distance. Another explanation may be that there is so little co-location between the teams and so many task dependencies with teams in other locations that the interviewees may not notice knowledge is shared by co-located teams. However, this does not mean that the teams do not prefer to share knowledge with teams close by. Co-location still has a facilitating effect on the reciprocity of knowledge sharing. It is just that the teams perceive its effect as less present.

To summarize, we found that the effect of co-location on the reciprocity of knowledge between teams is experienced as mainly facilitating, although this effect is hard to support with empirical findings because there is much less 'real' co-location between teams than within teams. The strength of the effect seems to depend on how the distances are perceived by the teams.

5.1.3 The explanatory strength of the theories for reciprocity

The empirical findings for knowledge sharing within teams indicated that it is mainly Proximity theory and Social Exchange theory that offer supported explanations for the reciprocity of knowledge sharing.

Between the teams task dependency is leading in knowledge sharing. From both observations and interview data it becomes clear that knowledge sharing between teams is highly demand-driven. Teams mainly share knowledge with other teams when if they need input for their tasks. Team members do no tend to spontaneously allocate or distribute knowledge over the borders of their team. This implies that Social Exchange theory does not explain the direction of knowledge sharing between teams very well. Social Exchange theory is based on the notion that teams initiate knowledge sharing because they need knowledge and think they can offer knowledge in return. The first mechanism where teams approaching other teams when they need knowledge from them does take place. Support for this mechanism was found in answers from all respondents. One team leader said for instance: *"(...) I just take care of getting the information I think I need. I do have to think of that myself, and then I just approach the persons who I need to get the knowledge from*". This statement suggests that this person strongly thinks from a demand-side. This team leader basically says that when his team has a need for knowledge, he will get it somewhere. Other team leaders and interviewees made similar statements. However, the other mechanism central to Social Exchange theory is that a team also takes into consideration whether it is able to give valuable knowledge in return. No support is found that this mechanism takes place. We did notice a difference between the two projects. Respondents from project Space indicated: *"it rarely happens that people say he needs to know this, so I take the initiative to inform the other group or persons "* and *"Well, my experience is not that people spontaneously come with ' I think that you can use this'".* The interviewees in Project Ground on the other hand indicated teams sometimes do approach others when they think they have knowledge to offer. Statements supporting this are: "*at the moment you feel like you have something to tell the world, you will communicate*", and "…*everyone just has specific knowledge that they want to share*". However, this still does not take place very often. Therefore we conclude that Social Exchange theory explains the direction of knowledge sharing in project Ground only for a small part. For project Space it does not explain the direction of knowledge sharing between teams.

Similar we conclude that in terms of Transactive Memory theory the process of information allocation does not really takes place between teams because knowledge sharing is highly demand driven. Teams do not pass on information that they themselves do not need, but that may be interesting for other teams, at least not spontaneously. From the answers the managers and project leaders gave it appeared that the mechanism of expertise recognition does not play a role in the direction of knowledge sharing between teams. Two interviewees describe that when teams have a problem for which they need outside knowledge they ask these questions in general. At consortium meetings, for instance, the teams come forward with their problems so that other teams can respond to that. "*For example one team says 'we do not understand this effect' and then another team reacts like 'we have seen this effect before'*." This indicates teams do not approach other teams based on their perception of what expertise the teams have. A probable cause for this is that that the accuracy of expertise recognition is low. Several answers of team leaders, project leaders, and managers indicate that this is the case. One team leader said: "*It is very hard to know who is doing what and be able to find the nuggets of information that you need.*" The interviewees also provide reasons why this process of directory updating is missing. One reason they provide is that there are continuously changes in the people working for the project: "*But well, at a certain point in time about 300 people worked on the project and there were many changes in work force*". A second reason the interviewees give is the physical dispersion of the teams. Both the changes in workforce and the physical distance between teams may hinder the development of transactive memory systems because it complicates the process of knowing what expertise the other teams have and keeping this knowledge up to date. Because the accuracy of expertise recognition is low, there may be no alternative than to ask the questions in generic meetings.

Proximity theory best explains the direction of knowledge sharing between teams. Proximity theory regards task dependencies as a form of organizational closeness. We identified task dependencies as the main enablers for knowledge sharing between teams. This was supported by statements like: *"Task dependency is the main trigger to share knowledge…"* and *"There is interaction between different teams, because they need each other and that means they are dependent on each other".* These statements indicate that the organizational closeness does play a large role in shaping the direction of knowledge sharing between teams. Additionally, the interviewees indicated that physical proximity and cognitive proximity also play a role. On the role of cognitive proximity one of the project leaders stated: *"What I see in practice is that people need to have the mutual respect. If they have mutual respect, there is communication. Well, you can only have that respect when you understand each other. At least partially (…) What helps most is the cognitive closeness."*

To summarize, we conclude that mechanisms of Proximity theory most underly the direction of knowledge sharing between teams. It is mainly their organizational closeness in terms of task dependencies that determines whether teams share knowledge and the direction of their knowledge sharing.

5.2 Frequency

5.2.1 The effects of the enablers on the frequency of knowledge sharing

Task dependency

Table 5-2 shows that the findings from the questionnaires indicated that task dependency is the most influential variable in the frequency of knowledge sharing within teams. This effect is positive as having task dependency increases the probability of the team members sharing knowledge daily, weekly, and monthly. For knowledge sharing between teams we expect task dependency to also have a strong positive effect on

Findings for frequency at the intra-team level	
Explanatory variables	Frequency
Expertise overlap	+
Co-location	+
Involvement in multiple	
projects: one actor	=/+
both actors	+
Task dependency	+

-: the findings indicate that the enabler negatively affects frequency
+: the findings indicate that the enabler positively affects frequency
Table 5-2: Empirical findings for frequency of knowledge sharing within teams

the frequency of knowledge sharing.

From the interview data this expectation is confirmed: it is supported that task dependency is highly related to the frequency of knowledge sharing between teams. The interviewees all stressed the "*need to share knowledge*" as leading for how often two teams share knowledge, which appears from several statements. One project leader said: "*If you need someone, you will approach that person more often*".

One of the managers gave a more extensive description: *"If there is task dependency, there are reasons for knowledge sharing. Even if it is only like 'does this fit in this place' and 'if I want to make a change here, is that ok with you', there is much more knowledge sharing there and much more problems are solved. This also means that the intention of knowledge sharing is much higher. And I assume that when a problem is solved, knowledge is shared, because you always have to give reasons why you want certain things. And preferably you also indicate what the implication is."* This indicates that task dependency is a strong enabler for the frequency of knowledge sharing, because when teams are task dependent they perceive knowledge sharing necessary for problem solving.

From examples interviewees gave it appears that task dependencies in these projects are strongly related to interfaces. The manager above states that teams have to share knowledge when there is an interface between their parts. "*Does this fit in this place?*" and "*if I want to make a change, is that ok with you?*" are typical questions for these type of dependencies. One of the project leaders gave an example of an antenna team and a receiver team. There was a natural contact point between these teams as the antenna ends at one end of the coax cable and the receiver starts at the other end of the cable. There was a clear interface and a direct task dependency which caused the teams to share knowledge very frequently. The positive effect of task dependency is also supported by the examples the interviewees gave for teams who rarely shared knowledge. In the examples given for low frequency the need for knowledge sharing caused by task dependencies is lacking. One interviewee described the case where two teams only occasionally share knowledge. Even though management tried to stimulate knowledge sharing by organizing meetings

and system workshops, the teams did not feel the need to share knowledge and therefore did not initiate knowledge sharing.
To summarize, between teams empirical findings indicate that task dependencies cause teams to share knowledge more frequently. This strong positive effect is similar to the effect found within teams.

Expertise overlap
Within teams we found expertise overlap leads team members to share knowledge more often. We think it plausible that the same effect takes place at the inter-team level. This means that we should find support that teams with expertise overlap share knowledge more frequently.

We found that an overlap in expertise between teams indeed seems to have a positive effect on the frequency of their knowledge sharing. Similar to the reciprocity of knowledge sharing between teams this effect is mostly facilitating. An example given by one of interviewees was a subsystem formed by teams that developed type A parts. He reports that these teams shared knowledge very frequently. This however did not mean that the teams agreed on one way of designing and developing the type A parts. The interviewee reported: "*You see there are for instance five groups working on very similar technical issues. To my opinion, one of the lacks of the projects was that they couldn't come to a common technical approach. So if you take the type A parts, you have five different solutions*." Still, in general an overlap in expertise has a positive effect on the frequency of knowledge sharing between teams. Interviewees described that the frequency of knowledge sharing was quite low between teams with very different areas of expertise. Even when these teams felt that the knowledge sharing between them is very valuable, their knowledge sharing is not very frequent. On this topic one manager describes the following case: "*Between the teams representing different expertise at the higher level, there is very little interaction. There are few moments of contact there. But when there is interaction, this is very useful (…) These teams have more difference in their knowledge so they share more knowledge, but less frequently. You may think that is weird, because both parties have the feeling that the knowledge sharing is valuable in the sense that they learn from each other. Then why don't they meet more often? Apparently then the teams have enough knowledge sharing so that they can progress with their work. Or the pressure to share knowledge is less present.(…)Or they get a lot of information from each other, maybe it takes time to process that…*". This indicates that when teams have no overlap in expertise they perceive this as a higher threshold for sharing knowledge. Additionally, teams with no overlap in expertise need more time to process the knowledge they get from each other. This may lead them to share knowledge less frequent.

To conclude, the answers of the project leaders, managers, and team leaders indicate that having an overlap in expertise leads to more frequent knowledge sharing between teams. This positive effect found is similar to the effect found within teams; however between teams the facilitating character of expertise overlap is emphasized.

Co-location

Within teams we found a positive effect was found for co-location on the frequency of knowledge sharing. We expect this to be similar for knowledge sharing between teams even though the physical dispersion between teams is much higher than within teams.

The empirical findings show that the effect of co-location on knowledge sharing between teams is mainly facilitating. Several quotations indicate this positive effect on frequency:

- *"If you are not co-located, you miss certain natural moments, like coffee breaks and spontaneously walking by"*
- *"It would have helped if these teams had been in the same location"*
- *"Well, people know each other better, run into each other, and consult each other more often"*

The respondents from project Ground point out that when people are physically dispersed, the chance is higher that they get isolated. One interviewee stated that when teams are co-located "*they are condemned to each other*". He argues that when the teams are physically apart, "*they will each go their own way*". He draws on previous experience in explaining his statements: "*In other international projects, we also noticed that each team gets on with their work, occasionally having a moment of contact, by email, by telecom. Maybe once a year or multiple times they have a physical meeting, but still they each go their own way*".

Section 5.1.2 on reciprocity already mentioned a difference in perception between the two projects. The difference in strength of the effect of co-location can also be explained by the difference in how communication between teams is formalized. In project Space (formal) meetings are planned regularly and the communication between teams is more formalized. This is necessary because most teams are geographically dispersed. If there are frequent formal meetings co-location can be facilitating. It is however expected that co-location then has a smaller effect because the teams meet anyway. In project Ground the degree of formalization in communication is lower. There are less formal meetings and more knowledge is shared ad hoc. A team leader of a team that is in a different place from most of the development teams working on project Ground points this out: "*They are all in location X. That is kind of funny, because we are an odd one out in this. Actually most of the teams are situated at company A (location X), and some are sometimes at organisation B (location Y), they commute between two work places. Four members of our team are actually in location Y. One team member is stationed at company A. With a quite informal communication structure you can miss a lot. The hallway is some kind of communication-medium. That is where you get a lot of information. So as a team we miss out on some things. So I think that is one of the reasons, you hear less over coffee simply because you are less often at the coffee machine*". This team leader perceives it as an obstacle that his team works in a different location than the other teams. If there are less formal meetings and the emphasis is on informal communication, teams have to depend more on spontaneous meetings in hallways, conversations during lunch breaks, et cetera. Co-location then plays a larger role in how often knowledge is shared between teams as it increases the chances of meeting spontaneously. The difference between the two consortia was also illustrated by the opinions the managers have of co-location and spontaneous interaction. The interviewed manager from project Space doubts whether the spontaneous interaction caused by co-location is really knowledge sharing: "*people come together more often when co-located, but if this is useful interaction or just the monkey-behaviour that we have to have to make conversation…?".* He noticed occasions where the knowledge sharing between physically distant teams was far more intense than between co-located teams.

The interviewed manager of project Ground states quite the opposite. He argues that a large part of knowledge sharing takes place in informal moments: *"…knowledge sharing does not always take place in meetings, it is probably even the other way around, that it mainly takes place in the hallway*". The high degree of informality sometimes causes problems in project Ground. One team leader reports: "*In general things go quite informal. I mean the contacts are formal, but it is not formally arranged. You just have to come to the idea of walking into the right office. This works fine when you really need each other, but else nothing happens. So quite often you find out that some team has been on a side track for a long time which you did not notice, but on which you are dependent."*

Although the respondents do agree co-location facilitates knowledge sharing by creating more frequent opportunities to meet each other, the strength of the effect of co-location is different for both consortia. However, the interviewees indicate that when the natural contact moments are missing because of the physical distance this is coped with in other ways. One interviewee illustrated this with an example of two teams working on the same part of the instrument. One team was located in Canada and the other in the Netherlands. He indicated that "*there were weekly meetings using videoconferencing*". Also other communication media were mentioned varying from sending emails to having teleconferences. One team leader mentions the use of wiki's: "*We send emails all the time and we use a wiki-site now. It's a webpage, but anyone going to the webpage can type into it. It's like a whiteboard. And you can link documents to it, and you can edit someone else's when you have permission to write on the same page. Wiki wiki means quick in Hawaiian. Wiki is now an international thing you just search wiki on the internet and you will see it is a new communication method where people can comment on other people's comments without sending emails, because emails just sit upon some disk area and take up space and you rarely go back. But this is a living document.*"

To summarize, co-location between teams facilitates knowledge sharing by creating more opportunities for knowledge sharing. We therefore conclude that the effect of co-location is positive for the frequency of knowledge sharing between teams. The strength of the effect of co-location on the frequency depends on how it is perceived by members of the project. Additionally, the effect depends on how important the informal spontaneous contact moments are. To deal with physical distance, the teams use a variety of communication media.

5.2.2 The explanatory strength of the theories for frequency

As indicated in the previous section on reciprocity we found knowledge sharing between teams is highly demand-driven. We discussed that this already limits the role Social Exchange theory plays. This finding is supported by the answers the interviewees gave. Three respondents share the opinion that the supply-side of knowledge is not really present in knowledge sharing between teams. This is supported by statements like "*no this is not initiated by the supply-side*" and "*the supply-side is only seldom ventilated, like 'we have this knowledge*'". One project leader argues: "*If you think the other team is just fooling around, you will not initiate knowledge sharing. When you do not feel like you have anything to offer, why would you share knowledge*?".

