Learning Through Cognitive and Collaborative Problem-Solving Processes in Technological Product Development

ACADEMIC DISSERTATION
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Nokia, New Year's Eve 2001,

Riikka Rahikainen
ABSTRACT

Riikka Rahikainen

Learning through cognitive and collaborative problem-solving processes in technological product development

The purpose of this study was to formulate a novel approach to cognitive problem-solving and learning processes taking place in collaboration with others during work-related problem-solving tasks. The phenomena of cognitive and collaborative problem-solving and learning were approached by investigating the collaborative problem-solving and learning processes embedded in technological product development. Theories of information processing and efficient action were used as theoretical stepping stones, but combined and amplified with the theories of human metacognition, distributed cognitions, as well as theories of producing human, intellectual, and social capital.

The explanatory power of the novel approach was tested through empirical data gathered by observing and videotaping two research and development (R & D) teams. All team members were interviewed twice. Also, twelve engineers from the fields of industrial design, planning engineering, and teaching were interviewed. All empirical data was transcribed and analyzed using qualitative research techniques.

Based on both the theoretical framework formulated in the course of this research and the findings from the empirical data gathered for this research, the joint problem space in which the collaborative problem-solving takes place is composed of the following elements: a) a problem, b) problem solver/s, c) cognitive tools, d) practical tools, e) human capital, f) intellectual capital, and g) social capital.

The problems occurring in technological product development are large in size and complex by nature. They are ill-defined problems which are most often caused by the further development of the already existing technology or by the need to increase the security of that technology. The problems in technological product development do not usually have absolutely right or wrong answers and are "never-ending" by nature. The problem-solving in R & D processes is usually carried out in situations in which the actual problem is known, but the solution and the means to reach the solution are missing, as well as in situations in which the initial and the goal state of the problem are known, but phrased according to people's previous knowledge and experience of the field. The issues of problem constraints found in the course of this research also have a great impact on the actual problem-solving situation. The constraints are either related to nature, society/situation, or person/group, and they can either be seen as a negative or a positive factor while proceeding in the problem-solving. The personal attributes investigated in this research were more cognitive than e.g. emotional by nature. An individual uses certain elementary as well as higher cognitive and metacognitive tools during the collaborative problem-solving situation. Also, personal knowledge, skills, and attitudes are brought to bear. Therefore, and eventhough, the problem-solving processes studied in this research take place in collaboration with others,
individuals are understood as single entities interacting with others at a cognitive level. This is called an interactive view of distributed cognitions.

The existence of cognitive as well as practical tools in the joint problem space support the view of cognitions interacting in a spiral-like fashion in which the individuals' elementary and higher cognitive, as well as metacognitive inputs affect the joint distributed cognitive system formed by all members of the team. In collaborative problem-solving, human collaborative cognitive functioning is enabled by the intervening nature of both practical tools: mental and instrumental mediational tools. Mental mediational tools (e.g., individual experience, experience of others, knowledge acquisition through written, visual, or audio material) enable the usage of both the individual cognitive and metacognitive tools, as well as the distributed cognitive and metacognitive tools during the joint process of problem-solving. Moreover, with instrumental mediational tools (e.g., professional jargon, computer software, timetables), the group's cognitive functioning becomes more efficient and faster.

The three other elements of the joint problem space are human, intellectual, and social capital. Once a team starts its work, all team members bring in the human as well as the social capital they possess. Moreover, during the collaborative problem-solving process, all three forms of capital are gained: the development of social capital facilitates the development of both the intellectual and the human capital. It is argued in this research that the process of gaining so called capital "surplus" is actually a three-veined learning process in which learning occurs through problem-solving and in which the cognitive-level products (i.e., what has been learned) of this process are: a) the human capital of an individual (i.e., new knowledge, skills, and attitudes of a single person), b) the intellectual capital created in a team (i.e., the knowledge and knowing capability of a group), and c) the social capital created in the team (i.e., knowing-who knowledge partly possessed by individuals and partly by the group).

In many organizations, the issues of human resources, the value and the validity of the company's intellectual capital, as well as the utilization of the personnel's full competence are being widely discussed but underused and, often, misunderstood. I argue that the functionality and the success of team-work and collaborative problem-solving in teams, in particular, are more depended on the cognitive-level processes taking place in such situations than some external frameworks (i.e., team-work instructions, team-work techniques etc.). If people engaged in a collaborative problem-solving enterprise are not able to use their own cognitive as well as metacognitive functions to create distributed cognitive processes and, moreover, if they are not able to exploit the human, intellectual, and social capital they possess on behalf of the knowledge creation process of the whole team, no team-work technique or motivational trick will do any good. For that reason, people working in collaboration with others should understand and be knowledgeable of the influence and the effects of their own cognitive processes on behalf of the distributed cognitive processes as well as the ultimate success of the whole process of collaborative problem-solving and learning.

Keywords: collaborative problem-solving, learning, individual cognition, distributed cognition, metacognition, human capital, intellectual capital, social capital.
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Problem-solving and learning are the most essential human cognitive activities in modern work. Moreover, most often these cognitive activities are practiced in collaboration with others simply because the problems people get confronted with in work-related circumstances are complex and multi-faceted and require a wide variety of knowledge and competence in order to be solved. Another pervasive phenomenon we are experiencing at the moment is the exponential growth of new technological innovations. These innovations are most often cognitive products of groups engaged in joint problem-solving and learning activities. In industry, these processes are called research and development (R & D) activities.

Scientific studies on technological research and development activities have concentrated mostly on the social, cultural, or economical factors of these processes. During the 1970's and 1980's, different stages of R & D processes were on the focus of research. This led to the development of many so called "Follow these steps - your innovation will be a success story" -process models of R & D processes. This line of research was probably challenging and economically profitable, but it kept the focus of the innovation and problem-solving research at the organizational level. Many theories on organization, management, and leadership saw the light in the 1990's. However, the cognitive factors actually enabling the R & D processes have been left on the background. When the cognitive factors of problem-solving and learning processes have been studied, it has mostly been done from the point of view of the contemporary cognitive psychology or the information processing approach. Actually, the research carried out on human problem-solving and learning has been dominated by the views of cognitive scientists and information processing theorists since the 1950’s.
However, in recent years, there has been a growing awareness of the kaleidoscopic nature of the human cognitive processes taking place during problem-solving and learning activities. Moreover, it has been acknowledged that, in this information age, groups, rather than individuals alone perform cognitive activities. These cognitive processes performed in collaboration with others during work-related problem-solving and learning tasks are the main interests of this research.

The ultimate goal of this research is to formulate a novel approach to cognitive and collaborative problem-solving and learning processes. Eventhough, in this research, the information processing theory’s way of investigating and defining the human cognitive processes of problem-solving and learning are criticized of basing their arguments mostly on laboratory experiments in which people are confronted with rather simple, well-defined problems, their value is acknowledged. This approach, along with the cognitive science, has provided researchers with valuable information about the functionality of the human brain and memory systems. Moreover, the construct of the problem space formulated by the information processing theorists is seen as the basic construct according to which the whole cognitive and collaborative problem-solving process is investigated in this research. The constructs of the problem space, the initial and goal states of the problem, and the problem constraints adopted from the information processing approach and the concepts of collective action and instrumentalization introduced by the theory of efficient action are used as theoretical stepping stones of this research, but combined and amplified with the theories of human metacognition, distributed cognitions, as well as theories of producing human, intellectual, and social capital. The theoretical orientation applied in this research is presented in the following figure:
Figure 1. The theoretical orientation applied in this research.

This formulated theoretical framework is then applied, modified, and tested according to the findings of the empirical data gathered in real-life circumstances in which two R & D teams solve work-related R & D problems. In figure 1., the theoretical framework through which the researcher examines the phenomena of collaborative and cognitive problem-solving has been presented from the bottom up, as in the form of a tower or a ladder. There are two reasons for this. First, it shows the order in which the researcher became cognizant of theories and former research carried out in the area of human problem-solving and learning. Secondly, to illustrate how these different theoretical constructs in some degree, but by no means fully, complement each other, so that the removal of one "brick" might cause the breakdown of the whole "tower". Another researcher, in another time and place, might have chosen other theoretical constructs to investigate the very same phenomena.
There are two reasons for investigating collaborative problem-solving and learning in R & D contexts. First of all, the cognitive and collaborative problem-solving and learning processes embedded in technological product development are a critical component of modern Western industries. Secondly, the problems occurring within technological product development are most often ill-defined, complex problems that demand a collaboration of many experts in order to be solved.

The construct of the joint problem space forms a core of a novel approach of cognitive and collaborative problem-solving and learning processes formulated during the course of this research. Within this joint problem space, an individual with certain cognitive and metacognitive tools, as well as with certain human capital is engaged in a collaborative problem-solving and learning process with other people. This distributed cognitive process is enabled by the intervening nature of practical tools (both mental and instrumental). The cognitive-level outcome of this process is assumed to be a three-veined learning process in which the participants together produce new human capital of a single person, intellectual capital of a group, and social capital partly possessed by the individual and partly by the group. The elements of the joint problem space can be illustrated with the following figure:
All elements of the joint problem space and their overall nature are taken under a detailed investigation during the course of this research by asking the following four research questions:

1. What are the characteristics of an R & D problem and problem-solving situations of R & D processes?
2. What practical tools are used by problem solver/s in solving R & D problems?
3. What cognitive tools are used by problem solver/s in solving R & D problems?
4. What kind of learning takes place in a collaborative problem-solving process?

