Chapter 1

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 deduced 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
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.