From the interview data we conclude that of the mechanisms as proposed by Transactive Memory theory only information retrieval takes place between the teams. As one respondent formulated: "*Yes, that does play a large role: 'I will seek out this person, because one time he has done something with that'… And then you talk with each other, like 'how do you do this?' and then together you come to a solution*". Conversely, another respondent questions whether these mechanisms actually play a role. Between teams he says: "*I don't think a team will actively search for extra knowledge at another team, because by doing so they give themselves a 'diploma of incapability' (…) Not that this would be the case, but that is the perception*". Howeverm he noted that it does happen when people know each other from previous projects, conferences, et cetera. The cognitive dependencies emphasized by Transactive Memory theory are mentioned as highly important for how often teams share knowledge. One interviewee stated: "*If you need someone's knowledge, you will approach him more often for knowledge sharing*". The enabling effect of task dependencies is stressed, as task dependencies mainly shape cognitive dependencies in these consortia. We can conclude that for the frequency of knowledge sharing between teams mainly the mechanism of information retrieval takes place. Processes of expertise recognition and information allocation which also take a central position in Transactive Memory theory rarely play a role.

The interviewees identify mechanisms of Proximity theory as best explaining the frequency of knowledge sharing between teams. Cognitive closeness is mentioned as very influential. As one of the respondents formulated: "*They have the same language, so they share knowledge very intensively. The cognitive closeness is there, that leads to more frequent knowledge sharing*." Another interviewee refers to seniority in expertise: "*We are all scientists and respect the knowledge the other has. There is also some competition in who knows more than the other. But at a certain moment it is clear who your peers are*". Although this role of cognitive proximity is also toned down by statements like: "*When there is a perceived need for information, than physical and cognitive closeness don't matter.*" Several statements underline the importance of organizational closeness represented by task dependencies. The mechanism of closeness on which

Proximity theory is originally based – physical closeness - is not really perceived as playing a role.

Our conclusion is that Transactive Memory theory and Proximity theory best explain the frequency of knowledge sharing between teams and not by mechanisms of Social Exchange theory.e

5.3 Multiplexity

5.3.1 The effects of the enablers on the multiplexity of knowledge sharing

In the interviews the projects leaders and managers were first asked to talk about the presence of the different content types of knowledge. We asked the interviewees to identify to which extent the content types are shared between teams. The project leaders and managers clearly stated that know-how and know-what are dominantly shared in the projects. Managers stressed that persons in the project are selected because of their know-how, and that '*… nearly everything that we do is how do you do it*'. One of the project leaders emphasized that '*projects have a so called methodology, how you do things. This is very specific for space research projects*.' Know-what is strongly related to the interfaces. Know-what is most dominantly shared between teams that are designing, integrating, and developing, because these teams have to know from each other what they are working on.

Know-who and know-why take a much smaller place in the knowledge sharing between teams. In project Ground know-who was less important; the interviewees stated that '*project Ground is quite orderly so you know-who is where and who is doing what*'. This indicates that everyone in the project principally has all know-who. There are little to no differences between the teams in know-who, which makes it hard to measure the differential effect. In project Space where teams are physically more dispersed the differences in know-who were larger between the teams.

Findings for multiplexity at the intra-team level

Explanatory variables		Multiplexity
Expertise overlap		+
Co-location		+
Involvement in multiple		
projects:	one actor	+
	both actors	+
Task dependency		+

-: the findings indicate that the enabler negatively affects multiplexity
+: the findings indicate that the enabler positively affects multiplexity

Table 5-3: Empirical findings for multiplexity of knowledge sharing within teams

The effect of these differences was more visible. As one interviewee said: "… *know-who, I remember that it was very important for team X, perhaps even more important than know-how, because knowledge had to be gathered from everywhere in the project and then had to be integrated. Only if a team has an integrative function, know-who starts to become very important*". In general over all teams, know-who was mainly shared in the beginning of the project: *"… know-who that has indeed grown. That is also about who knows what? … At a certain moment that has become clear*".

Interviewees perceive know-why as mostly shared between teams who have a more integrating function; "*The know-why is more in the system layers, where people work on the specification and on testing and commissioning"*. For the teams that had to design and develop the parts of the instruments know-why is not perceived as useful knowledge and therefore seldom shared. One interviewee formulated: "*If you are on the work floor, what use has it to know that instrument can do certain measurements and that this results in a new type of knowledge for astronomy? For most people that is not interesting information, so it has the least priority*". The project leaders of the two projects regret this because they believe that it is important to take the time to explain why things have to be done in a certain way and what the broader sense of the project is. One project leader argued that "*even a developer should know what the larger picture is, otherwise he will step into pitfalls. He will for example scrape some corners in the design, which can have consequences. One can write all of this down, but at all levels people should know this is important*". Some of the team leaders stated that they regret this type of information is not distributed very well across the project members. One team leader said: "*There are only two members who are solely involved in my team. The other members are also involved in other teams in the project. So in that way they get some information. But I think a structural way of keeping every project member up to date on the progress or the status quo of the project is lacking*". This opinion was shared by other team leaders. One of them for example said: "*Within the team I sometimes get complaints. Then one member for example tells me 'I get very little information from outside the team. He likes to know what issues play outside the team*".

To sum up, know-how and know-what are mainly shared between teams whereas know-who and know-why are less regularly shared. After having discussed the content types of knowledge, we asked the respondents questions on the effects of task dependency, expertise overlap, co-location, and involvement in multiple projects on the number of knowledge contents shared between teams. Table 5-3 shows the findings within teams, where all explanatory variables were positively related to the multiplexity of knowledge shared.

Task dependency

Like for the reciprocity and frequency, within teams it is task dependency that has the largest effect on the multiplexity of knowledge sharing.

For knowledge sharing within teams we found that team members who were task dependent shared more types of knowledge than team members who were not task dependent. Between teams we expect the same to take place. Primarily because task dependency is the main enabler for knowledge sharing between teams. We expect it not only to shape the direction and the frequency of knowledge sharing, but also the topics on which knowledge is shared. The answers in the interviews however indicate an opposite effect. Between teams, the respondents indicate that when teams are task dependent they tend to focus on the exchange of know-what and/or know-how. They describe that these teams share knowledge of less different contents than teams who do not have a task dependency relation. This was illustrated by the examples the interviewees gave for knowledge sharing with a low multiplexity (on one type of knowledge). In these examples they all mentioned teams that had clear task dependencies in the form of functional interfaces. One of the examples mentioned was that of different parts of the instrument in project Space that had to be connected to the instrument computer: "*Well, all the electronic steering boxes for the local oscillator and the focal plane unit and the backhand of the WBS and HRS, had to be connected to the computer. The instrument computer that was made in Italy. (…) Yes, that is know-what, the sharing of knowledge of 'what exactly', the interface, that happened quite often. That did not go perfectly, but in the end it did go.*" These interfaces are mostly between technical teams that develop and design certain parts that in the end have to be integrated. As one of the project leaders concluded: "… *and if these teams exchange something it is only on the know-what layer, for example: how many bits to you deliver?, and tell me what the formula is that I have to use? These are all what-questions*". Statements like these indicate that having a task dependency leads to more focused, less multiplex knowledge sharing. The content the teams share depends on the type of task dependency: *"(…)task dependency may also imply that you need a lot of know-what. That strongly depends on the type of dependency. If the only thing you need to know is 'what is the impedance of the amplifier' then it is a know-what question. … and if you need to know what you are doing things for, it is a know-why question."*

The perception that task dependency leads to more focused knowledge sharing between teams is also supported by the examples given for very multiplex knowledge sharing. In the examples described by the respondents two types of dyads were mentioned. The first type of dyads are dyads between system-teams and sub-system teams. The system teams are concerned with all content types of knowledge: *"… on one hand the system team is strongly concerned with know-what. But these are also the people that have understanding of the way to do things. And at the same time they are engaged in 'why are we doing all of this?', and 'are we doing the right things?'. This team shares this knowledge at all levels*". The second types of dyads are dyads between teams with very different areas of expertise. The teams that highly differ in expertise are also not task dependent, as follows from one of the statements of a manager: "*If you look at the multidisciplinary teams, geophysics, astronomy, and agriculture, these are not dependent on each other*". These types of sets of teams were also described as sharing knowledge of multiple type of knowledge contents: "*They are not condemned to each other. But eventually you made the choice to share knowledge and then it helps you and there is a drive behind it. Why it does take place there and why do they share knowledge of more than know-how? (…) Perhaps it is curiosity…*"

Concluding, we can say that the positive effect found for task dependency within teams, appears not to be present between teams. Instead, teams that are task dependent tend to focus their knowledge sharing on know-how or know-what.

Expertise overlap

In the empirical study on knowledge sharing within teams, expertise overlap was found to be positively related to the multiplexity of knowledge sharing. One of the benefits of a multidisciplinary project often mentioned is that synergy is reached and innovative solutions are found. This should lead to the expectation that when teams have different areas of expertise, they share knowledge of multiple content types and thereby come to solutions. Several arguments made by the interviewees support this notion. One of the project leaders mentions: "… *and then you see that observers do things very different from astronomers; beautiful things come from that*". Also supporting is the statement of one of the managers that when there is no or a small overlap in expertise, people have a lot of knowledge to share. He argues that a difference in expertise positively influences the multiplexity of knowledge shared and the quality of solutions: "… *we have several applications; we have an astronomical application, we do something with geophysics and agriculture. These are very different people…And what is really good for the multiplexity of knowledge shared is to let these people collaborate*".

Also the examples given for teams that share knowledge of a number of types of content support this effect. In the examples of the dyads where teams highly differ in expertise, the interviewees reported highly multiplex knowledge sharing. One example given was knowledge sharing with teams that find themselves somewhat in the periphery of project Ground. Because the antennas have to be placed in relatively interference-free areas, they are mostly placed in protected nature areas. About the placement of the antennas there is also collaboration with people who know about nature development. The manager narrates: "*Yes, nature development is an example of multiplex knowledge sharing. There they share know-what, know-why and know-how, all types. It is not only knowledge, but also facts. Like 'well you can place an antenna station there, but there is archeology in the ground that contributes to the archeology we have'. That is enrichment of knowledge. Before project Ground I had no clue about archeology I still don't but I know a little bit more about it. And that can help me in my decision making."*

Additionally, both project leaders mention the knowledge sharing of system teams with other teams as multiplex knowledge sharing. System teams are teams that oversee the whole instrument that is developed. They have to keep an overview on the interfaces, how the separate parts fit in the instrument and the functioning, testing, of the parts and the instrument as a whole. One of the project leaders describes the knowledge sharing between the system team with the other teams : "*On one hand, the system team is strongly concerned with sharing know-what. Mainly in the receiving side, but also in giving. These are also the people that have the expertise and tell others 'this is the way you should do it'. At the same time they are concerned with 'why do we do this?' and 'are we still doing the right things?' and 'for whom are we actually doing this?'. They share knowledge with other teams on all these levels.*"

To summarize, in the qualitative data we found evidence that differences in expertise lead to a higher number of knowledge contents shared. This means that if teams with differences in expertise share knowledge they tend to share knowledge of multiple types of knowledge. This effect between teams is different from the effect we found for expertise overlap within teams, where the findings indicate that an overlap in expertise leads team members to share multiple content types of knowledge.

Co-location

Within teams we found a positive effect for co-location on the number of knowledge contents shared. The shared opinion of the interviewees was that this positive effect is similar for the multiplexity of knowledge sharing between teams. As one project leader formulated: "*you share more broad knowledge when you are physically more close*". The interviewees especially observe this effect for sharing know-how and know-what: "*It is easier to share know-how and know-what when you meet regularly"*. One of the project leaders illustrated this by giving an example of teams that were co-located: "*the sharing of know-how comes easier and more naturally when the teams are co-located, because then you see how others work and how they solve problems. … we have now set up this group, and there you see it happen every day. The interaction they have, they also exchange models of problem solving*." The sharing of know-what is considered to be facilitated by co-location. However, for know-who and know-why two respondents stated that it does not matter whether teams are co-located or not. One of these respondents said: "*But sharing know-who, that is easily done by email nowadays. (…) And the background information ironically stays at the background*."

Despite of the differences in physical dispersion between the two consortia the respondents all indicate that co-location of teams causes them to share multiple types of knowledge. This effect is similar to the effect found within teams.

5.3.2 The explanatory strength of the theories for multiplexity

Within teams the empirical results indicated that Transactive Memory theory and Proximity theory best explain the number of knowledge contents shared within teams. Social Exchange theory on the other hand did not explain the multiplexity of knowledge sharing particularly well.

For the number of contents shared between teams we found different mechanisms to play a role. Most of the respondents indicated that the mechanisms of Proximity theory are probably most influential for the multiplexity of knowledge sharing between teams. In their words:

- "*I think when it comes to the content of knowledge that is shared, it is physical proximity that is most important*."
- "*Intuitively I would say that closeness is most important*."
- "*The physical distance is important, but the cognitive is more important*."

The respondents differ in their views on the role of cognitive closeness. Two respondents of project Ground indicated that a difference in expertise often leads to multiple types of contents shared. One respondent explained this: "*The larger the cognitive distance, the richer the knowledge shared. Simply because the knowledge itself can be more rich than when there is an overlap in knowledge*". In this context the respondent referred to sharing multiple contents of knowledge when he talked about 'rich' knowledge shared. This effect is the opposite of what Proximity theory proposed. One respondent of project Space on the other hand, thinks that cognitive proximity is important for the number of content shared. He states: "*Well, I think cognitive proximity helps in the sharing of all four types of knowledge. But that is obvious, if you are equipollent on your topic, then it is easier to talk on multiple subjects*". The aforementioned statements indicate the respondents agree that physical proximity mainly shapes the multiplexity. Teams seem more likely to share multiple content types of knowledge when they are physically proximate. When teams are physically close their team members meet spontaneously, it is easier for them to share documents, and they can observe the way other teams work. Or as a project leader formulated: "*(…) you see how others do their work. You observe that from the corner of your eye, you cannot avoid that. (…) Whilst if you have two teams which are physically distant, we see that in telecons, well they talk about schemes, but you do not see a webcam standing in their workplace where they are solving problems*". We therefore conclude that mechanisms as described by Proximity theory do play a role in the number of knowledge contents shared between teams, but mainly when it comes to the physical closeness and the organizational proximity.

Apart from Proximity theory, we found that Transactive Memory theory plays a role in shaping the multiplexity of knowledge shared between teams. The interviewees see the perception of knowledge other teams have as important for the types of knowledge shared between teams. This is similar to our empirical findings are the intra-team level. Several quotations indicate mechanisms of Transactive Memory theory taking place:

- "*This has an impact, yes. Like 'don't ask him, because he doesn't know' or 'I would rather ask someone else, because he doesn't know."*
- " *… in the choice of the subjects, if you for example think some team does not have the knowledge to make a design, you will not ask know-what questions. And if you have the idea that a team has no clue of what they are doing, you will not ask them know-why questions.*"

- "*Well from person to person I think perception plays a large role; 'he*
- *will know this, so I find it interesting to talk to him about this'. Only I do not see this as a conscious choice of the team, but of the people*."