By asking and answering these questions, it is possible to capture the nature of the cognitive and collaborative problem-solving and learning processes embedded in technological product development (R & D), in all their glory. However, in order to investigate these real-life phenomena, all aspects of the emerging joint problem space must be studied.
simultaneously. In order to do that, the team meetings of two R & D teams are observed and videotaped and all members of both teams are interviewed twice. Also twelve engineers from the fields of industrial design, planning engineering, and teaching are interviewed using the theme interview method. All empirical data is transcribed and analyzed using qualitative research techniques. To be able to test the formulated theoretical framework and, at the same time, to be able to be truthful to the empirical data, the abductive research logic, in which the theoretical framework is engaged in close conversation with the empirical data, is followed.

Before proceeding any further in this research, one important notion must be made. The empirical data from which the conclusions of the different factors of the cognitive and collaborative problem-solving and learning processes are drawn consists of the words of those people engaged in the collaborative activities. However, we cannot be sure that those words can be understood as reflecting the real thoughts of the people expressing them? On the other hand, what other methods could we have to investigate thought processes in such real-life contexts? In spite of this rather practical methodological dichotomy, the fundamental ontological orientation of this research is the assumption that the a language is at least the nearest and perhaps the only access to higher-order cognitive processes a researcher can get at all.
2 INFORMATION PROCESSING THEORY AND PRAXIOLOGY AS THEORETICAL STEPPING STONES

2.1 A brief history of human problem-solving research

Human problem-solving has been in the interests of philosophers and researchers for decades. One could write a comprehensive description of the history of this subject matter, starting from the Greek philosophers’ thoughts. However, it is not necessary to go that far in the present research. Therefore, in this chapter I will go through the most essential states of human problem-solving research carried out during the last century. The studies can be divided into four categories.

The stimulus-response approach to human problem-solving

One of the first approaches to human problem-solving can be called the stimulus-response approach, first introduced by Thorndike (1898). In his studies on problem-solving with cats, Thorndike emphasized the acquisition of responses in a particular stimulus situation that permitted the goal to be attained. The stimulus-response view of problem-solving was extensively developed by Maltzman (1955). Maltzman’s approach emphasized problem-solving as the occurrence of a response that had an initially low probability of occurrence in a particular situation. Responses were assumed to be organized in a hierarchical manner, and the solution of a problem was achieved by selecting a response from the hierarchy until the one was chosen that would enable the solver to obtain the goal or advance toward it. (Voss 1989, 254.)

The Gestalt and neo-Gestalt psychology’s approaches to human problem-solving

The second, so called Gestalt psychology's approach (‘Gestalt' is the German word for 'form' or 'shape' and it also refers to 'image' and 'figure') emphasized problem-solving as a holistic process, understanding the solution process as a restructuring of the solvers organization of the problem. Such reconstruction was typically presumed to be accompanied by an insight experience. Köhler (1947), who was one of the founders of the Gestalt psychology, studied
animals and was the first researcher who introduced the term 'insight' when solving a problem. Köhler suggested that problem-solving involves mentally combining and recombining various elements of the problem until a structure that solves the problem is achieved (Ormrod 1999, 153). An interesting point he made was that the failure in solving a problem was biological in nature. Although this point was rejected later, and the Gestalt approach has received its share of criticism, the influence of the Gestalt and the neo-Gestalt writers has been extensive in the field of problem-solving research.

**Piaget’s approach to human problem-solving**

Although Piaget was mainly interested in children's cognitive development, he used problem-solving as a means to study the processes involved in the mental growth of a child. He argued that the problem-solving ability was related to the ontological development of particular mental structures. (Piaget 1954.) Even though Piaget has been later criticized by his neglect of contextual knowledge, his theoretical notions have been very influential particularly in developmental psychology. More recently, Piaget’s work has been reinterpreted in terms of other theoretical viewpoints, such as information processing. (Voss 1989, 254.)

**The descriptive approach to human problem-solving**

The fourth, so called descriptive approach, which can also be called mental stage analysis, involved identifying the mental stages through which problem-solving proceeded. Attempts to describe problem-solving as a step-wise process have actually been very popular when trying to describe the problem-solving process itself. There are many such stage analyses which have been modified through different methods, such as:

- interviewing people while or after problem-solving
- observing people while they are solving a problem
- using various introspective methods
- collecting "think-alouds" while people are solving a problem
Maybe the best-known stage analyses have been introduced by Wallas (1926), Polya (1957), and Dewey (1971). For example, Wallas (1926, 79-107) described problem-solving as a four-step process including:
1. Preparation: defining the problem and gathering information relevant to its solution.
2. Incubation: thinking about the problem at the subconscious level while engaging in other activities.
3. Illumination: having a sudden insight into the solution of the problem.
4. Verification: checking to be certain that the solution is correct.

Preparation consists of defining and studying the problem, incubation involves a relatively quiescent period in which the solver does not work on the problem, illumination consists of coming up with a possible solution, and verification involves the testing of the solution.

Polya (1957) described problem-solving as consisting of five different stages:
1. Understanding the problem
2. Making a plan for solving the problem
3. Carrying out the plan
4. Evaluation
5. Possible corrections

Also Dewey (1971) found five steps, but those differ from Polya's. Dewey's steps are:
1. An individual experiences a difficulty
2. The difficulty is defined
3. The generation of a possible solution
4. The solution is tested by reasoning
5. The solution is verified

Unfortunately, Wallas, Polya et al. derived their conceptualizations of problem-solving more from introspection and informal observation than from controlled experimentation, and they were somewhat vague about how each step could be accomplished. Therefore, descriptions like those mentioned have not produced much theoretical advancement, but
they have brought the importance of problem-solving into focus by pointing out that it is an integral facet of the thinking process (Lester 1985, 44; Voss 1989, 254; Mayer 1992, 17; Schoenfeld 1992.)

2.2 Human memory as a fundamental base to human problem-solving activity

During the late twentieth century, a substantial amount of problem-solving research was conducted within a general framework called information processing. The main focus of this theory approach has lied on human learning, problem-solving, and memory.

The research on human memory (cf. e.g. Atkinson & Shiffrin 1968; Ericsson & Kintsch 1995; Massaro & Cowan 1993) has helped theorists to describe the process in which information is either remembered or forgotten. The Atkinson-Shiffrin model of information processing defines how the information is dealt with in the human mind. See figure 3. below.

Figure 3. A model of human information processing (Atkinson & Shiffrin 1968)

The first component of the memory system is the sensory register. The sensory register receives large amounts of information through the senses and holds it for a very short time,
no more than a couple of seconds. If nothing is done with the information held in the sensory register, it is rapidly lost. On the other hand, the information that a person perceives and pays attention to is transferred to the second component of the memory system: the short-term memory. The short-term memory is a kind of storage system that can hold a limited amount of information for a few seconds. The thoughts we are conscious of having at any given moment are being held in the short-term memory. Another term for the short-term memory is working memory (Ericsson & Kintsch, 1995). The working memory is where the mind operates on information, organizes it for storage or dismissing, and connects it with other information. The long-term memory is the part of our memory system where we keep information for long periods of time. The long-term memory is thought to be a very large capacity (we do not live long enough to fill it up), a very long-term (even life-long) memory storage. The theorists divide the long-term memory into at least three parts: episodic memory, semantic memory, and procedural memory. The episodic memory is a memory of personal experiences, a mental "movie" of things we saw or heard. The semantic memory contains the facts and generalized information that we know: concepts, principles, or rules, and how to use them. Our problem-solving skills and learning strategies are also ought to be located in the semantic memory. The procedural memory refers to “knowing how” in contrast to “knowing that”. The abilities to drive and ride a bicycle are examples of skills that are retained in the procedural memory. (Slavin 1997, 185-193.)

The theory of human memory can be seen as a fundamental base to all human memorizing, learning, thinking, and problem-solving activity. Therefore, the capacities of the short-term and the long-term memories can be seen as cognitive constraints, which we cannot overcome. However, research on human memory alone cannot explain the human problem-solving activity.
2.3 Information processing approach to human problem-solving

The so called information processing theory provides us with a broader framework of human problem-solving. In the 1950s, computer scientists started programming computers to play chess and solve problems that involved the manipulation of symbols as well as numerical calculations (Baron 1994, 57). Although artificial intelligence (AI) research did not cover complex human problem-solving in ill-structured problem situations, important notions were made. These were e.g. that it is possible that the ways people solve problems are constrained by the limitations of the human short-term memory capability and by problems themselves.

The classic Newell and Simon (1972) theory of human problem-solving defines the cognitive system as a physical symbol system, also known as the information processing system. The fundamental difference between the earlier research made in the field of human problem-solving and Newell and Simon’s research is that human problem-solving behavior must be seen as inherent in the problem itself, rather than in the problem solver (Baron 1994, 58). Newell and Simon’s (1972) information processing theory provides us with three major theoretical constructs:

1. Information processing system
2. Task environment
3. Problem space

The information processing system is a human being with a problem (Newell & Simon 1972, 9, 19). The task environment refers to the problem statement and its context. The problem statement includes the description of the initial state of the problem. The goal state is also defined in the problem statement. The problem statement also includes constraints. The constraints are the limiting conditions of both the problem solver and the problem situation under which the problem must be solved. (Voss 1989, 255-256; Davidson, Deuser & Stenberg 1994.) Before being able to solve a problem, an individual must recognize that the problem exists (i.e. problem finding). In other words, a person needs to identify and define both the initial and the goal state of the problem-solving situation.
(Davidson et al. 1994). In other words, the first step in problem identification is to encode the critical elements of the problem situation (Newell & Simon 1972).