Some respodents noticed that when someone just needed an answer, and therefore in spite of these perceptions engaged in knowledge sharing, the perceptions were adjusted. This is part of the directory updating process. For information allocation however, the third process Transactive Memory theory includes, respondents indicated that these seldom take place. Respondents rarely see information allocation taking place: "*that supply side is seldom actively acted on*". This is also why Social Exchange theory very poorly explains the number of knowledge contents shared between teams. Similarly to reciprocity and frequency of knowledge sharing, the managers and project leaders emphasized that the supply side is not active in knowledge sharing between teams; *"… marketing one's own knowledge, does not really happen. Mostly it is a reaction to 'I have a problem'"*.

To summarize, mechanisms of Proximity theory and Transactive Memory mainly shaping the number of knowledge contents shared between teams.

5.4 Conclusion

The objective of the empirical study on knowledge sharing between teams is two-fold. The first intention was to explore to which extent the effects of enablers on knowledge sharing between teams are similar or different to the effects within the teams. The second intention is to explore whether there is a difference in mechanisms explaining the knowledge sharing within teams and between teams.

The first knowledge sharing characteristic studied between teams is reciprocity. The interviewees indicated that task dependency is the main enabler for reciprocity of knowledge sharing between teams. This strong positive effect of task dependency on knowledge sharing between teams is similar to the effect we found within teams. Both within and between teams task dependencies lead to knowledge sharing. For expertise overlap, the effect that is found between teams is different from within teams. Within teams expertise overlap has a positive effect on the reciprocity of knowledge sharing, whereas between teams the effect of expertise overlap seems to highly depend on the situation at hand. Expertise overlap may facilitate knowledge sharing between teams, there is also the risk of them not sharing knowledge if they are not willing to learn from each other. If two teams think they can learn from each other, *no* overlap in expertise may also lead to mutual knowledge sharing. This effect of expertise overlap between teams is different from the effect within teams. Even though co-location of teams facilitates knowledge sharing between teams similarly to knowledge sharing within teams, the strength of the effect depends on how the distances are perceived by the teams.

The second knowledge sharing characteristic studied is the frequency of knowledge sharing between teams. The empirical findings show that

Empirical findings intra-team vs inter-team level						
Explanatory variables	Within teams (intra-team)			Between teams (inter-team)		
	Reciprocity	Frequency	Multiplexity	Reciprocity	Frequency	Multiplexity
Task dependency	+	+	+	+	+	-
Expertise overlap	+	+	+	+/-	+	-
Co-location	+	+	+	+	+	+
Involvement in multiple projects: One actor	-	+/-	+	X	X	X
Both actors	+	+	+	X	X	X

-: the findings indicate that the enabler negatively affects multiplexity
+: the findings indicate that the enabler positively affects multiplexity
X: the effect of this enabler is not measured at the inter-team level

Table 5-4: Comparison findings within and between teams between teams it appears to be mainly task dependencies causing teams to share knowledge frequently. This positive effect is similar to the effect of task dependency on the frequency of knowledge sharing within teams. Additionally, the findings support that when teams have an overlap in expertise this leads to more frequent knowledge sharing between them. This positive effect we found between teams is similar to the effect we found within teams. For co-location the findings furthermore indicate that co-location between teams facilitates knowledge sharing by creating more opportunities for knowledge sharing. This means co-location appears to have a facilitating effect on the frequency of knowledge sharing between teams. This is similar to the effect co-location has on the frequency of knowledge sharing within teams. Although between teams it is noted that the strength of the effect co-location depends on how distances are perceived and on how important the informal spontaneous contact moments are.

The third knowledge sharing characteristic studied is multiplexity of knowledge sharing. The findings indicate that teams mainly share know-how and know-what. Know-who and know-why seem to be less regularly shared between teams. One difference we found for the effect of enablers on multiplexity of knowledge sharing within and between teams is the effect of task dependency. We found task dependency positively affects the number of knowledge contents shared within teams. The empirical findings indicate an opposite effect for knowledge sharing between teams. Task dependent teams tend to focus their knowledge sharing on know-how or know-what. The effect of expertise overlap on the multiplexity of knowledge sharing between teams also differs from that within teams. Within teams an overlap in expertise facilitates to share multiple contents of knowledge. Between teams the findings indicate an opposite effect. Between teams *differences* in expertise between teams seem to lead to multiple types of knowledge being shared. The effect of co-location on the multiplexity of knowledge shared between teams seems to be similar to the effect we found for the intra-team level. At both levels, co-location appears to facilitate knowledge sharing of multiple types of knowledge.

Figure 5-3 is an illustration of which theories appear to explain the knowledge sharing characteristics between teams. The mechanisms as proposed by Proximity theory seem to shape the reciprocity of knowledge sharing between teams. The teams' organizational closeness in terms of task dependencies appears to shape whether teams share knowledge and the direction of their knowledge sharing. This is similar to the findings at the intra-team level. The frequency between teams is partly explained by mechanisms of Transactive Memory theory, and for a large part by mechanisms of Proximity theory. At the intra-team level we found similar mechanisms shaping the frequency of knowledge sharing.

Figure 5-3 shows that Social Exchange theory does not seem to accurately explain any knowledge sharing characteristic between teams. This leads to the conclusion that for explaining and predicting knowledge sharing between teams Social Exchange theory could be left out. For intra-team knowledge sharing we concluded that Social Exchange theory mainly has added value in situations where the basic closeness is low, where

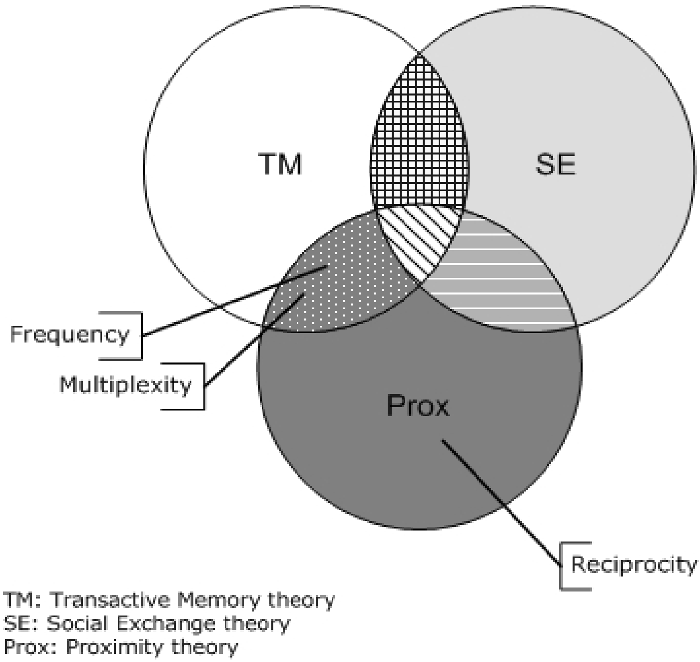


Figure 5-3: knowledge sharing characteristics explained by the theories

Proximity theory did not seem to apply. We found that the role of mechanisms described in Transactive Memory theory seems to be larger between teams. Within teams Transactive Memory theory mainly has added value in explaining the multiplexity of knowledge sharing. Between teams mechanisms described in Transactive Memory theory seem to play a role in shaping the frequency as well as the multiplexity of knowledge sharing. This is remarkable because the main underlying mechanism of Transactive Memory theory is that teams form a Transactive Memory when teams are part of a group (the project) and work closely together. The teams start relying on each other to be specialists in their own area to reduce the cognitive workload. Knowing which teams are specialists in which areas is very important for these systems. However, the empirical findings indicate that know-who is not very regularly shared between teams. A possible explanation is that teams share know-who at the start of the consortium and that this is sufficient for the teams to develop a Transactive Memory system. The findings indicated that knowledge sharing between teams is mainly demand-driven. This would imply that in the processes described by Transactive Memory theory, the emphasis is clearly on the process of information retrieval.

Similar to knowledge sharing within teams mechanisms of Proximity theory have a large role in shaping knowledge sharing between teams. Even though between teams it is more of a combination of Proximity theory and Transactive Memory shaping knowledge sharing. This is not a surprise because from the findings within teams it was already concluded that Proximity theory seems to lose its explanatory strength in situations where the proximity is very low. Between teams the basic physical and cognitive closeness is much lower than within teams. As a consequence teams have fewer opportunities to base their knowledge sharing on which team is most proximate. There are less possibilities for the mechanisms of Proximity theory to shape knowledge sharing.

We ask the same question we asked for knowledge sharing within teams: Is it possible to unify Proximity theory and Transactive Memory theory in a new theory that predicts and explains knowledge sharing between teams? The mechanisms of Proximity theory and Transactive Memory theory are for a large part complementary. The theories differ in their notions on the effects of co-location and expertise overlap. In the above we concluded the teams have fewer opportunities to base their knowledge sharing with other teams on mechanisms of closeness. This may be included as a condition in a unifying theory: in situations where it is possible for teams to find knowledge in 'çlose' teams, the mechanisms of Proximity theory shape knowledge sharing. In situations where teams do not really have a choice in approaching 'close' teams for knowledge sharing, they will share knowledge with teams who they perceive to be experts in the required area of expertise. Under these circumstances distance does not play a role in shaping knowledge sharing anymore. If a team needs certain knowledge, it will get this knowledge. Even if a team on the other side of the world has it, they will approach this team to get the knowledge because they need it for the execution of their tasks.

Chapter 6

Discussion and conclusion

6 Discussion and conclusion

6.1 Introduction

In the introductive chapter it is argued that knowledge sharing is crucial for New Product Development (NPD) consortia to make optimal use of the specialized knowledge present in participating organizations and to combine the knowledge into a new product. In practice professionals working in the NPD consortia have a hard time sharing knowledge effectively. As pointed out, existing literature sheds no light on how to enable knowledge sharing in the consortia. Taking four possible enablers as a starting point, this study aims to provide insight into how these enablers affect knowledge sharing within pairs of team members and within pairs of teams. Moreover, the research aims to contribute to the understanding of mechanisms underlying knowledge sharing relations within teams (intra-team level) and between teams (inter-team level). Finally, the study explores the differences between knowledge sharing at the intra-team level and at the inter-team level. By creating a multi-theoretical framework, we were able to explore the effects of the enablers and the theories' explanatory values in an empirical study.

This chapter starts by highlighting the key findings of this research. Subsequently, the scientific and managerial implications of the findings are discussed in section 6.3 and 6.4, respectively. This chapter ends with a discussion of the limitations of the study and by making suggestions for future research in section 6.5.

6.2 Key findings

As far as the effects of the enablers on knowledge sharing are concerned, a key finding is that task dependency is the main enabler for knowledge sharing within teams. It enables team members to share knowledge more reciprocally, more frequently and on more content types. Co-location and expertise overlap also enable knowledge sharing between team members, but less strongly than task dependency. Being involved in multiple projects reduces the probability of team members sharing knowledge with others who are involved in a single project. However, when two team members are both involved in multiple projects they are more likely to share knowledge mutually, more frequently and on multiple content types.

In relation to the mechanisms underlying knowledge sharing relations within teams (intra-team level), the main finding is that Proximity theory has the most explanatory strength for the effects of co-location and expertise overlap. Furthermore the empirical findings indicate that the effects of project involvement are best explained by Social Exchange theory. For the effect of task dependency it is found that Proximity theory, Social Exchange theory and Transactive Memory theory equally explain the effects that are found. Focusing on the knowledge sharing characteristics explained, we found that, overall, Proximity theory best explains knowledge sharing within teams. Transactive Memory theory was found to have added value in explaining the number of contents shared, whereas Social Exchange theory has added value in explaining the frequency of knowledge sharing between team members.

The findings at the inter-team level suggest that task dependency has a large enabling effect for the reciprocity and frequency of knowledge sharing between teams. For the number of content types shared between teams (multiplexity), task dependency was found to make knowledge sharing between teams more focused on one or two types. Expertise overlap and co-location also enable knowledge sharing between teams. Both appear to increase the probability of mutual and more frequent knowledge sharing. Between teams, a difference in overlap expertise seems to be related to multiple contents shared. Furthermore, support was found that co-location enables teams to share particular contents of knowledge (know-how and know-what).

For the mechanisms underlying knowledge sharing between teams, the key finding is that knowledge sharing between teams is highly demand-driven. The empirical evidence suggests that it is a combination of mechanisms as proposed by Transactive Memory theory and Proximity theory that shape the frequency and multiplexity of knowledge sharing between teams. No support was found for the premise that Social Exchange theory is applicable to knowledge sharing between teams.

Comparing the findings for knowledge sharing within and between teams, we found that at both levels task dependency has a large enabling role. For knowledge sharing at both the intra-team and the inter-team level it appears that co-location and expertise overlap are also enablers. Three main differences are found between the two levels of knowledge sharing. Firstly, task dependency leads to more content types shared within teams, but focuses knowledge sharing between teams. Secondly, expertise overlap within teams makes team members more likely to share knowledge mutually, but between teams it is found to negatively affect the reciprocity of knowledge sharing. Thirdly, where expertise overlap is found to result in a tendency to share multiple types of knowledge within teams, at the inter-team level it makes teams less likely to share knowledge of multiple content types.

A comparison between the levels of knowledge sharing on the theories explaining knowledge sharing shows that overall Proximity theory provides the most supported propositions. Between teams Transactive Memory theory has a larger role in explaining knowledge sharing than within teams. Whereas Social Exchange theory does have added value in explaining knowledge sharing within teams, between teams it does not seem to play a role.

6.3 Scientific implications

The overall contribution of this study to literature is threefold. It enhances the comprehension of how task dependency, co-location, expertise overlap and project involvement enable knowledge sharing within and between teams of large instrument consortia. Additionally, it contributes to the understanding of social theories explaining knowledge sharing in instrument consortia and the conditions under which knowledge is shared. Finally, it shows similarities and differences in knowledge sharing between team members and between teams, by comparing the intra-team level with the the inter-team level. This section discusses the scientific implications.

First of all, adopting a social network approach proved to be very useful for studying knowledge sharing. Even though most of the enablers included in this study are mentioned by other authors (Allen, 1977; Baughn, Denekamp, Stevens, & Osborn, 1997; Cummings & Teng, 2003b; Dougherty, 1992; Hamel, 1991; Hollingshead, 1998a; Nonaka et al., 1995; Szulanski, 1996; von Krogh et al., 2000), their effects were not yet directly measured. Certainly not within the context of instrument consortia, even though in both practice and literature they are perceived as strongly affecting knowledge sharing. The social network approach made it possible to study the effects of the enablers on knowledge sharing in this context, because it allows for direct measurement of knowledge sharing interaction between team members and between teams, respectively.

Secondly, our study proves that simultaneously studying multiple characteristics of knowledge sharing gives a more multi-dimensional picture than just focusing on one characteristic of knowledge sharing. Including multiple characteristics of knowledge sharing relations is not common in current literature. Using a social network approach for studying knowledge sharing is relatively new and in the cases where it is used, the research merely includes elementary characteristics such as the existence of a knowledge sharing relation or, in a few cases, the strength of the relation (Akgun et al., 2005; Cross, Parker, Prusak, & Borgatti, 2001; Hansen, 1999). Monge and Contractor (2003) conclude that network research in general "…focuses on relatively obvious elementary features of networks such as link density and fails to explore other, more complex properties of networks such as attributes of nodes or multiplex relations". Our study does not just include the strength of knowledge sharing relations. The use of a social network approach enabled us to give a more multi-dimensional picture by including reciprocity and multiplexity as characteristics of knowledge sharing. Incorporating different characteristics of knowledge sharing proved to have added value, for the empirical results of this research show that there are differences among the knowledge sharing characteristics in how they are affected by the enablers. For example, we found that task dependency leads to more frequent knowledge sharing between teams, but also to less contents of knowledge shared. Additionally, the empirical findings suggest that there are differences in mechanisms underlying the different characteristics of knowledge sharing. For example, within teams it is mainly the mechanisms as proposed by Proximity theory that explain the direction (reciprocity) in which knowledge is shared, and it is mainly mechanisms as proposed by Transactive Memory theory that explain the number of contents shared. This leads to the conclusion that studying knowledge sharing by including one characteristic only gives a partial view on knowledge sharing, and including multiple characteristics of knowledge sharing does have added value, for it gives a more multi-dimensional view.

Thirdly, this thesis shows that differences between different levels of knowledge sharing should be taken into account. In this thesis knowledge sharing is studied at two levels. Current literature on knowledge sharing mostly makes no explicit difference between different levels of knowledge sharing. In general knowledge models, authors make implicit assumptions that what plays a role in knowledge sharing within teams also plays a role in knowledge sharing between teams (McElroy, 2003; Nonaka et al., 1995; von Krogh et al., 2000). In articles on knowledge sharing one level of analysis is generally chosen, for example knowledge sharing within teams (Palazzolo, 2005), knowledge sharing between units of firms (Hansen, 2002; Tsai, 2001), or knowledge sharing between firms (Lam, 1997). Our empirical findings show that between the intra-team and the inter-team level there are differences in the effects of enablers on knowledge sharing characteristics. For example, whereas expertise overlap increases the number of contents shared between team members, it decreases the number of contents shared between teams. Furthermore, the findings suggest that there are differences between the intra-team level and inter-team level in the mechanisms underlying knowledge sharing. At the intra-team level the mechanisms of Social Exchange theory do seem to underlie knowledge sharing between team members, as some of the effects found could only be explained by Social Exchange theory. Between teams Social exchange theory did not have any explanatory value, implying that the mechanisms as proposed by Social Exchange theory do not seem to shape knowledge sharing between teams. These findings imply that it does not seem to be realistic to assume that mechanisms that play a role in knowledge sharing within teams are similar to mechanisms that underlie knowledge sharing between teams. When studying knowledge sharing, these differences should be acknowledged.

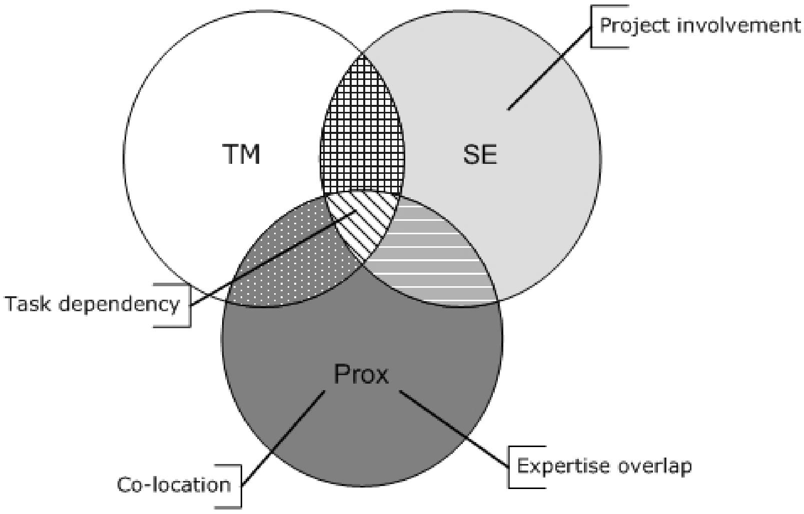
Fourthly, we found that using a multi-theory perspective is very useful in studying knowledge sharing. Using multi-theory approaches is not yet very common in studying networks or in studying knowledge sharing. Contractor, Wasserman and Faust (2006a) were, to our knowledge, the first to test multi-theoretical hypotheses on knowledge sharing networks. There are other authors that use a multi-theory model for explaining knowledge sharing, for example Watson and Hewett (2006). Watson and Hewett (2006) use two theories to explain the effectiveness of intra-firm knowledge transfer. They use social exchange theory to develop a model of factors that impact the frequency of knowledge transfer. Expectancy theory is used to build a model of factors that lead to knowledge reuse. In doing so, they do not account for one phenomenon by combining the two theories, but use two theories to develop separate models for separate phenomena: a model for knowledge transfer and a model for knowledge reuse. We adopted a multi-theory approach more similar to that advocated by Monge and Contractor (2003). Our theoretical framework incorporates three social theories. From Proximity theory, Transactive Memory theory and Social Exchange theory propositions were formulated for the effects of the enablers on the frequency, reciprocity and multiplexity of knowledge sharing. Our empirical findings support the notion that using a multi-theory perspective to explain knowledge sharing is useful. By using a multi-theory approach, we were able to account for all of the effects found and to explore which social theory may have explanatory value and under which conditions. At the start of our research there was no single theory available to explain knowledge sharing within the context of NPD consortia. The social theories included in the theoretical framework made differential predictions about how the enablers would effect knowledge sharing. Not all of the predictions were differential, with contradictory explanations given by the social theories. Some of the predictions were similar, with complementary underlying mechanisms proposed by the theories. Our empirical findings suggest that there are multiple mechanisms simultaneously shaping knowledge sharing in instrument consortia. Not one of the theories could exhaustively explain the effects found, but by using multiple theories all of the effects found could be accounted for. This implies that in research where it is yet to be explored what theory might be applicable to the subject studied, and in research where one supposes that multiple mechanisms may play a role, the multi-theory approach seems to be useful.

Not only does the present study prove that a multi-theory approach is useful for studying knowledge sharing, but by contributing to the understanding of social theories explaining knowledge sharing in instrument consortia and the conditions for sharing knowledge it also prompts the development of a new theory for explaining knowledge sharing in new product development consortia. This is discussed in more detail below.

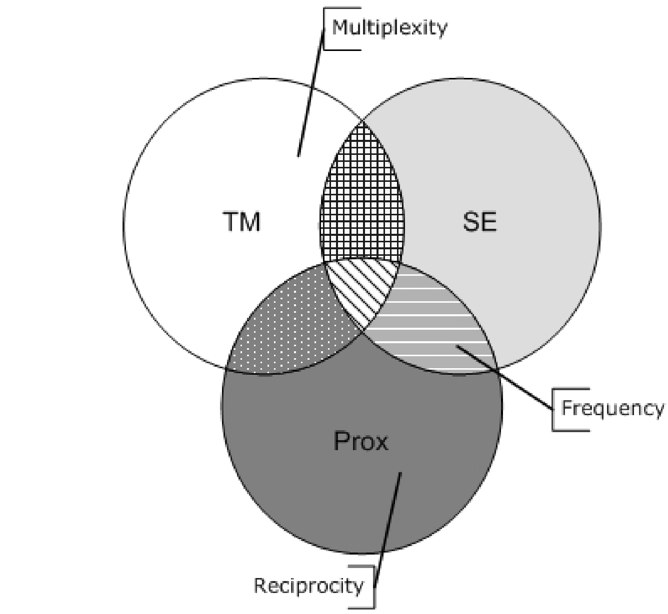
Starting point for a new theory

For intra-team knowledge sharing, the findings indicated that the effects of expertise overlap and co-location are best explained by Proximity theory. The effects of involvement in multiple projects are best explained by Social Exchange theory and the effects of task dependency were explained by both Proximity theory, Social Exchange theory and Transactive Memory theory. Figure 6-1 illustrates the explanatory value of the three theories for knowledge sharing within teams. From the results we concluded that in situations where the basic closeness between the team members is very low or variable, knowledge sharing between team members is not necessarily positively affected when they are more alike. In other words, the mechanisms as described by Proximity theory do not apply under the circumstances in which the basic closeness varies or is low. One situation in which the basic closeness is particularly low is when team members are involved in multiple projects. Under these circumstances Social Exchange theory best explains knowledge sharing within teams. Comparing the theories on their affirmed propositions for knowledge sharing characteristics (figure 6-1B), the conclusion is that overall Proximity theory best predicts the knowledge sharing characteristics. This means that team members mainly approach each other on the basis of who is most proximate to them. Compared to Proximity theory, Transactive Memory theory mainly has added value in explaining multiplexity when the basic closeness varies (when team members are involved in multiple projects). This indicates that when the basic closeness varies or is low, team members base their knowledge sharing more on the perceptions they have of each other's knowledge. This supports the conclusion above, i.e., that Proximity theory is less applicable under conditions with low basic closeness. Under these circumstances a team member just wants the knowledge he needs for the execution of his tasks. He will approach the person he thinks is expert and can give him the knowledge he needs, regardless of how proximate this person is to him. For frequency of knowledge sharing we found that exchange mechanisms as proposed by Social Exchange theory also play a role. This could indicate that for critical or specialty knowledge team members share knowledge with fellow team members who have the most appropriate knowledge, and closeness is less important.

These insights can be used as a starting point for a new theory explaining knowledge sharing within teams in NPD consortia. In this new theory, one can state that mechanisms of closeness underlie the reciprocity of knowledge sharing. In other words, team members prefer knowledge sharing with team members who are physically close, with whom they have a shared area of expertise, and with whom they are task dependent. Also, they tend to share knowledge mutually with team members who are close. For frequency and multiplexity of knowledge sharing, the new theory would explain knowledge sharing by the basic closeness of the situation and the extent to which a person needs specialist knowledge. Depending on the basic closeness and the extent to which specialist knowledge is required, mechanisms of Proximity theory or mechanisms of Social Exchange theory explain the frequency of knowledge sharing. When the basic closeness is relatively low or varies, team members share knowledge more often with other team members whom they perceive to have the knowledge they need and to whom they can offer knowledge in return. This mechanism also shapes the frequency of knowledge sharing when team members need critical or specialist knowledge. In situations where the basic closeness is relatively high, team members share knowledge more frequently with other team members who are proximate.



A: explanatory value in explaining the effects of the dyadic attributes



B: explanatory value in explaining the aspects of knowledge sharing

TM: Transactive Memory theory
SE: Social Exchange theory
Prox: Proximity theory

Figure 6-1: Explanatory value of the theories for intra-team knowledge sharing

The number of contents of knowledge shared (the multiplexity of knowledge sharing) is explained by a combination of mechanisms of Proximity theory and Transactive Memory theory. Team members share multiple contents of knowledge with other team members who they consider to be experts. Team members prefer experts who are proximate to them. It helps when team members are co-located, because then they are better able to identify expertise. But even when the basic closeness is low or varies and their expertise recognition may not be very accurate, they turn to team members who they perceive to be experts in the areas in which they need knowledge. These starting points for a new theory explaining knowledge sharing in NPD consortia are summed up in text box 1.

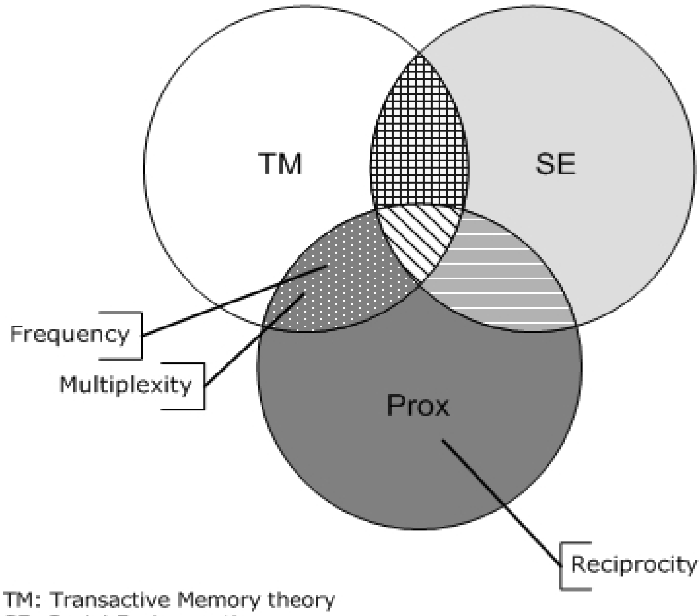
From the empirical research between teams we found knowledge sharing to be strongly demand-driven. This means that, in contrast to knowledge sharing within teams, mechanisms as proposed by Social Exchange do not seem to play a role (see figure 6-2). Teams that seek knowledge from other teams are not concerned with having any knowledge to offer in return. Thus, between teams Transactive Memory theory and Proximity theory have the most explanatory value for knowledge sharing.

The reciprocity of knowledge sharing between teams is best explained by Proximity theory, as is the case with knowledge sharing within teams. It is mainly task dependency that determines whether teams share knowledge and in which direction they do so. Also we concluded that the frequency of knowledge sharing between teams is explained by a combination of mechanisms proposed by Transactive Memory theory and Proximity theory. Contrary to the intra-team level, where mechanisms of closeness as proposed by Proximity theory play an important role, Proximity theory seems to lose explanatory strength between teams. This can be explained by the relatively low basic closeness between teams. Teams are formed on the basis of their expertise and are regularly dispersed over a number of locations. Teams simply have less opportunities to base their knowledge sharing on what team is proximate. We found that teams mainly base their knowledge sharing on cognitive dependencies they perceive to have with other teams. Teams are cognitively dependent when they are dependent on each other’s knowledge. These dependencies are highly related to task dependencies. This indicates that mechanisms of Transactive Memory underlie knowledge sharing between teams. Findings also indicate that if it is possible, teams prefer to find the knowledge required in teams that are cognitively close. This indicates that mechanisms as proposed by Proximity theory also play a role. For multiplexity we concluded that similar mechanisms shape the number of contents shared between teams. The perception that teams have of the expertise of other teams is the most important for the number of contents of knowledge shared between teams. If teams are physically close, mechanisms of closeness also play a role. Teams will share more contents of knowledge with teams that are physically close.

Starting a new theory for knowledge sharing in NPD consortia

	Basic closeness low or varies or Specialist/ critical knowledge is required	*Basic closeness high*
Within teams	Team members prefer knowledge sharing with 'close' team members (reciprocity shaped by mechanisms of closeness)	Team members prefer knowledge sharing with 'close' team members (reciprocity shaped by mechanisms of closeness)
	Team members share knowledge more often with whom they think have knowledge and to whom they can offer in return (frequency shaped by exchange mechanisms)	Team members share knowledge more often with 'close' team members (frequency shaped by mechanisms of closeness)
	Team members share more contents with persons they perceive to be experts (multiplexity shaped by expertise recognition)	Team members share more contents with 'close' team members
Between teams	Teams seek knowledge sharing with other teams they think have the expertise they need (reciprocity shaped by mechanisms of transactive memory)	Teams prefer (mutual) knowledge sharing with teams that are close in terms of task dependencies (reciprocity shaped by mechanisms of closeness)
	Teams share knowledge more frequent with teams on which they are cognitively dependent and have the knowledge they need (frequency shaped by mechanisms of transactive memory)	Teams share knowledge more frequent with teams on which they are cognitively dependent and/or cognitively close (frequency shaped by mechanisms of transactive memory and closeness)
	Teams share more contents with teams they perceive to have the knowledge required (multiplexity shaped by mechanisms of transactive memory)	Teams share more contents with teams they perceive to have the knowledge required and/or with the teams that are physically close (multiplexity shaped by mechanisms of transactive memory and closeness)

Text box 1: Starting point for a new theory explaining knowledge sharing in NPD consortia



TM: Transactive Memory theory
SE: Social Exchange theory
Prox: Proximity theory
Figure 6-2: Explanatory value of the theories for inter-team knowledge sharing

It should be noted here that because of the demand-driven nature of knowledge sharing between teams, when mechanisms of Transactive Memory theory shape knowledge sharing, the processes of directory updating and information retrieval have the upper hand. Information allocation is less present.