The problem solver does not work directly with the task environment. Rather, the solver forms a new representation based on his/her perception of the task environment and other knowledge (Baron 1994, 59). This new representation is called a *problem space*, and it refers to the individual's knowledge of what is relevant to the problem interpretation and solution. It also allows the solver to understand the problem and to think through its solution (Voss 1989, 256; Davidson et al. 1994). With Newell and Simon’s words: the problem space is the internal representation of the task environment used by the problem solver, and all problem-solving occurs in some problem space (Newell & Simon 1972, 56, 789). Therefore, the problem space represents a demarcation of the information that the solver has, that is of potential use in solving the problem.

The solver does not need to search through all of the areas of memory, but only through a highly restricted space. The steps necessary to take in the problem space in order to solve the problem are defined in terms of *states* and *operators*. The problem states are like *subgoals* on the way to the goal state. The operators consist of the actions that must be taken toward the solution in moving from one state to the next. Viewed in terms of states and operators, the solution involves starting from the initial state, going through a series of intervening states, and reaching the goal state, with each state-to-state transition occurring by the application of an operator. The problem solver must apply an operator and move on to another state. In applying an operator, the problem solver uses a *strategy* (i.e. a reasonably systematic method that at least has the potential of leading to a solution). (Voss 1989, 256-257.)

Trying to understand how complex and ill-structured or open-ended (opposite to well-structured) problems (like technological product development) are solved has led to the development of a concept of problem representation. When solving an ill-structured problem, the solver will usually interpret the problem in terms of his/her own perception of the major causes of factors contributing to the problem, including the constraints of the
problem. This personal interpretation constitutes the representation of the problem. (Voss 1989, 257.) The term 'problem representation' originally comes from Newell and Simon who define it as the problem solvers internal representation of the external environment (Newell & Simon 1972, 88). In order to develop this representation, the solver must "draw" on his/her memory and/or, possibly, on other sources of information. What the individual already knows about the problem is quite important. (Voss 1989, 257.)

The information processing theory's approach to human problem-solving can be illustrated with the following figure:

![Diagram of information processing approach to human problem-solving]

Figure 4. Information processing approach to human problem-solving.
2.4 Praxiology – the theory of efficient action

Another theoretical stepping stone for this research is the theory of efficient action - praxiology. Praxiology may not be as widely known as the information processing theory, but it has its own potential.

The term 'praxiology' or 'praxeology' (both names are used in the literature) literally means 'theory (logos) of action (praxis)'. The term 'praxiology' was initially introduced by a Polish philosopher Tadeusz Kotarbinski, whose book “Praxiology – An Introduction to the Science of Efficient Action” (1965) laid the foundation to the later discussion and research in the area of praxiology and is the main exposition of Kotarbinski’s praxiology. This is how Kotarbinski himself defines the term 'praxiology':

“Praxiology - the general theory of efficient action. Both the need for, and the possibility of, such a discipline are obvious. Recipes for good work possess varying degrees of generality. ‘Write so distinctly that at least you will be able to read your own notes without difficulty is a very detailed instruction; festina lente, on the contrary, has a very wide range of application. The praxiologist concerns himself with finding the broadest possible generalizations of a technical nature. His objective is the technique of good, efficient work as such, indications and warnings important for all work which is intended to achieve maximum effectiveness.’” (Kotarbinski 1965, 1, emphasis original.)

Praxiology is a general theory of efficient human action, the main task of which is to find broad generalizations of a work, which requires achieving maximum effectiveness. Praxiology reflected the culmination of Kotarbinski’s interest in practicality, whereas praxiology is the ABC of practicality (Gasparski 1993 71, 77). As Kotarbinski writes:
“…in my opinion the principal concern of praxiology consists in the formulation and justification of standards appropriate to efficiency. That principal concern, however, requires support in the form of practical experience, the result of the toil and struggle of innumerable agents. The theorist of efficient work will build his generalizations mainly on such practical experience…practical experience can be utilized in at least two ways: either by drawing general conclusions directly from facts observed, or by taking over and including in one’s own system generalizations made by others.” (Kotarbinski 1965, 2, emphasis original.)

“And what is practicality? It is clearly an equivocal term. Sometimes ‘practical’ means ‘resourceful’, able to find a way out of any situation; at other times, a practical man is one who is devoted to action as opposed to those who are devoted to theory; and still other context, practicality should be identified with efficiency in a broader understanding. And such is the understanding of practicality in the above…definition of energy.” (Kotarbinski 1961, 178-179, emphasis original.)

Therefore, 'practicality' is synonymous with 'efficiency' (in its broader meaning) (Garparski 1993, 16).

The main tasks of praxiology can be divided into three parts:

1. Analysis of notions concerning any intentional action.
2. Criticism toward the actual methods of acting from the point of view of their efficiency, effectiveness, purposefulness, practicality, and criticism based on the knowledge of forms of acting (i.e. on typology of action).
3. Normative or advisory part containing instructions concerning the realization of any action with greater technical competence. (Kotarbinski 1983, 22.)
Kotarbinski’s theory of efficient action twists around the following terms:

“External work, of whatever kind and by whomsoever done, always involves some agent, some free impulse, some material, some product, some tool of instrument, some way of acting, some goal, some result” (Kotarbinski 1965, 22).

I will next briefly explain what Kotarbinski means by acting, agent, free impulse, material, product, instrument, and result. More precise and broader definitions will be found in his book “Praxiology – An Introduction to the Sciences of Efficient Action” (1965).

I will start from the concepts of simple act, free impulse, and agent. Let Kotarbinski himself explain:

“ALL work, all activity, and in general all active behavior is fully reducible to simple acts. Any separate simple act, for instance a physical blow, may be of decisive importance for the achievement of a given aim. That is why the analysis of the concept of simple act is a gratifying task.” (Kotarbinski 1965, 14.)
And he continues:

“Let us now proceed to analysing the relation of agenthood – that is, the relation between the agent and the result of his action. We obtain that relation simply by applying the concept of causality. The agent of an event is he whose free impulse is a cause of that event. …Every impulse is directional and intentional; it is an impulse aimed at something; yet we, of course, are always agents not only of what we intended, but, in so many instances, of precisely what we did not intend.” (Kotarbinski 1965, 17-18.)

The second set of key elements of the theory of efficient action consists of result, product, material, and instrument.

In Kotarbinski’s theory, the term 'result' is not equal to the term 'goal'. Instead, by 'result' Kotarbinski means all effects of a cause consisting of a free impulse, and an effect is always an event. Therefore, every result is an event, and the classification of events into changes and states of things is transferred into results. He defines four kinds of results: constructive and destructive results, which are kinetic in nature, and preservative and preventive results, which are static in nature. In other words, a result is always an event, and an event is always either a change in something or a state of something. Next, by the product of an agent (with respect to his meaning of free impulse), Kotarabinski means any object (or thing), the state of, or change in which was the result of that agent with respect to that free impulse. He also adds that this definition of product covers both intentional and unintentional products. From the concept of 'product' Kotarbinski continues to the concept of 'material'. By 'material' he simply means the something of which the product is made. By 'instruments' he means objects which are either themselves sources of power, and which, aided by our work, exert direct or indirect pressure upon a given thing, or objects which serve to transmit such a pressure, or our own free impulse, from an object pressed to some other object; in both cases, they are objects made for the particular purpose, of an external substance. (Kotarbinski 1965, 23-33.)
What has Kotarbinski’s theory of efficient action to do with problem-solving in technological product development? Kotarbinski does not even mention problem-solving in his writings about the theory of efficient action. There is something about progress made in technical improvements in his work, but he does not mention technological design as such. Why is the theory of efficient action, then, interesting in the context of this research? I actually find two answers to that question. First, there are obvious similarities between the information processing approach and the theory of efficient action, but there is also a significant difference between these two theories, a fact that makes Kotarbinski’s ideas worthwhile and important for this research.

2.4.1 Similarities between the theory of efficient action and the information processing approach

Jakob Meloe (1983), a Norwegian philosopher uses the term 'praxeology' in his writings and his use of the term diverges slightly from Kotarbinski’s. 'Praxeology', in his sense, is a conceptual analysis and reflective discussion about the way human activities are interwoven with their agents and with the things at which they are directed within our everyday world. Meloe talks about practical operations (instead of actions like Kotarbinski) and formulates the basic form of practical operation as follows: \( x \) operates on \( y \), and “\( x \)” marks the place of the agent, or the subject of the operation, “\( y \)” the object of the operation, or its target, and the verb “operate”, or “operate on”, is a stand-in for some suitable verb of action. Meloe (1983) gives the following example: When a man (\( x \)) chops firewood, the operation is chopping firewood, while the object of the operation is the log (\( y \)) he is busy splitting. (9, 15.) If we now make a comparison between Meloe and Kotarbinski, the firewood chopping example, according to Kotarbinski, would go as follow: When a man chops firewood, the agent is a man, the act is chopping, the product is a piece of firewood, the material is wood, the result is a pile of firewood, and the instrument is an axe.

I see Meloe’s formulation of praxeology as a simplification of Kotarbinski’s theory of efficient action. I am uncertain whether Kotarbinski was familiar with the work of information processing theorists at the time he formulated his own theory, but even though
being quite different in vocabulary, praxiology has a particular resemblance with Newell and Simon's theory of information processing. Next, I will compare both Meloe’s formulation of praxeology and Kotarbinski’s ideas of efficient action with Newell and Simon’s theory of information processing. I have to note here that Meloe’s and Kotarbinski’s key terms are not identical to one and other, but they are closely related. Newell and Simon’s information processing theory, on the other hand, does not identify the key terms in such detail like both Kotarbinski and Meloe do; therefore, the terms of the latter are included in the terms of the former. Also, it is important to notice at this point that the information processing theory is the theory of problem-solving per se, whereas praxiology is a theory of efficient action of whatever kind.

<table>
<thead>
<tr>
<th>Kotarbinski’s key terms</th>
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<td>AGENT</td>
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Table 1. A comparison between Meloe’s formulation of praxeology, Kotarbinski’s ideas of efficient action, and Newell and Simon’s theory of information processing.
Now, it is possible to add Kotarbinski’s and Meloe’s elements into the information processing approach. The figure will look like follows:

Figure 5. Adding praxiological elements into the information processing approach of human problem-solving.

2.4.2 Differences between the theory of efficient action and the information processing approach

In Kotarbinski’s theory of efficient action, he takes the notion of collective action under a detailed consideration. By *collective action* he means action which is performed by a number of agents. This is what Kotarbinski calls *co-operation*. Kotarbinski divides collective action into two parts: positive co-operation and negative co-operation. Co-operation is positive if, and only if, the co-operation of many agents with respect to their definite actions and with respect to their definite goals occurs so that each of them helps some other agents belonging to the same group, or is helped by some other agent. On the
other hand, co-operation is negative if the agents hinder each other from reaching the goal. (Kotarbinski 1965, 61-63). Kotarbinski also writes about the effects of co-operation that must be considered if one wants to examine efficient work carried out in groups. He says:

“It is obvious that a group admits of an incomparably greater variety of types of abilities than does even a single individual, even the most gifted” (Kotarbinski 1965, 65).

And he continues:

“Even in the case of a compound action performed by a single agent,…a plan is necessary, but it is only in a collective action that the requirement of co-ordination, the plan becoming necessary for the co-ordination of behavior of the members of the group: every member must know what other members intend to do, and hence communication is an indispensable element in human collective action” (Kotarbinski 1965, 65).

Kotarbinski goes even further when he writes about effective action. He actually argues that the notion of effective action forms the skeleton of praxiology (Kotarbinski 1965, 95). He argues that the economization of action, the instrumentalization of action, and the preparatories of action are the key elements in producing effective action. By the *economization of action* Kotarbinski means that when actions are economic, they are either more cost saving or more productive. The action preparatories are actions that make the action possible or easier, or which enable or facilitate its better execution. A specific action preparatory he mentions is planning. The plan is a form of preparation, which is characterized by several features:
• A plan should be purposive i.e. it should serve the purpose for which is has been made.
• A plan must be as easy to use as possible.
• A plan must be uniform and continuous.
• A plan should be flexible.
• A plan should be future-oriented.

By the instrumentalization of action Kotarbinski simply means that with the aid of certain instruments, one works incomparably more economically than without them. (Kotarbinski 1965 95, 117-121, 126.)

It has to be remembered that the philosophy of Tadeusz Kotarbinski is some forty years old. So the vocabulary he uses is somewhat old, and the meaning of work has gone through a dramatic change since he wrote down his ideas of efficient work. Still, I see his ideas as having been very much ahead of his time, and much of what he has said about efficient action still applies today. As Gasparski (1986) has argued, praxiology in its present form is clearly akin to the French operation analysis, to American pragmatism, and to the most recent direction in cybernetics. It also interfaces with the theories of decision-making, information, and game theory. For this research, the most important notions of praxiology are the ideas of efficiency, co-operation, and instrumentalization.

Today the most complex, work-related problem-solving is carried out in groups (or teams). The team consists of highly qualified individuals who solve highly complex problems. A single person cannot solve these problems because they demand a wide variety of knowledge, expertise, and competence, which can only be reached by a group of people. The demand for fast and efficient problem-solving is also the dominant character of today’s work of whatever kind, and this is especially true in technological product development. Very often problem-solving is also aided by tools of some kind. Those tools may not be hammers anymore, but computer programs, for instance. Therefore, Kotarbinski’s notions of efficiency, collective action, co-operation, and instrumentalization are very important
elements, which must be included in when studying modern technological product development and problem-solving.
3 TOWARD AN EMERGING THEORY OF COGNITIVE AND COLLABORATIVE PROBLEM-SOLVING AND LEARNING PROCESS

The information-processing approach and the research on human memory are essential parts for the understanding of human problem-solving, but when it comes to explaining problem-solving in technological research and development (later R & D) processes, they alone cannot define the whole system of the complex human problem-solving process. I have found at least three constraints that have to be overcome before it is possible to explain the cognitive features of problem-solving in R & D processes: (1) the nature of problems, (2) the nature of cognitive processes, and (3) the nature of cognition in R & D problem-solving processes.

3.1 Nature of problems in R & D processes

“Problem solving is a bit like beauty, morality, and good art. We are in favor of it, we know it when we see it, but we cannot define it” (Hunt 1994, 215).

Within the next two chapters I will take a closer look at the definitions of problem and problem-solving in technological product development, by asking if problems and problem-solving in R & D processes have some peculiar characteristics compared to other kinds of problems and problem-solving situations.
3.1.1 Problem - defining the concept

The definition of the term 'problem' is not so straightforward as it might first seem. In fact, there are many definitions depending on the viewpoint.

Problem defined in terms of problematic situation:
Baron (1994, 49) defines a problem as a situation which exists when an individual in a particular situation has a goal but is unable to obtain this goal immediately. A problem is also viewed as a situation when an individual cannot use his/her previous knowledge or reactions to solve a particular situation. In addition, it is frequently assumed that there is some type of an obstacle or a barrier that prevents the solver from reaching the goal. (cf. Schoenfeld 1985, 35; Greene 1975, 16; Mayer 1977.) Obstacles can be defined to be such characteristics of both the problem solver and the problem situation that make it difficult for the solver to transform the initial state into the goal state (Davidson et al. 1994, 207).

Also Newell and Simon define the term 'problem' as a situation in which a person is confronted with a problem when he/she wants something and does not know immediately what series of actions to perform to get it. The desired object may be very tangible or very abstract, it may be specific or quite general, it may be a physical object, or a set of symbols. The actions involved in obtaining desired objects include physical actions, perceptual activities, and mental activities. Newell and Simon also give the following rather simple definition of the implications of a problem: To have a problem implies that certain information is given to the problem solver: information about what is desired, under what conditions, by means of what tools and operations, starting with what initial information, and with access to what kind of resources. (Newell & Simon 1972, 72-73).

Problem as having specific characteristics:
On the other hand, the term 'problem' can be defined as having some common features. As Mayer (1992, 5) argues, most psychologists agree that a problem has certain characteristics: Givens – a problem is born in a certain state with certain conditions, objects, and pieces of information.
Goals – the desired or terminal state of the problem is the goal state.
Obstacles – the problem solver has at his/her disposal certain ways to change the given state or the goal state of the problem. However, the problem solve does not know the correct answer beforehand; i.e. the correct sequence of actions that will eventually solve the problem is not immediately obvious.

Problem as well- or ill-defined:
A third way to define the term 'problem' is to make a distinction between different kinds of problems or, in other words, how well they are defined. The problem is well-defined when it lends itself to a relatively algorithmic solution; its parameters are finite, the necessary subgoals are evident, and its resolution is easily testable (Petraglia 1998, 39). In a well-defined problem (well-structured problem), the solver is provided with all the information needed in order to solve the problem. The solver is provided with four different sorts of information:
1. information about the initial state of the problem
2. information about the goal state
3. information about legal operators
4. information about operator restrictions which constrain the application of operators.
(Kahney 1986, 20.)

The classic examples of well-defined problems include those involving the chess-play and mathematics (Collins, Brown, & Newman 1989).

At the other end of the spectrum, an ill-defined problem (ill-structured problem) provides little or no information on the initial state, the goal state, the operators, or some combination of these. When solving an ill-defined problem, the solver has to define the problem to him/herself. (Kahney 1986, 21; Pertaglia 1998, 39.) Barrows and Felтовich (1987), who have studied decision-making in the medical diagnosis process, have described ill-defined problems having the following characteristics: defining the problem requires more information that is initially available – the nature of the problem unfolds over time. Also, when the problem is ill-defined, there is no single right way to get the required information
and, as new information is obtained, the problem changes. They also argue that decisions must be made in the absence of definitive knowledge, and there may never be certainty about having made the right decision.

### 3.1.2 Problem and problem-solving in R & D processes

The information processing approach and cognitive science have successfully defined how the human brain and memory works when solving well-structured problems like puzzle-games, but when it comes to more ill-structured and open-ended cognitive problems, the information processing theory’s or cognitive science’s ability to explain the relevant cognitive processes approaches zero (Goel 1995, 6). Many researchers have argued that the entrée into the real world that the ill-structured vs. well-structured distinction provides has been ignored by the information processing movement of problem-solving. The computational metaphor can largely be blamed for this. (cf. e.g. Hutchins 1995b, 363; Neisser 1967, 9; Petraglia 1998, 39-40.) For example Coulter (1983, 5) states that: "There are many for whom theoretical questions about 'cognition' are less relevant, interesting or important than endogenous programming and hardware problems generated by attempts to construct simulations of complex tasks of whatever kind."