The conclusions above can be taken as a starting point for formulating a new theory for explaining knowledge sharing between teams in NPD consortia. Teams have fewer opportunities to base their knowledge sharing on which team is most proximate. Nevertheless, there are situations in which teams seem to have a preference for sharing knowledge with teams that are proximate in task dependency, physically close or cognitively close. Under certain circumstances, teams do not really have a choice of 'close teams' because there are no 'close teams' or because 'close teams' do not have the specialist knowledge they need. In these situations, the teams will still share knowledge with other teams they perceive to have the expertise they need. In these situations distance does not play a role: if a team needs certain knowledge, it will get this knowledge because it is needed for the execution of its task(s). The starting points for a new theory at the inter-team level are summarized in text box 1.

6.4 Managerial implications

The main objective of this thesis is to explore the role of enablers in knowledge sharing in instrument consortia. In this section I take the liberty of freely interpreting and translating the empirical findings in terms of managerial implications.

For practical purposes one of the most important findings of our study is that knowledge sharing is indeed a process that can be enabled in the consortia. The empirical study shows that the enablers influence the way in which people in instrument consortia share knowledge. Considering the enablers and their effects on knowledge sharing, indications can be given of when to use which variable in order to influence the knowledge sharing characteristics. Textbox 6.1 gives an overview of the enablers and their role in knowledge sharing.

Based on the present study it is possible to give some practical guidelines on how to manage knowledge sharing in instrument consortia. A distinction is made between guidelines for the start-up phase of a consortium and guidelines for managing knowledge sharing during the NPD process. The guidelines differ because when starting up a consortium, decisions are made that create the context in which knowledge is shared. In the interviews held with team leaders and managers, it became clear that during the NPD process the managers have to deal with this context and anticipate the situations at hand. During the process it is not really possible for them to change the task dependencies, for example. Both situations are discussed below.

Starting up a project

In starting up an instrument consortium, the environment in which the professionals have to work and share knowledge is created. The most important implication of our research is that there should be awareness of which enablers play a role in how people share knowledge and what their effects are. We will illustrate three effects that the decisions made in the start-up phase of the project may have.

First, there are many dependencies between tasks of teams and between tasks of team members. Professionals have to share knowledge where these task dependencies exist. Our findings indicate that they do indeed share knowledge where they perceive task dependency. If they do not perceive task dependencies, the probability of their sharing knowledge is small. To have the professionals share knowledge where task dependencies exist, it is crucial for them to be well informed on the task dependencies that exist. So it is important that from the start of the project, the task dependencies are explicitly communicated to all professionals working in the consortium (at least the dependencies relevant to them).

Effects of enablers on knowledge sharing

Co-location:
Facilitates knowledge sharing, both within and between teams
Stimulates people to mutually share knowledge
Increases the chance that people share knowledge more frequently
Increases the number of knowledge contents shared

Expertise overlap:
Facilitates knowledge sharing both within and between teams
Makes people more likely to share knowledge
Intensifies the frequency of knowledge sharing
Increases the multiplexity of knowledge sharing within teams
Makes knowledge sharing more focused between teams

Task dependency:
Is the largest enabler of knowledge sharing
Stimulates mutual knowledge sharing
Increases the frequency of knowledge sharing
Makes professionals within teams more likely to share knowledge on multiple contents
Focuses the knowledge sharing between teams on one or two knowledge types

Involvement in multiple projects:
The involvement of team members in multiple projects stimulates them to share knowledge on multiple contents
The involvement in multiple projects stimulates mutual and frequent knowledge sharing with other team members who are also involved in multiple projects

Text box 2: Effects of the enablers on knowledge sharing

Second, one of the findings in our study was that professionals do not tend to spontaneously share knowledge, but mainly when they need knowledge. They rarely share knowledge because they think someone may be interested in their knowledge. However, a more active attitude may prevent some problems. Actively passing on knowledge enables professionals to better anticipate changes in the design, for example. This active attitude in knowledge sharing may be stimulated by creating awareness among the professionals that it is important to approach others when you think you might have useful knowledge for them. It may also help increase their awareness of the instrument they are working on and show them the chain of activities in the module. Often the bigger picture is clear to team leaders or managers, but this know-why is lacking on the level of professionals working in the teams. Showing the professionals in the teams the importance of the tasks they perform, and the relation their tasks have to the complete instrument, is likely to make them more aware of the importance of active knowledge sharing.

Third, at the beginning of a consortium decisions are made in selecting institutes, forming teams and picking who will be working on the project. Although these decisions are mostly based on who can make the necessary investments, they have consequences for the differences in expertise. The development of an instrument requires different areas of expertise to be represented in the project. This is not only because the instrument has components that require different specialists, but also to stimulate creativity in the project. Therefore it is neither desirable nor realistic to advocate expertise overlap in all sets of team members where knowledge sharing is necessary. A possibility to create common knowledge in the consortium is to provide some sort of basic course on instrument development for everyone who participates in the project. It is also advisable that project management courses are offered to team leaders and managers in the projects. Team leaders and managers in the instrument consortia are often "best engineers" who are promoted to team leader. Their strong point is their excellent knowledge as regards content. Their level of project management knowledge varies. Offering team leaders and managers project management courses is likely to increase their awareness that they have an important role in monitoring and steering the process of their team. Also, the courses would help create common ground between team leaders. At the same time they would allow the team leaders to get to know each other better, which may be of use later in the project when they need each other for solving problems.

Fourth, knowledge sharing between teams mainly occurs through contact persons, and the expertise overlap can be taken into account when appointing these contact persons. Especially for teams where knowledge sharing among members is crucial, this can be done by appointing two contact persons who are expert in similar areas. Another possibility is to appoint separate contact persons for sharing knowledge with specific teams, in such a way that the contact persons who have to share knowledge have an overlap in expertise.

Fifth, selecting institutes and forming teams results in a certain degree of physical dispersion. Co-location is found to enable knowledge sharing. If this is a relevant variable in setting up a consortium, the consortium members should be aware of this. In some cases deliberate decisions can be made on who will be working co-located and who will not. Co-location may in some cases be impossible or too costly in the whole process of the project. In these situations it can be decided to co-locate people for a limited period of time or for a particular phase of the project, for instance at the beginning of the project, so that people get to know each other personally and learn about each other's expertise. This will facilitate knowledge sharing over a distance in later project phases. Text box 3 summarizes the guidelines for managing knowledge sharing in the start-up phase of a consortium.

Guidelines for managing knowledge sharing in the start-up phase

- ★ Be aware that the decisions made in this phase create the context in which people have to share knowledge during the NPD process
- ★ Be aware of the enablers that play a role in how people share knowledge, and the effects they have on knowledge sharing
- ★ Stimulate a more active attitude in sharing knowledge by placing the activities of the professionals in the perspective of the complete instrument they build.
- ★ Explicitly communicate task dependencies between teams and within teams
- ★ Provide opportunities for acquiring common knowledge, for example by providing a basic course
- ★ Match contact persons for knowledge sharing between teams, where possible
- ★ Take deliberate decisions on (temporary) co-location

Text box 3: Guidelines for managing knowledge sharing in starting up a project

During the NPD process

In managing knowledge sharing during a project, the most important is to be aware of the variables that play a role in the way people share knowledge and how this may affect knowledge sharing. Most circumstances are given by the setting of the project. If the enablers are not ideal, the team leaders and managers can anticipate this and manage the situation. For example, when a team leader knows that his team members are also involved in projects outside the consortium, he should be aware that this may have an impact on how they share knowledge. He should regularly monitor this knowledge sharing. Also in situations where the enablers are 'ideal', it is still no guarantee that knowledge sharing is optimal. Thus also when the enablers are ideal, the team leaders and managers have to actively monitor and manage knowledge sharing.

Monitoring knowledge sharing can be done in different ways. Talking to team members is an important source of information to monitor knowledge sharing within the team. The team leader could ask his team members regularly if they have regular meetings, for example, or whether they get enough information from one another and from the other teams, and evaluate whether the team meetings are perceived as useful. Another possibility, certainly when the team consists of a large number of people, he could use an instrument like social network analysis to monitor the frequency, reciprocity and multiplexity of knowledge sharing within his team. Monitoring knowledge sharing in the team enables the team leader to anticipate better. If he notices that two team members do not share knowledge frequently enough, for example, he can pro-actively respond by deciding to temporarily co-locate them. In this way the manager can actively anticipate the knowledge sharing to prevent problems. Being able to pro-actively manage knowledge sharing therefore not only requires awareness on the variables that play a role, but also requires monitoring knowledge sharing on a regular basis. This is necessary because the knowledge sharing characteristics may change over time. Also in different phases in the project, different states/values of reciprocity, frequency, and multiplexity may be optimal.

When it is necessary to stimulate knowledge sharing between team members or between teams, in some cases the enablers can be used for influencing the reciprocity, frequency, and/or multiplexity of knowledge sharing. When using the variables to influence knowledge sharing between teams, the knowledge sharing characteristic one wants to influence should be carefully considered. Using an enabler to influence a knowledge sharing characteristic can simultaneously influence other knowledge sharing characteristics in an unintended way. For example, an overlap between task dependency and expertise enables mutual and frequent knowledge sharing but impairs multiplex knowledge sharing. This also implies that one should consider the whole repertoire of possible enablers and carefully weigh the effects and side-effects when one wants influence knowledge sharing.

Some enablers are easier to use for influencing knowledge sharing characteristics than others. Text box 6.1 summarizes the effects of enablers on knowledge sharing. Some suggestions on how the enablers can be used to influence knowledge sharing are given below.

Using the enabler *task dependency* for influencing knowledge sharing is not easy during the project. The original task structure is created for good reasons. Teams and team members are selected for tasks because of their expertise or because of more political reasons. These reasons are under pressure if the task dependencies are changed. Therefore it is not always possible to change task dependencies. When teams or team members are simply not aware of their task dependencies, this awareness can be created using task flow diagrams, for example, to clarify where task dependencies exist.

Enabling knowledge sharing by creating *expertise overlap* is somewhat limited during the project. During the project it may seem possible to shift tasks between team members. Nevertheless, this may be difficult because team members have already gained task specific knowledge. Also, it takes a lot of time when someone has to learn a new task and in some cases this is impossible because in-depth knowledge is missing. In some cases it may be possible to have two professionals attend a conference together or to have them (or one of them) take a course so they have some common knowledge overlap.

Co-location can be used as an enabler of knowledge sharing at any time in the NPD process. It is a relatively easy way to stimulate knowledge sharing. However, co-locating teams or team members can be quite costly, certainly if it is for long periods. Co-locating complete teams may also be not (financially) practicable. However, in most cases it will not be necessary to co-locate teams completely. For example, when in a certain phase of the development process it is very important that two teams share knowledge, it may be decided to co-locate some members of these teams for some weeks or months. And in some cases it may just be enough to get the team members or teams together more often in a temporary form of co-location.

To actively use *involvement in multiple projects* as an enabler for knowledge sharing is not very feasible. A team leader may notice that a team member who is involved in multiple projects does not share knowledge frequently enough or only asymmetrically with the other team members. In that case he may look into the option of not involving this team member in multiple projects anymore and have him/her work at the consortium only. Mostly this is not an option in actual practice. We also found that when two team members are both involved in multiple projects, they are more likely to share knowledge, to do this more frequently and on multiple contents. Nevertheless, if two team members do not share knowledge when they are both involved in this one project, it is not very plausible that they will start sharing knowledge when they are both involved in multiple projects. Perhaps the increased reciprocity, frequency, and multiplexity are a side-effect. It is likely that team members who have crucial knowledge are also involved in multiple projects. Then the team members in the consortium need them for their knowledge and therefore share knowledge with them very frequently. Another explanation is that team members who are involved in multiple projects also work together in these projects. This is a plausible explanation because the world of expertise in which these professionals find themselves is a small community. In conclusion, we would not advise to use involvement in multiple projects as a variable to enable knowledge sharing between team members, because the effects are not straightforward, not very strong and/or not statistically significant compared to the effects of the other variables.

The findings of the present study have one other important implication for managing knowledge sharing during the NPD process. An important finding for practice is that team members or teams in the consortia do not tend to spontaneously share knowledge but mainly when they feel the need to. The strong effect of task dependency indicates this, but it is also one of the main findings in our qualitative study of knowledge sharing between teams. Knowledge sharing is highly demand-driven. The emphasis is clearly on knowledge retrieval, whereas knowledge distribution or allocation is not so much the case. This has two implications.

First, this is probably the reason why knowledge sharing, especially between teams, is strongly focused on know-how and know-what. Know-why and know-who are only rarely shared between teams and spread through projects. Instrument consortia may benefit if these types of knowledge are shared more. The management of the consortia should consciously distribute know-why and know-how and stimulate the sharing of these types of knowledge for two reasons. (1) Know-why, because people then have more background knowledge about the project and understand why they are doing the things they do, what the importance of their part is and how their part relates to other parts. As shown, this perception of task dependencies is the main enabler of knowledge sharing. Sharing know-why is also crucial as it gives an overview of the distribution of task dependencies. (2) Sharing know-who is mainly important between teams. As our qualitative study showed for both projects, teams did not sufficiently know which expertise the other teams had and which teams they could best approach for particular problems. Between teams knowledge sharing can be more efficient when teams directly approach those teams who have the relevant knowledge.

The second implication of knowledge not being spontaneously distributed or allocated through projects is that teams have a very reactive attitude in knowledge sharing. They only start to share knowledge when a problem is experienced. A more pro-active attitude in knowledge sharing is likely to prevent some of the problems experienced in projects. A pro-active attitude implies that teams actively distribute and allocate knowledge to other teams which they think have an interest in knowing. This requires that teams know what other teams are working on (know-why) and what knowledge other teams have and need (know-who). If the teams would actively distribute and allocate knowledge to other teams, they could anticipate situations better, manage the interfaces better (especially when making changes in their parts), but also reach synergy in foreseeing problems and reaching synergy in negotiations with third parties in buying parts, for example.

Who should manage knowledge sharing?