Technological product development is a particular kind of problem-solving process in which the ill-structured nature of problems is more a rule than an exception. Therefore, it is not possible to use definitions for the term 'problem' or 'problem-solving' given solely by information processing researchers. Furthermore, problems in R & D processes have their own characteristics. In literature, technological product development is often considered equal to engineering design or design-making. The following glance at the literature provides me with a selection of definitions for the term 'design-making'.

Asimov (1962) argues that engineering design is a purposeful activity directed toward the goal of fulfilling human needs, particularly those, which can be met by the technological factors of our culture.
Eastman (1981, 13), on the other hand, has studied designers opinions about the characteristics of design-making. He came to the conclusion that design-making is a process of the production of an artifact, and the main characteristics of that production process are the desired performance and certainty of the outcome. Therefore, design-making is not a random act, but a considered act the outcome of which will be viable.

Goel and Pirolli (1989) as well as Goel (1995) also claim that all problem-solving is not similar to design-making. However, they say that design-making is so multiple a process that it is impossible to define 'design-making' with a single sentence. They define 'design-making' through a task environment in which the design-making takes place. The following are features of the design task environment that make design-making a particular kind of problem-solving:

1. Availability of information: Each of the three components of design problems lack information. The starting state is incompletely specified, the goal state is specified even less, and the transformation function from the starting to the goal state is completely unspecified.

2. Nature of constraints: The constraints on design task environments are generally of two types: a) nomological and b) social/political/legal/economic/cultural, and the like. Nomological constraints are dictated by natural law, and are hard as well as unnegotiable. Still, at the same time, they vastly underdetermine design solutions. Social/political/legal/economic/cultural constraints may be regulative, but they are not constitutive or definitional. They are negotiable.

3. Size and complexity of problems: Design problems are generally large and complex, and require days or months to complete.

4. Component parts: Any problem of any size and complexity has parts. Practice and experience of the designer dictate the decomposition of the design problem.

5. Interconnectivity of parts: The components of design problems are not logically interconnected. However, there are many contingent interconnections between them.

6. Right and wrong answers: There are no right or wrong answers to design problems, only better and worse ones.
7. Input and output: The input of design problems consists of information about the people who will use the artifact, the goals they want to satisfy, and the design behavior the artifact (or process) needs to facilitate in order to satisfy those goals. The output, on the other hand, consists of the artifact specification. Functional information mediates between the input and the output information.

8. Feedback loop: There is no genuine feedback from the world during the problem-solving session. It has to be simulated by the designer. Real-world feedback comes after the design is completed and the artifact is constructed and allowed to function in its intended environment. At this point, the feedback cannot influence the current project, but only the next similar project.

9. Costs of errors: The cost of being wrong can be very high in design-making.

10. Independent functioning of artifact: The artifact is required to function independently of the designer.

11. Distinction between specification and delivery: The specification of the artifact is distinct from the construction and delivery of the artifact.


Using definitions presented in the previous chapters and the chapter at hand, I have formulated the following definitions for the concepts of 'problem' and 'problem-solving' in technological product development.
Problems in all R & D processes possess the following characteristics:

Problem-specific characteristics:
- Product development problems are large and complex by nature (Goel 1995; Goel & Pirolli 1989), therefore they are ill-defined problems in which the initial, goal, and transformation states are incompletely specified (Barrows & Feltovich 1987; Kahney 1986; Goel & Pirolli 1992; Pertaglia 1998).
- Product development problems need to be decomposed (Goel & Pirolli 1989; Goel 1995).
- There are no right or wrong answers to product development problems, only worse or better depending on specific criteria (Barrows & Feltovich 1987; Goel & Pirolli 1989; Goel 1995).

Problem-solving characteristics:
- Product development is not a random act, designers know what they are doing (Asimov 1962; Kotarbinski 1965; Eastman 1981).
- Problem-solving is limited by constraints (Davidson et al. 1994; Goel 1995; Greene 1979; Kahney 1986; Mayer 1992; Goel & Pirolli 1989; Schoenfeld 1985).
- The cost of being wrong can be very high. -> Product development is efficient action by nature (Goel & Pirolli 1989; Goel 1995; Kotarbinski 1965).
- There is no genuine feedback from the world during the problem-solving. -> Real-world feedback comes after the problem-solving (Goel & Pirolli 1989; Goel 1995).
- Product development is usually carried out by a group of people, a customer might be involved.
- The artifact is required to function independently (Goel & Pirolli 1989; Goel 1995).
3.2 Nature of cognitive processes in R & D processes

One of the facts that seem to emerge from the information processing research within problem-solving is that the question of how people solve problems cannot be answered by a simple rule or principle. In other words, there are no general methods, such as a stimulus-response chain in solving problems. Instead, people solve problems in many different ways, depending on the nature of the problem, the problem solver’s experience in the subject matter, the strategies used, and the metacognitive skills and knowledge applied by the problem solver.

The study of cognitive problem-solving strategies (often called problem-solving methods or processes) has a long and honorable history. As Pressley et al. (1985) define: “Strategies…are composition of cognitive operations over and above the processes that are a natural consequence of carrying out task, ranging from one such operation to a sequence of interdependent operations. Strategies achieve cognitive purposes (e.g. memorizing) and are potentially conscious and controllable activities.” (4, parenthesis original.) At least the following problem-solving strategies have been found: trial and error, hill-climbing, means-ends analysis, and heuristics (see e.g. Baron 1994, 60-74; Newell & Simon 1972).

The information processing approach to human problem-solving concentrates heavily on the so called straightforward cognitive strategies that enable a person to make progress and to achieve the goal of whatever cognitive enterprise he/she is engaged in. Also, attention is paid to the importance of those metacognitive knowledge and skills which enable a person to monitor and improve his/her progress in a cognitive enterprise, i.e. to evaluate understanding and apply knowledge to new situations. For example Newell (1990) talks about 'control knowledge' referring to the rational activity of deciding which operator a problem solver should apply in the course of a problem-solving activity. Therefore, metacognition is vital to cognitive effectiveness. (Flavell 1985, 106; Gourgey 1998, 82.)

As Carrell et al. (1998, 97), who studied metacognition in learning to read a second language, concluded: what matters is not so much what strategies a person uses in a
cognitive enterprise but, rather, his/her knowing when to use these strategies and how to coordinate between strategies. In other words, it is the metacognition about strategies, rather than the strategies themselves, that appears to be important.

3.2.1  Cognition about cognition – metacognition

Defining the term 'metacognition' is not an easy task. It is especially difficult because metacognition is, by its very nature, a “fuzzy concept” (Flavell 1981, 37). And it is made even "fuzzier" by the ballooning corpus of research of varying disciplines and for varying purposes (Hacker 1998, 2). To clarify and to move some "fuzziness" away from this faddish concept, it is necessary to distinguish some specific components of metacognition (e.g. metamemory, metacognitive knowledge, metacognitive experience, and metacognitive skills) from the specific components of pure cognitive performance. Therefore, in order to define this concept, the researcher conducted an in-depth review, synthesis, and interpretation of the writings and researches of John Flavell, Ann Brown, Scott Paris and a few others.

Two primary problems in defining the term 'metacognition' are: First, it is often difficult to distinguish between what is meta and what is cognitive. And second, in modern psychological literature, the term 'metacognition' has been used to refer to two distinct areas of research: knowledge about cognition and regulation of cognition. (Brown 1987, 66-67; Schraw & Moshman 1995, 352.)

As an attempt to overcome the first difficulty, it is important to differentiate metacognitive thinking from other kinds of thinking. The most common definitions of the concept of 'metacognition' seem to be the following: "Metacognition is the notion of thinking about one’s own thoughts." (Hacker 1998, 3). It is called metacognition because its core meaning is ”cognition about cognition” (Flavell 1985, 104). In other words, metacognition is a form of human thinking, and therefore it is necessary to clarify the source of metacognitive thoughts. John Flavell was the first to introduce the term 'metamemory' into the literature after his study on metamemorial processes in children (Flavell, Friedrichs, & Hoyt 1970).
He argues that metacognitive thoughts do not spring from a person’s immediate external reality; rather, their source is tied to the person’s own internal mental representations of that reality (Hacker 1998, 3). Metamemory involves intelligent structuring and storage, intelligent search and retrieval, and intelligent monitoring. This suggests that metacognitive thoughts are deliberate, planful, intentional, goal-directed, and future-oriented mental behaviors that can be used to accomplish cognitive tasks (Hacker 1998, 3; Weinert 1987, 8). On the other hand, a good deal of mental activity is unconscious in the strict sense of being inaccessible to phenomenal awareness under any circumstances (Kihlstrom 1992, 83). With this obvious problem at hand, it seems reasonable to adopt a convention that many researchers have (e.g. Carr, Alexander & Folds-Bennett 1994; Davidson, Deuser & Stenberg 1994; Paris & Winograd 1990), and reserve the term 'meta', as in metacognition or metamemory, for active monitoring, conscious control, or executive regulation of mental processes. As conscious and deliberate, metacognitive thoughts are not only potentially controllable by the individual experiencing them, but can also be demonstrated, communicated, and discussed. They are, therefore, accessible to the researcher (Hacker 1998, 8; Jacobs & Paris 1987, 258).

As an attempt to overcome the second difficulty, I shall introduce different researchers and their contributions to the areas of knowledge about cognition and the regulation of cognition.

### 3.2.2 Knowledge about cognition - metacognitive knowledge

As John Flavell argues: “Metacognitive knowledge is that segment of your (a child’s, an adult’s) stored world knowledge that has to do with people as cognitive creatures and with their diverse cognitive tasks, goals, actions, and experiences” (Flavel 1992, 4, emphasis original). He defines 'metacognitive knowledge' as “Knowledge or beliefs about what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises” (Flavell 1992, 4). The major categories of these factors or variables
are *person, task, and strategy*. The person category encompasses everything that a person believes about the nature of him/herself and other people as cognitive processors. The task category concerns the information available to a person during a cognitive enterprise; therefore, the metacognitive knowledge in the task category is an understanding of how the cognitive enterprise should best be managed and how successfully a person is likely to achieve his/her goal. It also refers to a person’s knowledge about the task demands or goals. The strategy category includes a great deal of knowledge that can be acquired concerning what strategies are likely to be effective in achieving what subgoals and goals and in what sorts of cognitive undertakings. (Flavell 1992, 4-5).

Flavell (1979) also expanded the concept of 'metacognition' to include the individual’s sensitivity to the need to use metacognitive knowledge. He argues that metacognitive knowledge can lead to a wide variety of *metacognitive experiences*, which are cognitive or affective experiences that pertain to a cognitive enterprise (Flavell 1985, 116). Metacognitive experiences can be brief or lengthy in duration and simple or complex in content. These experiences can also occur at any time before, after, or during a cognitive enterprise. A person is having a metacognitive experience whenever he/she has the feeling that he/she is far from the cognitive goal, or just about to reach the cognitive goal, or has the sense that the material is getting easier or more difficult than it was a moment ago (Flavell 1987, 24). Flavell argues:

“…metacognitive experiences are especially likely to occur in situations that stimulate a lot of careful, highly conscious thinking…where every major step you take requires planning beforehand and evaluation afterwards; where decisions and actions are at once weighty and risky” (1992, 6).
Metacognitive knowledge and metacognitive experiences interact with one another as they influence human cognitive activities (Flavell 1985, 116).

Along with John Flavell, the developmental psychologist Ann Brown and her colleagues have had a great impact in the research on human metacognition. Brown (1987, 68) argues that knowledge about cognition (i.e. metacognitive knowledge) refers to the stable, often storable, fallible, and late-developing information that humans have about their own cognitive processes. By storable Brown means that a person can reflect on the cognitive processes involved and discuss them with others. By fallible she means that a person can perfectly “know” certain facts about cognition that are not true. And finally, the knowledge about cognition is usually assumed to be late developing, which means that it is required that a person steps back and considers his/her own cognitive processes as objects of thought and reflection.

Whereas Flavell uses a person, a task, and strategy taxonomy to define 'metacognitive knowledge', others have categorized metacognitive knowledge based on a person’s awareness of his/her metacognitive knowledge: declarative, procedural, and conditional knowledge. Declarative knowledge is propositional knowledge which refers to “knowing what” (Brown 1987, 106; Jacobs & Paris 1987, 259; Schraw & Moshman 1995, 352; Winograd & Hare 1988, 134). For example, the research on metamemory indicates that adults have more knowledge than children do about the cognitive processes associated with memory (Baker 1989). Procedural knowledge, on the other hand, refers to “knowing how” to perform various actions (Brown 1987, 106; Jacobs & Paris 1987, 259; Schraw & Moshman 1995, 353; Winograd & Hare 1988, 134). Individuals with a high degree of procedural knowledge use skills more automatically (Stanovich 1990) are more likely to sequence cognitive strategies effectively (Pressley, Borkowski & Schneider 1987), and use qualitatively different strategies to solve problems (Glaser & Chi 1988). Conditional knowledge, in turn, refers to “knowing why and when” to apply various cognitive actions. It includes the person’s understanding on the value or rationale for acquiring and using a strategy, and when to use it. (Carrell, Gajdusek & Wise 1998; Jacobs & Paris 1987, 259.) The relationship between Flavell’s metacognitive knowledge taxonomy and categorization
of declarative, procedural, and conditional knowledge can be illustrated with the following figure.

![Figure 6](image_url)

Figure 6. Relationships between declarative, procedural, and conditional knowledge, and person, task, and strategy taxonomy.

### 3.2.3 Planning, monitoring, and revision of cognition - metacognitive skills

Ann Brown was the first researcher who introduced the concept 'metacognitive skills' into the literature. According to Brown, metacognitive skills entail the operation of specific mental processes by which individuals organize and monitor their own thinking (Kluwe 1987, 32). Brown (1978, 81-82) assigns metacognitive skills as a component of an information processing system that is designed as an executive; the central processor, or the monitoring system. She argues that being capable of performing intelligent evaluation of one's own operations is an essential and critical characteristic of an efficient problem solver. Brown and others have come up with the following metacognitive skills or abilities which are essential for every efficient problem solver: planning (e.g. predicting outcomes and scheduling strategies), monitoring (e.g. monitoring, testing, revising, and re-scheduling one’s strategies), and checking (e.g. evaluating the outcome of any strategy action against the criteria of efficiency and effectiveness, and monitoring). (Brown 1987, 68; Stenberg 1981, 1986; Jacobs & Paris 1987, 259.) Brown also argues that these metacognitive skills
are relatively unstable, not necessary statable, and relatively age-independent. (Brown 1987, 68.)

Brown’s metacognitive skills can be seen as correspondent with Flavell’s metacognitive strategies. Metacognitive skills make the usage of strategies possible. Brown (1978, 157) even claims that metacognitive skills are the basic characteristics of efficient problem-solving.

Also Stenberg (1981, 1986) outlined in his studies on human intelligence that metacognitive skills are essential to intelligent functioning. He argues that metacognitive skills are internal, “executive”, processes, which supervise and control cognitive processes. These skills enable a person to plan, monitor, and evaluate performance throughout the execution of a task.

Jacobs and Paris (1987) have studied metacognition in reading. They use the term 'self-regulated thinking' (instead of the terms 'metacognitive regulation' or 'skills') referring to the three different types of executive processes during a cognitive enterprise: planning, evaluation, and regulation. (259.)

Also Kluwe (1987) uses in his writings the term 'executive processes' instead of 'metacognitive regulation' or 'skills', but his executive processes involve both monitoring and regulating thought processes, and, therefore, correspond with Flavell’s metacognitive strategies and Brown’s metacognitive skills. Kluwe makes a distinction between executive monitoring and executive regulation processes.

Executive *monitoring* processes are those that “directed at controlling or monitoring the own ongoing cognitive activities generate information about the activity and about the present cognitive state” (Kluwe 1987, 36). The four executive activities that serve monitoring purposes are (1) *Classification*. The classification of one's own cognitive activity provides information about the status, or mode, of cognitive activity, and helps to identify the task which one is currently working on. (2) *Checking*. The checking steps taken during
the process of problem-solving provide information about the states of the cognitive system and cognitive activity. While classification provides information about what is done in order to find the solution to a problem, checking is directed at the how of one’s own cognitive activity, which means goals, their organization, progress, success, and the results. (3) Evaluation. The evaluation of one’s own cognitive states and activities provides information about the quality of those states and activities. It goes beyond checking because, in order to judge the course and the state of one's own thinking, some criteria are applied. However, as Kluwe argues, a little is known about the criteria a person uses to evaluate his/her own cognitive activity. (4) Prediction. The prediction of cognitive states and cognitive activities provides information about: (a) possible alternative options for the problem-solving, (b) the possible sequence of solution steps, and, (c) the possible outcomes. Prediction is an important component in problem-solving processes because it is assumed to be a function of the problem-solving experience in different domains of reality. Prediction is especially necessary in complex problem situations where the effects of one's own actions may expand and result in uncertain side effects. In the same way, prediction is needed in particularly important or risky situations in order to avoid “costs”. (Kluwe 1987, 36-40.)

Executive regulation processes, on the other hand, refer to decisions about the organization, effort, amount, course, and direction of one’s own cognitive activity (Kluwe 1987, 41). Executive regulation processes involve one’s own decisions that help the person (a) to allocate his/her resources to the task in hand, (b) to determine the order of steps to be taken in order to complete the task, and (c) to set the intensity, or (d) the speed at which one should work (Hacker 1998, 9).

Kluwe helped to make an even finer distinction between what is and what is not metacognition. He also helped to emphasize the importance of metacognitive research as a way to gain greater understanding of humans, not only as thinking organisms but as self-regulatory organisms who are capable of assessing themselves as well as others and directing their behavior toward specific goals. (Hacker 1998, 10.)
Kluwe (1982) writes:

“It is important that human beings understand themselves as agents of their own thinking. Our thinking is not just happening, like a reflex; it is caused by the thinking person, it can be monitored and regulated deliberately, i.e., it is under the control of the thinking person.” (222.)

The different components of metacognition and their relationships can be illustrated with the following figure.