In managing the knowledge sharing within as well as between teams we point out the crucial role for team leaders and managers. Their insight into how members of their team collaborate and share knowledge and their leading role makes them very suitable for monitoring and managing knowledge sharing. For knowledge sharing between teams they have an important bridging (gatekeeper) function between their team members and other teams. They have to identify what information is important for other teams and what information their teams need from other teams. In addition to the team leaders, the project level management has an important role in managing knowledge sharing. They are often involved in starting up the project and they are largely responsible for spreading know-why and know-how throughout the project. Both the project level management and the team leaders can also act as role models for the professionals working in the consortium. They can show the professionals that it is 'normal' to share knowledge with others by taking an active role in this and setting the example.

However, we observed that at the project level, neither subsystem managers nor team leaders are (fully) aware of their crucial role in knowledge sharing and distributing know-why and know-who. We would recommend creating more awareness at this level, for example by including knowledge sharing as a topic in the project plan at the start of a new project, and by integrating knowledge management as part of their tasks.

Guidelines for managing knowledge sharing

- ★ Be aware of the variables that play a role in how people share knowledge, and the effects they have
- ★ Take an active, anticipating role in managing knowledge sharing
- ★ Evaluate knowledge sharing between and within teams on a regular basis
- ★ Before using an enabler to influence knowledge sharing, clearly have in mind the knowledge structure that is meant to be changed
- ★ Be aware of the side effects that the use of an enabler has on other knowledge sharing structures
- ★ Keep in mind the differences in mechanisms that shape knowledge sharing within and between teams and adjust the use of enablers to this
- ★ There are multiple enablers at hand for influencing knowledge sharing; one should choose from this repertoire based on which best fits the situation at hand
- ★ Create awareness on all organizational levels that knowledge sharing is important to stimulate a more active attitude in sharing knowledge
- ★ Keep in mind that the management and team leaders have a crucial role in managing knowledge sharing

Text box 4: Guidelines for managing knowledge sharing

The project management should also consider including relational promoters (Ritter & Walter, 2003) in the project. The role of a relational promoter would be to manage the interaction between teams, so that knowledge is shared efficiently and effectively. He would act as an intermediate between teams, having an overview of where knowledge should flow and whether knowledge flows frequently enough between teams. In this way he would support knowledge exchange. This person could also promote knowledge sharing in the consortium, emphasize the importance of knowledge management types of issues during the project, monitor knowledge sharing between teams and mediate if problems occur.

6.5 Limitations and directions for future research

The study that we conducted is exploratory in nature because not much was known about what variables could be used to influence knowledge sharing in instrument consortia and what theories can explain these influences and/or the knowledge sharing in these consortia. The current study contributes to science in a number of ways. From our study it appears that the use of multi theory approach, network perspective, and study on multiple levels are complementary. The multi theory approach, network perspective and multilevel study can be used simultaneously and go together quite well. Using a network approach also makes it possible to conduct a more thorough multilevel study in which a number of levels are included and directly compared. This study focused on knowledge sharing at the dyadic level, between two team members or between two teams. A social network approach also allows for studying knowledge sharing at other levels, for example studying complete networks of teams. By studying complete networks of teams, more insight could be gained into gatekeeper functions, for example.

Concerning the multilevel study, an additional way of building on our findings is to include variables at the team level. In that way it is possible to explore what characteristics at the team level influence knowledge sharing between team members. We found that mutual knowledge sharing by team members can largely be explained by variance at the team level. This means that mutual knowledge sharing between two team members depends for a considerable part on the team of which they are a part. This also applies to the inter-team level; it may be of added value to explore whether project characteristics or team characteristics influence the way in which teams share knowledge. Nevertheless, the approach chosen for the study has limitations as well. First, the data we gathered was limited. We had to make selections because not all data was complete for many dyads. Perhaps if we had had more complete data, this would have given a more complete picture.

Second, only two consortia were included. Because of the number of teams and the dyads within the teams it was still possible to do a proper analysis. But the question is: *Do the findings apply to other settings?* The applicability of findings always depends on the context in which the study was conducted. The empirical data was colleted in one sector (space science). This has implications for the external validity, because it is hard to assess to which extent the findings are influenced by the sector in which the projects took place. The question of applicability is even more to the point because data collection took place in two consortia where measurement instruments for space science are developed. Two consortia is a small sample. However, the organizational structure and culture of the consortia show similarities with consortia in other sectors. The consortia are characterized by multifunctional teams spread over several institutes and countries that have to conduct knowledge intensive tasks in a high tech environment. Consortia in the automotive, airplane or energy sector seem to have similar characteristics. But also projects in service oriented organisations, like hospitals, may have circumstances that are highly comparable to the instrument consortia. Therefore it is not unlikely that the findings from the current study also apply to consortia in other branches, where the circumstances are highly comparable to those in the instrument consortia. Still it is open for future research to explore whether the findings of our research apply to other settings.

Third, a point related to the previous issue is that in our analysis, we considered that dyads of team members are nested in teams. It should preferably also be taken into account that dyads of teams are nested in projects. Because the teams were studied in just two consortia, it was not possible to include this in the analysis.

Like other studies, this thesis raises new questions that are leads for future research:

What is optimal knowledge sharing?
As discussed in the practical implications, the empirical findings raise the question when mutual knowledge sharing is optimal, for example, or what frequency of knowledge sharing is optimal in a certain phase of the NPD process. It is not possible to make statements like "the more frequent knowledge is shared, the better it is", or "mutual knowledge sharing is optimal", based on the current study. What knowledge sharing is optimal is likely to depend on the situation, the performance aimed for and the phase of the project. There are studies that indicate teams always need a minimum frequency of communication, and at the same time too frequent communication can impair the creative performance of a team (e.g Leenders et al. 2007). Our recommendation for future research is to explore whether these findings can be translated to knowledge sharing, focusing on questions such as: what knowledge sharing characteristics are desirable in what phases of the NPD process?

How do knowledge sharing relations develop over time?
Knowledge sharing relations are dynamic and change over time. This thesis gives insight into the mechanisms likely to underlie knowledge sharing and how enablers shape knowledge sharing. It does not cover how the relations change over time and what happens when the enablers are used to intervene in knowledge sharing. It would be of great value if the changing nature of relations are included in future research.

Is it possible to develop one unifying theory for knowledge sharing in instrument consortia?
Chapter four and five set out conditions under which the theories explain knowledge sharing within and between teams. Section 6.3 formulated starting points for a new theory for explaining knowledge sharing in instrument consortia. The theories are very similar in scope, as they were selected on criteria based on the scope of our study. The theories are to some extent complementary in their explanations for knowledge sharing. Our answer is therefore that it seems possible to develop one unifying theory for explaining knowledge sharing. The current study only made a start for a new theory. It is up to future research to further study how the theories should be unified and to validate the new theory. Before unifying the theories, it should be explored to what *extent* the mechanisms proposed by the theories actually take place. We tested three theories on their propositions for the effects of enablers on knowledge sharing characteristics. For some enablers the theories propose the same effect and when this effect is supported by the empirical data. That was the case for the effects of task dependency, for instance. Our study could not answer the question whether it is all three mechanisms simultaneously shaping knowledge sharing or whether it is one of the mechanisms and as a by

product the propositions of the other two are also supported. Furthermore, the difference in bringing and retrieving knowledge was not measured. Future research should make this difference, because this difference is clearly made in the mechanisms included in these theories. A more qualitative approach, as used for studying knowledge sharing between teams, is well suited to gain these insights.

Is the current thought line in product development literature useful?
In current product development literature, decomposition intends to diminish task dependency by decomposing in such a way that there are as less task dependencies as possible. In the current study, empirical findings indicate that from a knowledge sharing point-of-view this line of thinking may not be advisable. By reducing task dependencies, professionals in the instrument consortia feel less need to share knowledge. It is up to future research to shine a light on this question.

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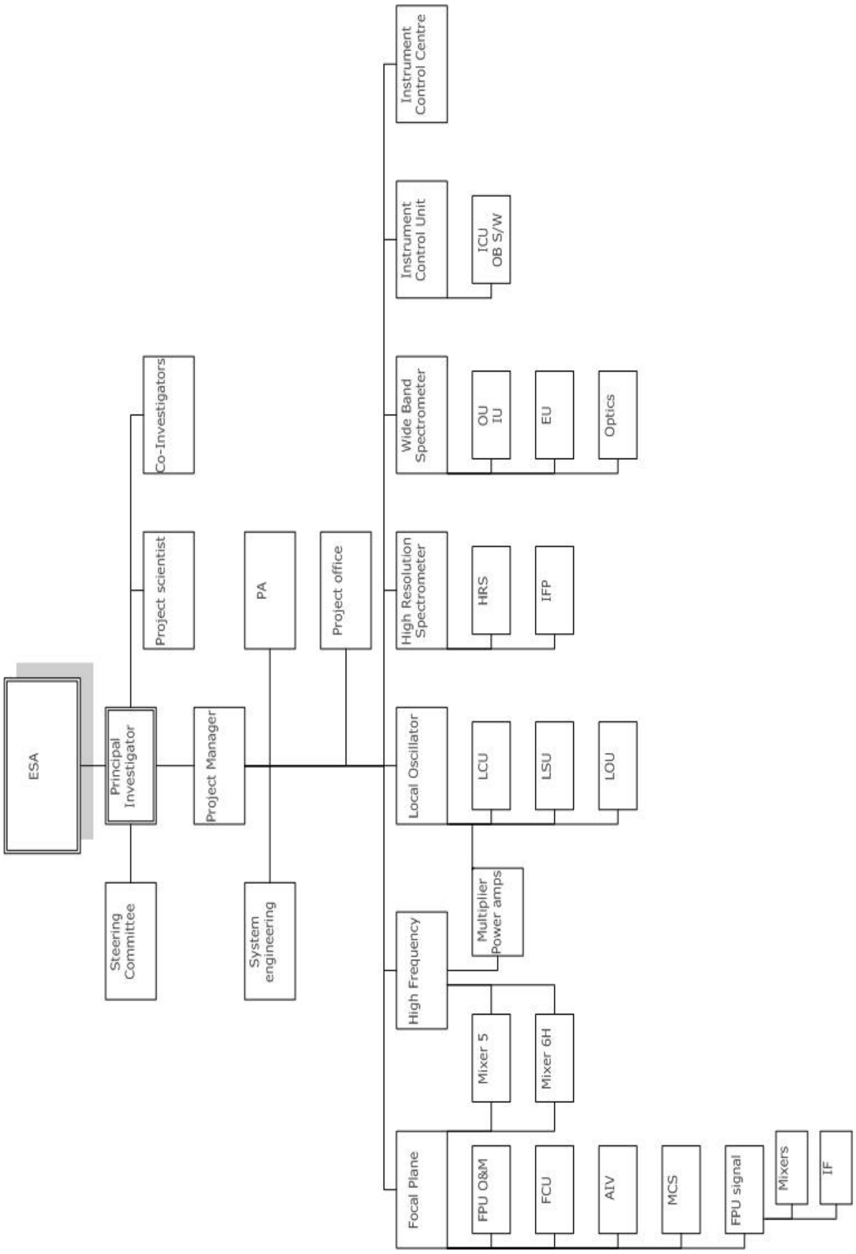
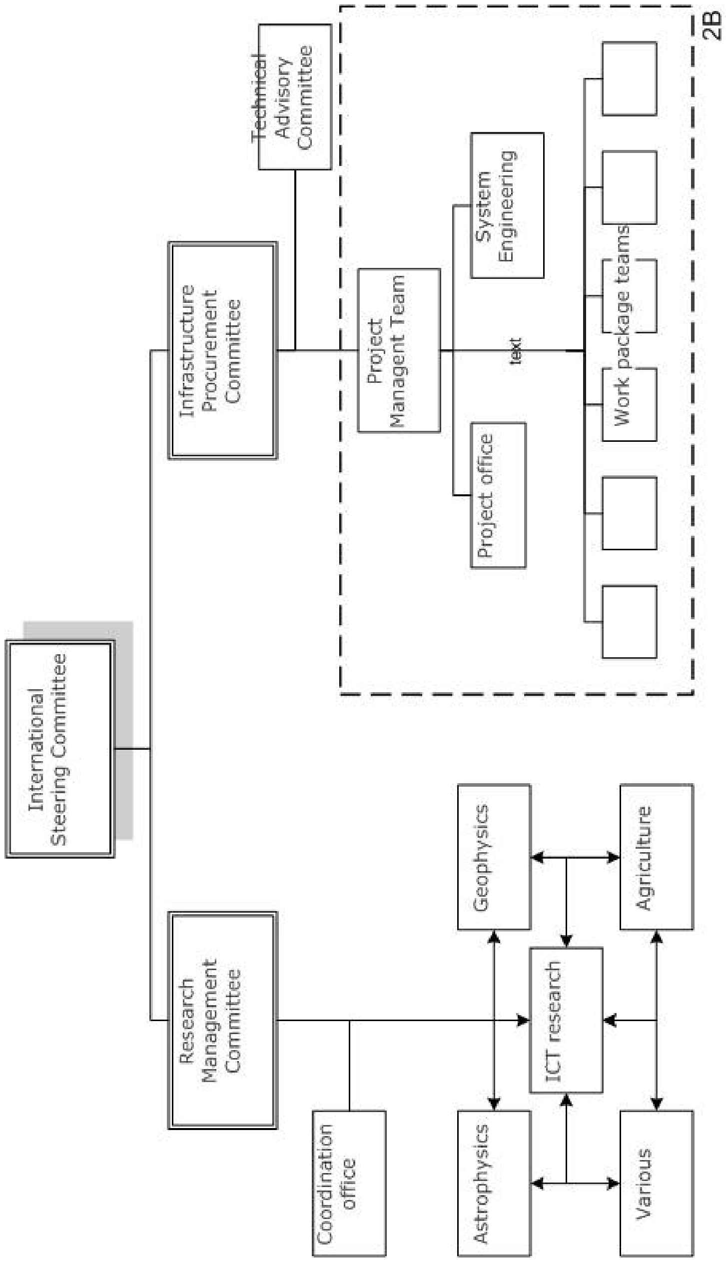
Appendices

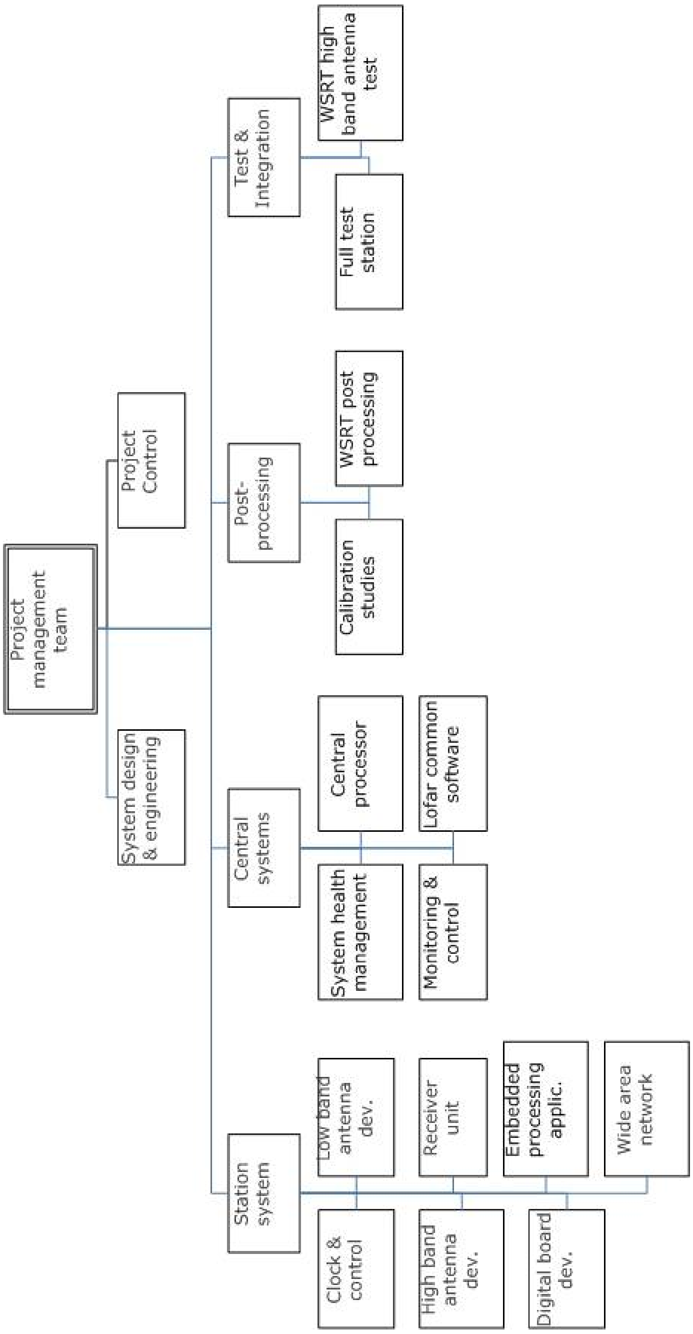
Appendix1: Organization chart project Space



Appendix 2: Organization chart project Ground *(A)*



(B)


Project management team
Project Control
System design & engineering
Station system
Central systems
Post-processing
Test & Integration
Low band antenna dev.
Clock & control
Receiver unit
High band antenna dev.
Embedded processing applic.
Digital board dev.
Wide area network
Central processor
System health management
Lofar common software
Monitoring & control
WSRT post processing
Calibration studies
WSRT high band antenna test
Full test station

Appendix 3: Questionnaire

1	What is the highest degree of education you received? **(please tick the box that applies)**
	☐ Elementary education ☐ Secondary education ☐ Higher secondary education ☐ Polytechnic education ☐ Academic education/University ☐ PhD ☐ Postdoctoral
2	What is your specialization? **(please choose from the list, multiple answers are possible)**
	☐ Astronomer ☐ Physicist ☐ Computer scientist/ software engineer ☐ Electrical engineer ☐ Mechanical engineer ☐ Optical engineer ☐ Structural engineer ☐ System engineer ☐ Test engineer ☐ Thermal engineer ☐ Instrument engineer ☐ Technician ☐ Other (please name):………………………………………………..
3	Since when have you been working on this project? **(please fill in month and year)** ………… (month) ………… (year)
4	Do you work fulltime on this project? If not, please write down how much time you time you spend on the project. ☐ Yes, I work fulltime on the **HIFI** project ☐ No, I work ……… hours / week on the **HIFI** project

<table>
<tr><td>5</td><td colspan="5">Are you involved in other projects? If yes, in which projects?

☐ No

☐ Yes, I am also involved in: ....</td></tr>
<tr><td>6</td><td colspan="5">What is your age?
(please round off to years)

………… (years)</td></tr>
<tr><td>7</td><td colspan="5">On average how often do you interact with other members **within your teams** about the following aspects of knowledge?</td></tr>
<tr><td rowspan="4">7a.</td><td colspan="5">The exchange of information about procedures, processes, and expertise.
(please tick the boxes that apply)</td></tr>
<tr><td>Member</td><td>Less than once a month</td><td>Monthly</td><td>Weekly</td><td>Daily</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">7b.</td><td colspan="5">The exchange of facts (e.g. designs, manufacturing drawings, models or test data).
(please tick the boxes that apply)</td></tr>
<tr><td>Member</td><td>Less than once a month</td><td>Monthly</td><td>Weekly</td><td>Daily</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">7c.</td><td colspan="5">The exchange of relevant background information (e.g. the scientific background of the project, the product specifications and requirements).
(please tick the boxes that apply)</td></tr>
<tr><td>Member</td><td>Less than once a month</td><td>Monthly</td><td>Weekly</td><td>Daily</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">7d.</td><td colspan="5">The exchange of information about the persons in the organization (e.g., knowledge about who has what role or task in the project or who has the formal authority to take certain decisions).
(please tick the boxes that apply)</td></tr>
<tr><td>Member</td><td>Less than once a month</td><td>Monthly</td><td>Weekly</td><td>Daily</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

8	There are dependencies in the context of work. What dependencies are you involved in (**within your teams**)? **(please tick the boxes that apply)**		
	Member	A This person and I need frequent mutual exchange of work outputs throughout the course of work.	B My ability to finish my work depends on this person first completing his or hers.

Appendix 4: Information requirements for interviews

Variables		Set of objects	Values
Dependent variable	**Explanatory variable**		
Reciprocity	Expertise overlap	• Dyads with mutual knowledge sharing • Dyads with asymmetrical knowledge sharing • Dyads with no knowledge sharing	Areas of expertise in common: • Large overlap • Small overlap
	Co-location		• Co-located • Not co-located
	Task dependency		• Task dependent • Not task dependent
Frequency	Expertise overlap	• Dyads with very high frequency (daily) • Dyads with very low frequency (monthly or less)	Areas of expertise in common: • Large overlap • Small overlap
	Co-location		• Co-located • Not co-located
	Task dependency		• Task dependent • Not task dependent
Multiplexity	Expertise overlap	• Dyads with very high multiplexity • Dyads sharing only one type of content	Areas of expertise in common: • Large overlap • Small overlap
	Co-location		• Co-located • Not co-located
	Task dependency		• Task dependent • Not task dependent

Variables		Set of objects	Values
The explanatory value of TM theory for:	Reciprocity	The dyads of teams	Extent to which TM theory explains reciprocity
	Frequency	The dyads of teams	Extent to which TM theory explains frequency
	Multiplexity	The dyads of teams	Extent to which TM theory explains multiplexity
The explanatory value of Prox theory for:	Reciprocity	The dyads of teams	Extent to which Prox theory explains reciprocity
	Frequency	The dyads of teams	Extent to which Prox theory explains frequency
	Multiplexity	The dyads of teams	Extent to which Prox theory explains multiplexity
The explanatory value of SE theory for:	Reciprocity	The dyads of teams	Extent to which SE theory explains reciprocity
	Frequency	The dyads of teams	Extent to which SE theory explains frequency
	Multiplexity	The dyads of teams	Extent to which SE theory explains multiplexity

TM= Transactive Memory
Prox = Proximity
SE = Social Exchange

Appendix 5: Interview scheme

(Translated to English)

Introduction:

In my research I focus on knowledge sharing between two parties. This is what we call the dyadic level. First I focused on explaining knowledge sharing between team members within teams. Now I want to focus on the level of teams, why pairs of two teams share knowledge. Doing so, I include three characteristics of knowledge sharing: the direction, the strength, and the content of knowledge sharing.

1. My first question concerns the direction of knowledge sharing. There are three possible situations in this: (1) there is mutual knowledge sharing, (2) the knowledge sharing is one-directional, (3) the teams do not share knowledge at all.

Main question:	**Sub-questions**	**Sub-sub-questions**
If we look at project Space/ project Ground, could you identify sets of teams for each of the situations sketched above and indicate why they share knowledge mutually, one-directional or not at all?	- Examples of mutual knowledge sharing? - Reasons for mutual knowledge sharing? - Examples of one-directional knowledge sharing? - Why do these teams have one-directional knowledge sharing? - Examples of two teams that do not share knowledge? - Why do these not share knowledge?	Could you indicate per set of dyads: - What is the overlap in expertise? Are they co-located? - Are they task dependent? - How do you think these variables influence the direction of knowledge sharing between teams?
	- To what extent to the ideas that teams have of each other's expertise play a role in the direction of knowledge sharing? - To what extent does the knowledge that teams can offer each other play a role in this? - To what extent does the closeness of teams play a role in the direction of knowledge sharing? (physical, cognitive, task dep)	- Why? - Could you indicate which of these three most shapes the direction of knowledge sharing?

2. In addition to the direction of knowledge sharing, I try to explain the strength of knowledge sharing between teams. For the strength I focus on how often two teams share knowledge, the frequency.

Main question:	**Sub-questions**	**Sub-sub-questions**
2-1. Was there in project Space/ Ground a lot of difference in the frequency of knowledge sharing between teams?	- Examples of dyads where the teams share knowledge very often (almost daily)? - Examples of dyads where the teams share knowledge only occasionally?	Could you indicate per set of dyads: - What is the overlap in expertise? Are they co-located? - Are they task dependent?
2-2. Can you try to indicate why some teams share knowledge more often than other teams?	- How do you think the factors expertise overlap/ co-location/ and task dependency influence the frequency of knowledge sharing between teams? - To what extent to the ideas that teams have of each other's expertise play a role in the frequency of knowledge sharing? - To what extent does the knowledge that teams can offer each other play a role in this? - To what extent does the closeness of teams play a role in how often teams share knowledge? (physical, cognitive, task dep)	- Why? Could you indicate which of these three most shapes the frequency of knowledge sharing?

3. The third characteristic of knowledge sharing that is included in my study is the content of the knowledge that is shared. Here I focus mainly on the multiplexity of knowledge sharing, which indicates the number of content-types that is shared between two teams. I discern four types of knowledge content:

- Know-how: knowledge of processes, for example how to solve problems and how to execute tasks.
- Know-what: factual knowledge, for example data, drawings
- Know-who: knowledge about persons in the project , for example who has what expertise
- Know-why: knowledge of the background of the project, for example the wider context of the project.

Main question:	**Sub-questions**	**Sub-sub-questions**
3-1. Could you make the difference between these types of knowledge in project Space/ Ground?	- know-how - know-what - know-who - know-why	Examples?
3-2. Could you indicate for each type of knowledge content teams that share this type of content and indicate why/ who and when?	- Examples of two teams that share one type of knowledge? - Examples of dyads where the teams share multiple types of knowledge content	Could you indicate per set of dyads: - What is the overlap in expertise? Are they co-located? - Are they task dependent? - How do you think the factors expertise overlap/ co-location/ and task dependency influence the frequency of knowledge sharing between teams?

	- To what extent to the ideas that teams have of each other's expertise play a role in the frequency of knowledge sharing? - To what extent does the knowledge that teams can offer each other play a role in this? - To what extent does the closeness of teams play a role in how often teams share knowledge? (physical, cognitive, task dep)	- Why? - Could you indicate which of these three most shapes the frequency of knowledge sharing?

4. Finally, I would like to talk about to what extent the knowledge sharing between teams is actually manageable.

Main question:	**Sub-questions**	**Sub-sub-questions**
What role does the project leader play versus the team members in knowledge sharing between teams?	- To what extent do the people in the team determine with what other teams they share knowledge and how often and on what? - To what extent is this manageable?	- Examples? - What are the tools/ possibilities to manage? - Why?

Summary

Summary

New Product Development (NPD) consortia become a more common form of organizing NPD activities. Organizing NPD in consortia brings challenges, because in the consortia specialized knowledge from multiple areas necessary for developing the new product is distributed across the participating organizations. To use and combine the specialized knowledge of the participating organizations, and combine it into a new product, knowledge sharing between the consortium members involved is crucial. The more effective project members share knowledge, the better they anticipate on interfaces, create new solutions and foresee problems. Effective knowledge sharing increases the probability the project members successfully complete their tasks and meet the quality, time and financial requirements. In other words, the way professionals share knowledge is crucial for NPD consortia. At the same time effective knowledge sharing is a real challenge for NPD consortia. This can result in a range of problems, from failure to meet quality requirements to budget and time schedule overruns. Some of these problems can likely be prevented by managing knowledge sharing more effectively. However, insight into the way knowledge sharing is enabled lacks both in practice and literature. The objective of this thesis is therefore to gain more insight into enablers that affect knowledge sharing in NPD consortia. Four enablers that shape the context in which knowledge is shared were the starting point for the current study: expertise overlap, co-location, involvement in multiple projects, and task dependency. The effects of these enablers on three knowledge sharing characteristics were studied: the reciprocity, frequency, and multiplexity of knowledge sharing. Additionallu, the effects were studied at two levels of knowledge sharing: within teams (intra-team level) and between teams (inter-team level).

In this thesis we adopted a multi-theory social network analysis perspective to study knowledge sharing in NPD consortia. We examined how expertise overlap, co-location, task dependency and project involvement affect the reciprocity, frequency and multiplexity of knowledge sharing in pairs of team members and in pairs of teams. Adopting a multi-theory perspective, it was explored whether Transactive Memory theory, Social Exchange theory and Proximity have explanatory value for knowledge sharing in instrument consortia and the conditions under which the theories explain knowledge sharing. Moreover, distinguishing between the intra-team and inter-team level, similarities and differenced between the effects of the enablers and the explanatory value of the theories at the two levels of knowledge sharing were studied.

From Transactive Memory theory, Social Exchange theory, and Proximity theory propositions were formulated for the effects of the enablers on the knowledge sharing characteristics. These propositions were tested in an empirical study conducted in two large NPD consorotia in the field of space science, so called instrument consortia. In the one consortium a measurement instrument for a satellite is developed, in the other

consortium a network of antennas is developed. The propositions for the intra-team level were first tested in a quantitative study conducted through questionnaires in which 261 persons from 48 teams were included. The quantitative study was mainly conducted through questionnaires. Multilevel regression analyses were used for analyzing these data. The results form an answer to the first research question:

1. *What is the effect of expertise overlap, co-location, involvement in multiple projects and task dependency on the reciprocity, frequency and multiplexity of knowledge sharing within teams?*

The empirical findings show that task dependency is the main enabler for knowledge sharing within teams; it makes team members share knowledge more reciprocal, more frequently and on more content types. Co-location and expertise overlap are found to enable knowledge sharing, but their effect is less strong. If a team member is involved in multiple projects, he is less probable to share knowledge with a team member who is not involved in multiple projects. If these team members do share knowledge, it is less often but on more content types than when they are both involved in a single project. If two team members are both involved in multiple projects, they are more likely to share knowledge mutually. Furthermore, they are more probable to share knowledge frequently and on multiple contents.

The empirical findings for the intra-team level were used as a starting point for studying knowledge sharing at the inter-team level. In the empirical study at the inter-team level the emphasis was on exploring knowledge sharing between teams using a qualitative method. The qualitative study involved interviews with in total 34 team leaders of both consortia and four more structured and extensive interviews with key persons in the projects. The findings from the qualitative empirical study answer the second research question posed in this thesis:

2. *What is the effect of expertise overlap, co-location and task dependency on the reciprocity, frequency and multiplexity of knowledge sharing between teams?*

The empirical findings indicate that task dependency is the main enabler for knowledge sharing between teams. Task dependency has an enabling effect on reciprocity and frequency and focuses knowledge sharing on one or two content types. Expertise overlap and co-location also enable knowledge sharing between teams: both appear to increase the probability of mutual and more frequent knowledge sharing. A difference in areas of expertise seems to be related to more multiplex knowledge sharing and co-location appears to enable particular content types of knowledge (know how and know what) to be shared between teams.