Figure 7. Components of metacognition

### 3.2.4 Metacognitive knowledge and skills of a group

There is a growing awareness that metacognitive processes are involved in group levels of problem-solving, as well as in individual levels. If metacognition is what an individual knows about the way he/she processes information, metacognition in a group must be what the group members know about the way the group processes information (e.g. “it is best putting heads together”) (Hinsz et al. 1997, 58). Hinsz et al. speculate about the metacognition in groups in their review of a research of groups as information processors.
In this review, they emphasize the importance of group mental models (i.e. mental models that the group members have of the way the group performs tasks), transactive memory, task performance metacognition (the knowledge the group members have about performing cognitive tasks as a group), and group interaction metacognition (the knowledge the group members have about the way groups interact while processing information) while studying collective problem-solving. (1997,58.)

Also Smith (1994) has studied collaborative groups as information processing systems. He argues that two metacognitive issues are relevant on the collaborative level of information processing; collective awareness and collective control. He states that by developing thick, overlapping areas of shared knowledge groups may be able to piece together a form of collective, but distributed awareness that is coherent enough to achieve this goal. Also control must be distributed over a group, otherwise information will not flow across the boundaries, and the group and its work will be brittle.

Wegner (1987) argues that other people can be locations of external memory storage for an individual. By this, he means that, within a group of people, an individual has access to information in someone else's memory by virtue of knowing that the other person is a location for an item with a certain label. This interdependence produces a knowledge-holding system, which is larger and more complex than either of the individuals' own memory systems. He calls this the transactive memory system of a group, which is a set of individual memory systems in combination with the communication that takes place between individuals (Wegner, Guiliano, & Hertel 1985). "Transactive memory is therefore not traceable to any of the individual alone, nor can it be found somewhere "between" individuals. Rather, it is a property of a group." (Wegner 1987, 191, quotation marks original). Wegner also argues that a transactive memory system is born when individuals learn something about each other's domains of expertise. Wegner's notions of the transactive memory of a group come close to its individual-level counterpart, the construct of metacognitive knowledge, or metamemory. If the term 'metamemory' (i.e. memory about memory) at the individual level refers to those beliefs that people have about their own
memory facilities (Flavell & Wellman, 1977), the term ‘transactive’ memory refers to beliefs a group has about its memory facilities.

On the other hand, Larson and Christensen (1993) talk about meta-knowledge to refer to the total pool of information that exists within a certain group. They argue that meta-knowledge appears within a group, and it is often increased to the extent that members are aware of the formal roles, areas of expertise, and information-gathering activities of other group members (16.)

In cognitive psychology and cognitive science, the notion of mental models has been used to explain how people organize knowledge into structured, meaningful patterns which are stored in the memory and used for interacting and coping with the world (Johnson-Laird 1983; Rouse & Morris 1986). The notion of ‘schema’ becomes close to the concept of ‘mental model’. The concept of ‘mental model’ also becomes close to the concept of ‘metacognition’. As several theorists have argued mental models allow people to predict and explain behavior, to draw inferences and make predictions, to understand phenomena, to decide what actions to take, to control cognitive execution, and to experience events vicariously (cf. e.g. Johnson-Laird 1983). On the other hand, the concept of ‘shared mental models’ has been used to explain the performance of teams in several circumstances. In his study on airplane cockpit crews’ work, Orasanu (1990) found that, in order to work efficiently, members of a cockpit crew must develop a shared understanding of the situation during emergencies, including the definition of the problem, plans and strategies for solving the problem, the interpretation of cues and information, as well as roles and responsibilities of the participants. (in Cannon-Bowers, Salas, and Converse 1993.) Banks and Millward (2000) studied team reasoning and found that the cognitive processes used during the reasoning task (a computer-based reasoning task) were distributed among the team creating shared mental models of the particular team. Also Rouse, Cannon-Bowers, and Salas (1992) have studied the creation of shared mental models within teams, and they propose that the overlap of different individuals' mental models leads to greater shared expectations and explanations within a team, which in turn leads to improved coordination, communication, and other team behaviors which lead to superior team performance. They also argue that
less planning time is required by teams with shared mental models because the team members are able to predict what others expect of them so it is not necessary to verbalize it.

Based on the examples of task performance metacognition, group interaction metacognition, collective awareness and control, transactive memory, meta-knowledge, as well as the shared mental model, it is possible to argue that a team, in order to function effectively:

- should be aware of the total pool of information and knowledge which exists in the group (cf. the metacognitive knowledge of an individual)
- should be aware of formal roles and responsibilities of each team member (cf. the metacognitive knowledge of an individual)
- should be able to define problems, plan strategies, and predict the outcomes of a given task (cf. the metacognitive skills of an individual).

However, it must be noted at this point, that the theories of transactive memory, meta-knowledge, and shared mental models explain team performance through the mental processes of individuals. Furthermore, and despite the different names several researchers give to the phenomena, they are all suggesting (but not using the term ’metacognitive’), from different perspectives, that a group possesses metacognitive knowledge of a group members, group task, and group strategies, as well as metacognitive skills of collective planning, revising, and monitoring the groups’ cognitive actions. Therefore, it is my intention within this research to investigate the occurrence of metacognitive skills as well metacognitive knowledge existing at the level of a group.
3.3 Nature of distributed cognition in R & D processes

The third constrain of the information processing approach to human problem-solving is the assumption that only research carried out in laboratory environment can reveal the ultimate features of the human problem-solving activity, and that the process of problem-solving is only individual by nature. Therefore, the study of human cognition as well as the study of human problem-solving have traditionally focused on individual cognition and individual problem-solving, seeking to characterize the processes by which individual minds perceive, manipulate, and interpret information (Levine & Resnick 1993, 586). However, in recent years, scientists from various domains have found this focus inadequate in capturing human thinking, learning, and problem-solving in all their variety, and have turned, instead, to the examination of cognition in real-life settings and social interaction. For example Pea (1993) and Cole and Engeström (1993) have pointed out that most, if not all, human intellectual activity, rather than, being a solo activity taking place in one’s own head, is a distributed process between individuals as well as between individuals and cultural artifacts and tools. Therefore, the distinction between purely cognitive and social cognitions becomes blurred. As a part of the effort to clarify this matter, many disciplines (such as sociology, linguistics, anthropology, and economics) have significantly contributed to the cognitive psychology once dominated by laboratory research (Damon 1991, 384).

Initially, the study of cognitive processes treated everything cognitive as being in the heads of individuals. At the same time, social, cultural, and technological factors were left background or treated only as external sources of stimulation. Actually, this initial approach has allowed cognitive scientist to examine some specific mechanisms of human information processing, problem-solving, and learning in great detail. But once human cognitive processes are examined in real-life problem-solving situations, a rather different phenomenon emerges: “People appear to think in conjunction or partnership with others and with the help of culturally provided tools and implements” (Salomon 1993a, xii-xiii, emphasis original). The contemporary psychology’s notion that cognition resides “in the head” is currently being challenged by a perspective of cognition as distributed over both

"Organizations are necessarily characterized by distributed cognition because their critically important processes and diversity of environments and technologies to be dealt with are too complex for one person to understand in its entirety" (351).

However, before going ahead to discuss distributed cognitions, it is important to examine the concept of ’a group’ more carefully. Then several writers’ and researchers’ ideas and viewpoints concerning the distribution of cognitions and the main differences between them will be studied.

3.3.1 Group as a cognitive being?

Traditionally, the cognitive psychology of problem-solving requires a subject to solve a problem in an isolated fashion. This is especially true for laboratory studies on problem-solving strategies, but it also holds true for field studies in which authentic problems have been investigated. The expert is treated as a ”lonely problem solver”. However, outside the context of a psychological laboratory, experts usually do not solve problems in an isolated fashion. Actually, the lonely problem solver is a bit unrealistic of a figure. (Bromme & Nuckles 1998, 176.) Håkansson (1987) illustrates this situation and the technical development in particular with an excellent metaphor, calling it ”the Newton syndrome”. He writes:

”According to the legend, Newton got his idea which led to the theory of gravitation when he was lying under an apple tree watching an apple falling. The lonely innovator and the flash of genius has since then characterized our way of looking at knowledge development and thereby also at technical development.” (Håkansson 1987, 3.)
The "lonely innovator" is not "lying under a tree" anymore, instead, he/she is working collaboratively with others in a group or team.

Still, is there a difference between the meaning of 'a group' and the meaning of 'a team'? How do we define the concept of 'a group'? How about the concept of 'a team'? What does it mean to do 'teamwork'?

When studying any kind of group or team phenomena the important issues to solve are a) the definitions of 'a group' and 'a team', and b) the appropriate unit of analysis (i.e. the group or the individual).

3.3.1.1 Defining 'a group' and 'a team'

There is an overwhelming abundance of definitions of 'a group' to choose from. For example, 'a group' has been defined as:

- Any collection of people that an individual perceives as related (Pryor & Ostrom 1987, 156).
- Two or more people who share a common social identification of themselves, or, which is really the same thing, perceive themselves to be members of the same social category (Reicher 1982).
- A collection of individuals whose existence as a collection is rewarding for them (Bass 1960).
- A set of individuals who share a common fate i.e. who are interdependent in the sense that an event which effects one member is likely to affect all (Fiedler 1967).
- Two or more people who are interacting with one another in such a manner that each person influences and is influenced by each person (Shaw 1981).
- An information processing system, meaning the emerging attempt to employ the classic information processing model of individual human cognition as an analogy to describing information processing in groups (Hinsz et al. 1997).
• A community of practice; that there is a set of relations among people, activities, and the world over time and in relation with other tangential and overlapping communities of practice. The term ‘community’ does not necessarily imply co-presence, a well-defined, identifiable group, or socially visible boundaries, but is does imply participation in an activity system about which the participants share an understanding. (Lave & Wenger 1991, 98.)