The effects found in the quantitative and qualitative study were compared to the propositions formulated in the theoretical framework. By making the comparison, we were able to evaluate which theory best predicts the effects found and answer the third and fourth research question:

3. *Compared on explanatory strength, which theory best predicts the effects of enablers and knowledge sharing characteristics within teams?*

Findings indicate that the effects of expertise overlap and co-location within teams are best explained by Proximity theory. The effects of involvement in multiple projects are best explained by Social Exchange theory and the effects of task dependency are predicted by all three theories. Focusing on knowledge sharing characteristics explained, Proximity theory was found to be dominant fin explaining knowledge sharing within teams. Transactive Memory theory has added value in explaining the number of contents shared. Social Exchange theory has added value in predicting the frequency of knowledge sharing in situations where the basic closeness between team members is very low.

4. *What is the effect of expertise overlap, co-location and task dependency on the reciprocity, frequency and multiplexity of knowledge sharing between teams?*

We found knowledge sharing between teams to be highly demand-driven. A combination of mechanisms as proposed by Transactive Memory theory and Proximity theory shapes the frequency and multiplexity of knowledge sharing between teams. The reciprocity of knowledge sharing appears to be best explained by Proximity theory. In our data Social Exchange theory offered no added value in explaining knowledge sharing between teams of instrument consortia.

Research question five and six cover the differences between the two levels of knowledge sharing studied. To answer these research questions empirical findings at the intra-team level and the inter-team level are compared on the effects of the enablers and on the theories that explain knowledge sharing.

5. *What are the differences between the intra-team level and inter-team level in the effects of enablers on knowledge sharing characteristics?*

Comparing the findings at both levels regarding the effects of the enablers on knowledge sharing characteristics, we found similarities as well as differences. Similar are the large enabling role of task dependency, the positive effect of co-location and the enabling effect of expertise overlap. Three differences are found for knowledge sharing within and between teams. First, where task dependency within teams leads to more content types shared, between teams it causes teams to be more focused on one or two content types. Second, within teams an overlap in expertise increases the likelihood of team members sharing knowledge mutually. Between teams an overlap in expertise is however found negatively affect the reciprocity of knowledge sharing. Third, an overlap in expertise between two team members was found to result in a tendency to share multiple contents types of knowledge. Between teams the opposite effect was found: an overlap in expertise decreases the likelihood teams share knowledge of multiple content types, whereas a difference in expertise causes the teams to share multiple content types of knowledge.

6. *Do the intra-team and inter-team level differ on the theories best explaining knowledge sharing?*

At both the intra-team and inter-team level, Proximity theory provides the most supported predictions of the effects of the enablers on knowledge sharing. Focusing on the knowledge sharing characteristics explained, there are however differences between the intra-team and inter-team level. A combination of mechanisms as proposed by Proximity theory, Social Exchange theory and Transactive Memory theory explained knowledge sharing within teams. We found that Social Exchange theory and Transactive Memory theory mainly have added value in explaining knowledge sharing in situations where the basic closeness between team members is low. Between teams our findings indicate differences. At the inter-team level mechanisms as proposed by Social Exchange theory do not seem to play any role in shaping knowledge sharing, and the role of Transactive Memory theory is much larger. Knowledge sharing between teams was explained by a combination of Transactive Memory and Proximity theory.

Samenvatting

Samenvatting

Productontwikkeling wordt in steeds vaker georganiseerd in de vorm van consortia. Het organiseren van productontwikkeling in consortia is iets wat uitdagingen met zich meebrengt omdat de specialistische kennis van verschillende domeinen die nodig is voor het ontwikkelen van een nieuw product is verspreid over de participerende organisaties. Om optimaal gebruik te maken van de specialistische kennis in de consortia, om de productontwikkelingstaken te kunnen uitvoeren en om nieuwe kennis te creëren is kennisdeling tussen de projectleden noodzakelijk. Des te beter de projectleden in staat zijn kennis te delen, des te beter zij in staat zijn te anticiperen op interfaces, tot nieuwe oplossingen te komen en problemen te kunnen voorzien. Effectieve kennisdeling verhoogt de kans dat de projectleden hun taken succesvol uitvoeren en voldoen aan de kwaliteitseisen, aan de tijdsrestricties en aan de financiële randvoorwaarden. In andere woorden: de manier waarop de professionals kennis delen in deze consortia is van groot belang voor het succes ervan. Echter, in de praktijk is kennisdeling juist een knelpunt en dit zorgt er voor dat de projecten hun budget overschrijden, hun planning overschrijden en de gestelde kwaliteit niet halen. Een aantal van deze problemen kunnen naar waarschijnlijkheid voorkomen worden als kennisdeling effectiever gestuurd wordt. Helaas is er nog weinig tot niks bekend over hoe kennisdeling bevorderd kan worden in productontwikkelingconsortia. Het doel van dit proefschrift is om inzicht te verwerven in de variabelen die kennisdeling in de productontwikkelingconsortia beïnvloeden en bevorderen,. Deze variabelen noemen we 'enablers' voor kennisdeling. Uitgangspunt hierbij zijn vier variabelen die de context creëren waarin kennis gedeeld wordt: expertise overlap, collocatie, betrokkenheid in meerdere projecten en taakafhankelijkheid. De effecten van deze enablers op drie kenmerken van kennisdeling worden bestudeerd. Deze kenmerken zijn: de wederkerigheid, de frequentie en het aantal gedeelde inhoudstypes. De effecten van de variabelen op kennisdeling worden bestudeerd op twee niveaus van kennisdeling; kennisdeling binnen teams (intra-team) en tussen teams (inter-team).

In dit onderzoek is een multitheoretische sociale netwerk analyse benadering gekozen. Onderzocht is hoe expertise overlap, collocatie, betrokkenheid in meerdere projecten en taakafhankelijkheid invloed hebben op de wederkerigheid, de frequentie en het aantal gedeelde inhoudstypes van kennisdeling tussen twee teamleden of tussen twee teams. Door het adopteren van een multitheoretische benadering, kunnen er ook uitspraken gedaan worden over in welke mate de Transactive Memory theory, de Social Exchange theory en de Proximity theory kennisdeling in productontwikkelingconsortia verklaren en onder welke omstandigheden zij verklarende waarde hebben. Door bovendien twee niveaus van kennisdeling te onderscheiden geeft dit onderzoek inzicht in de mate waarin de effecten van de variabelen en de verklarende waarde van de theorieën verschillen tussen het intra-team niveau en het inter-team niveau.

In het theoretische raamwerk van dit onderzoek zijn voor elk van de gebruikte sociale theorieën proposities geformuleerd voor de effecten van de variabelen op de kenmerken van kennisdeling. Deze proposities zijn getest in een empirisch onderzoek dat is uitgevoerd in twee omvangrijke consortia in ruimteonderzoek, zogenoemde instrument consortia. In het ene consortium wordt een meetinstrument ontwikkeld dat geplaatst wordt op een satelliet, in het andere consortium wordt een netwerk van antennes ontwikkeld voor metingen in de ruimte. De proposities voor het intra-team niveau zijn getest in een kwantitatieve studie, waarin 261 personen uit 48 teams betrokken zijn. De kwantitatieve studie is met name uitgevoerd met behulp van vragenlijsten. Multilevel regressie analyses zijn gebruikt om de data uit de kwantitatieve studie te analyseren. De resultaten hiervan vormen het antwoord op de eerste onderzoeksvraag die gesteld is in dit onderzoek.

1. *Wat is het effect van expertise overlap, collocatie, betrokkenheid in meerdere projecten en taakafhankelijkheid op de wederkerigheid, de frequentie en het aantal gedeelde inhoudstypes van kennisdeling binnen teams?*

De bevindingen laten zien dat taakafhankelijkheid de belangrijkste stimulator is voor kennisdeling. Taakafhankelijkheid zorgt ervoor dat teamleden vaker wederzijds, frequenter en over meerdere inhoudstypes kennis delen. De variabelen collocatie en expertise overlap bevorderen kennisdeling ook, maar minder sterk. De betrokkenheid in meerdere projecten heeft ook invloed op kennis delen. Is een teamlid betrokken in meerdere projecten, dan is hij minder geneigd om kennis te delen met een teamlid dat alleen in het betreffende project betrokken is. Als deze teamleden kennis delen gebeurt dat minder vaak, maar dan delen zij wel meerdere inhoudstypen van kennis. In een situatie waarin twee teamleden beide betrokken zijn in meerdere projecten, zijn zij meer geneigd tot wederzijdse kennisdeling. Bovendien zijn zij geneigd om vaker kennis te delen en delen zij meerdere inhoudstypes.

De bevindingen binnen teams zijn gebruikt als uitgangspunt voor het bestuderen van kennisdeling tussen teams. In het empirische onderzoek op het inter-team niveau ligt de nadruk op het verkennen van kennisdeling in sets van twee teams door middel van een kwalitatieve studie. In het kwalitatieve onderzoek zijn interviews gehouden met in totaal 34 teamleiders van beide consortia en er zijn vier meer gestructureerde uitgebreide interviews gehouden met een aantal sleutel personen in de projecten. De bevindingen van de kwalitatieve studie beantwoorden de tweede onderzoeksvraag.

2. *Wat is het effect van expertise overlap, collocatie, betrokkenheid in meerdere projecten en taakafhankelijkheid op de wederkerigheid, de frequentie en het aantal gedeelde inhoudstypes van kennisdeling tussen teams?*

De resultaten van de kwalitatieve studie laten zien dat tussen teams ook taakafhankelijkheid de voornaamste enabler is voor kennisdeling.

Taakafhankelijkheid vergroot de kans dat teams wederzijds kennis delen en dat de teams vaker kennis delen. Daarnaast delen teams die taakafhankelijk zijn kennis over minder inhoudstypes, vaak maar één of twee. Ook een overlap in expertise en collocatie faciliteren kennis delen, beide vergroten de kans dat teams wederzijds kennis delen en vaker kennis delen. Een verschil in expertise tussen teams lijkt gerelateerd te zijn aan meer multiplexe kennisdeling en collocatie lijkt het delen van bepaalde inhoudstypes te faciliteren (know how en know what).

De effecten die zijn gevonden in het kwantitatieve en kwalitatieve onderzoek zijn vergeleken met de proposities zoals geformuleerd in het theoretische raamwerk. Door de resultaten naast de proposities te leggen, is het mogelijk uitspraken te doen over welke theorieën de meeste overeenkomsten vertonen met de gevonden effecten. Dit is gerelateerd aan de derde en vierde onderzoeksvraag.

3. *Als we kijken naar de verklarende waarde van de theorieën, welke theorie voorspelt dan het beste de effecten van de kennis 'enablers' op de kenmerken van kennisdeling binnen teams?*

Proximity theory is de theorie die de effecten van expertise overlap en collocatie het beste verklaart binnen teams. De effecten van de betrokkenheid in meerdere projecten worden het beste verklaard door Social Exchange theory en de effecten van taakafhankelijkheid worden door alle drie de theorieën even goed verklaard. Als we kijken naar de kenmerken van kennisdeling die worden verklaard, dan is Proximity theory dominant in het verklaren van kennisdeling binnen teams. Transactive Memory theory heeft met name toegevoegde waarde in het verklaren van het aantal inhoudstypen dat gedeeld wordt. Social Exchange theory heeft toegevoegde waarde in het verklaren van de frequentie van kennisdeling in de situaties waar de basis nabijheid van de teamleden laag is.

4. *Als we kijken naar de verklarende waarde van de theorieën, welke theorie voorspelt dan het beste de effecten van de 'enablers' op de kenmerken van kennisdeling tussen teams?*

Uit de onderzoeksresultaten is gebleken dat kennisdeling tussen teams zeer vraaggestuurd is. De bevindingen wijzen uit dat een combinatie van mechanismes van Transactive Memory theory en Proximity theory de frequentie en multiplexiteit van kennisdeling tussen teams vormen. De reciprociteit van kennisdeling tussen teams wordt het beste verklaard door Proximity theory. Tenslotte blijkt in onze data dat Social Exchange theory geen toegevoegde waarde heeft in het verklaren van kennisdeling tussen teams van instrument consortia.

Onderzoeksvraag vijf en zes hebben betrekking op de verschillen tussen de twee niveaus van kennisdeling die bestudeerd zijn in dit onderzoek. Om deze vragen te beantwoorden zijn de empirische bevindingen van kennisdeling binnen teams en tussen teams vergeleken, zowel op de effecten van de enablers als op de theorieën die kennisdeling verklaren.

5. *Wat zijn de verschillen tussen kennisdeling op het intra-team niveau en het inter-team niveau wat betreft de effecten van de enablers op de kenmerken van kennisdeling?*

Als we de effecten van de enablers op kennisdeling op beide niveaus vergelijken zien we zowel verschillen als overeenkomsten. Overeenkomsten zijn: de grote faciliterende rol van taakafhankelijkheid, het positieve effect van collocatie en het faciliterende effect van expertise overlap. We zien drie verschillen voor kennisdeling binnen teams en tussen teams. Ten eerste leidt taakafhankelijkheid binnen teams tot het delen van meerdere inhoudstypes, terwijl het tussen teams leidt tot kennisdeling die meer gefocust is op één of twee inhoudstypes. Ten tweede zorgt een overlap in expertise er binnen teams voor dat team leden vaker wederzijds kennis delen. Tussen teams is voor de overlap in expertise juist een negatief effect gevonden op de wederkerigheid van kennis delen. Ten derde wijzen de bevindingen erop dat een overlap in expertise tussen twee teamleden resulteert in een neiging tot het delen van meerdere inhoudstypes van kennis. Tussen teams is het tegenovergestelde gevonden. Daar leidt een overlap in expertise tot het delen van minder inhoudstypes, terwijl een verschil in expertise tussen teams gerelateerd is aan het delen van meerdere inhoudstypes van kennis.

6. *Verschillen het intra-team niveau en inter-team niveau in welke theorieën kennisdeling het beste verklaren?*

Op beide niveaus van kennisdeling levert Proximity theory de meeste gevalideerde proposities voor de effecten van de enablers op de kenmerken van kennisdeling. Als we echter de aandacht verleggen naar de kenmerken van kennisdeling die worden verklaard, dan zijn er verschillen tussen kennisdeling binnen en tussen teams. Kennisdeling binnen teams wordt verklaard door een combinatie van mechanismes zoals beschreven door Proximity theory, Transactive Memory theory en Social Exchange theory. Binnen teams hebben Social Exchange theory en Transactive Memory theory met name verklarende waarde in situaties waar de basis nabijheid van team leden laag is. Tussen teams lijken de mechanismes zoals beschreven door Social Exchange theory geen rol te spelen. De rol van Transactive Memory theory is daar veel groter. Kennisdeling tussen teams wordt namelijk verklaard door een combinatie van mechanismes zoals beschreven door Transactive Memory theory en Proximity theory.