These definitions seem to capture many important elements of what a group is; a social categorization, interdependence, influence, and relation to one another.

A team on the other hand, is most often differentiated from a group. A literature review of the concept of ‘a team’ provides the following definitions:

• A team is an organizational concept; the definition of ‘a team’ is interdependent on the definition of the concept of the organization where a team practices its activities; furthermore, the organizational analysis of teams is concerned with the patterns of the information flow, role demarcation, interprofessional jealousies, leadership, working cultures, etc. (Middleton 1996, 234).

• A team is a group of two or more individuals who must interact cooperatively and adaptively in pursuit of shared valued objectives (Dyer 1984; Orasanu and Salas 1993). In addition, the team members have clearly defined differentiated roles and responsibilities, hold task-relevant knowledge, and are interdependent (i.e. must rely on one another in order to accomplish goals). Given this definition, teams can be distinguished from groups in which members are homogeneous with respect to expertise, roles, and responsibilities. (Orasanu & Salas 1993).

• A team is a tightly integrated group with supplementary skills, mutual accountability, and a common goal (Katzenbach & Smith 1997).

• A team is a living, evolving community defined by its practices and tools it uses to carry out its practices (Brown et al. 1989). The practices refer to team activities as regulated, explicitly or implicitly, by rules or standards called norms. The tools refer to intangible tools such as shared concepts and language conventions, as well as tangible and
technological ones, such as computer systems, and are believed to play an important role in shaping a community’s thoughts and actions. (Derry, DuRussel, & O’Donnell 1998, 26.)

- Boland, Tenkasi and Te’eni (1994) define ‘a team’ as a ”community of knowing” in which specialized knowledge workers, each dealing with a part of an overall problem, interact to create patterns of sense-making.

To conclude, a team is an organizational creature, which is put together in order to accomplish a certain task. The team members have clearly defined roles, tasks, and expertises. The team works for a certain time, usually until the task is accomplished. The team can be held accountable, responsibility can be allocated to it, and it can have goals (Tuomi 1999). Groups, on the other hand, function with broader contexts - cultural, institutional, and physical - that form and constrain their development (Derry, DuRussel, & O’Donnel 1998, 26). Tuomi (1999) also stresses the difference between a team and a community of practice but sees that: ”Although teams are not, by default, real communities of practice, in practical organizational settings they approximate communities” (398). The distinctive features of a group and a team are illustrated in the following figure:
When it comes to the research at hand, the question is whether technological product development is group work or team work. As noted earlier, technological product development does not occur in an isolated fashion, but collaboratively. However, can that collaboration be seen as going on in a group or in a team? If a group is defined as social and including long-term collaboration between independent and interdependent people whose roles are somewhat vague and who may not have any specific task to accomplish, then technological product development does not take place in a group, but in a team in which highly specialized people work together to accomplish a certain task which they are held responsible for.

3.3.1.2 Team-work

Maybe the most critical aspect of a team that shapes its practices is the task. The benefit of team-work should always be considered through the characteristics of the task the team has to accomplish. It is often assumed that teams perform better than individuals on various tasks, including learning and problem-solving. However, based on various researches, this is not always the case. There is a considerable amount of research that has compared the
problem-solving effectiveness of groups and individuals (cf. e.g. Hill 1982; Laughlin 1980). The conclusion often drawn from this line of research is that while groups typically perform better than their average members, they consistently fall short of performing at the level of their best members (Larson & Christensen 1993, 25). An extreme example of this phenomenon is “groupthink”, strongly addressed by Janis (1982). Groupthink can be defined as an extreme concurrence seeking which produces poor group decisions. Janis (1982) argued that factors such as external threat, high group cohesiveness, and directive leadership produce symptoms of groupthink (e.g. illusions of invulnerability, pressure on dissenters) which in turn undermine members’ ability to process information and arrive at sound group decisions. However, an important shortcoming of this line of research is that the generability of this conclusion is restricted by the type of task groups are engaged with. Like Hastie (1986) pointed out in his review of research on individual versus group accuracy in judgement tasks, the relative performance of individuals and groups depends heavily on the task (see also Davis 1980, 1982; Hinsz 1990; Kerr 1992; Laughlin 1980; Tindale & Davis 1983). The conclusions cited above are therefore limited to those situations where the use of a group to solve the problem is optional. In other words, to situations where the tasks do not necessarily require group interaction, but can be completed by an individual alone.

Yet, there are a wide variety of problems that simply cannot be solved by individuals working alone. Technological product development is a task that requires a high level of experience not possessed by any single person alone. However, team-work, to be successful, requires cognitive processes that help to align the language and understanding among team members. Therefore a team, to be able to work efficiently, has to find perspectives and a language that are already shared to some extent by team members from different areas of expertise (Boshuizen & (Tabachneck)-Schijf 1998, 142; Derry, DuRussel, & O’Donnell 1998, 26-27). Boshuizen & (Tabachneck)-Schijf (1998) provide us with a pretty explanatory example. They write:
"The engineer will look at the product aspects that make the product work smoothly; the designer will focus on whether the product looks and feels pleasing; the marketing person will look at the product at the light of how it should look and act in order to sell better; the human factors specialist at those aspects that have to do with how the customer will interact with it. All are looking at the same product; all have a different representation of it, with different data sets, and different operators. It is no wonder that team members sometimes have a hard time talking to each other - in a way, they really are thinking about completely different product.” (143, emphasis original.)

Both the language and the knowledge development in groups are driven by a process characterized by Lave (1991) et al. as “negotiation”. Negotiation is necessary because different members bring their own cognitive histories to the group, and these unique perspectives cause members to understand and interpret work-related problems in significantly different ways. Negotiation describes communication processes that also help to align the language and understanding among community members. Negotiation appears to start with team members finding ”common voices” (Wertsch 1991b). This term refers to finding perspectives and a language that are already shared to some extent by team members from different disciplinary cultures.

3.3.1.3 Appropriate unit of analysis

When studying a group phenomenon of any kind, one of the critical issues to solve is the appropriate unit of analysis. Do we treat a group as an entity, as a living being, or do we consider a group as merely individuals working together?

A review of the history of sociology and psychology reveals that scholars of the late nineteenth and early twentieth centuries adopted one of the two philosophical
positions. Either they supported the notion that the group was the true unit of analysis in the study of social behavior, and that collective reality supplanted the reality of individuals; or they believed that the individual was the proper unit of analysis, and that phenomena that arose at the individual level could adequately explain collective action. (Allison & Messick 1987, 112.)

At one extreme is the position that the group is more real than the individual and that the appropriate unit of analysis is, therefore, the group. The pre-eminent proponent of this position was Emile Durkheim. He writes in his widely sited passage:

"The group thinks, feels, and acts quite differently from the way in which its members would were they isolated. If, then, we begin with the individual, we shall be able to understand nothing of what takes place in the group. ...Consequently, everytime a social phenomenon is directly explained by a psychological phenomenon, we may be sure that the explanation is false." (Durkheim 1938, 104.)

At the other extreme is the position that the individual is more real than the group, and the appropriate unit of analysis is, therefore, the individual. The pre-eminent proponent of this position was Floyd Allport. He argues:

"All theories which partake of the group fallacy have the unfortunate consequence of diverting attention from the true locus of cause and effect, namely, the behavior mechanisms of the individual” (Allport 1920, 9).

There are also positions that integrate both of these levels. One attempt to integrate the individual level of analysis with the group level of analysis involves supposing a parallelism between the individual and the group. In the past, it was fairly common to assert that the group is just like the individual in some ways. During the early development of contemporary social psychology, the conceptualizations of the group mind (e.g. Boodin
1913; McDougall 1920) and the collective unconscious (Jung 1922) addressed this tendency to analogize the individual and the group. Another reconciliation between the individual level of analysis and the group level of analysis was developed by Donald Campell (1958). He proposed that social compositions vary in their degree of entitativity, or in the extent to which they have the nature of an entity or real existence. Thus, the group may be quite real in some instances, and in those cases the group is a more appropriate unit of analysis. In other instances, the group may be a fictitious abstraction, and in those cases the individual is more appropriate unit of analysis. (Mullen 1987, 3-4.) Sociologists or psychologists were not the only scholars who battled between the individual and the group level of analysis. For example, an anthropologist called Leslie White (1947) was perhaps the most outspoken about the group - individual issue. He argued that all behavior is culturally determined and that it is foolhardy to explain group behavior from a psychological perspective. He writes in his classic passage:

"Polls of opinion are sometimes interpreted psychologically, i.e., upon the assumption that what "the people” think and desire determines the behavior of a nation. This is one of the illusions of democracy: "the people rule". But what the people think and feel, in concrete and specific terms, is determined not by themselves, but by the socio-cultural magnetic field in which they are but articulate, protoplasmic iron filings.” (White 1947, 691.)

In summary, depending on whom one reads, the debate is either solved or unsolvable. Throughout the history, there has been a division in theoretical perspective between those who believe that the group is the primary reality in life, and those who maintain that true reality resides only in the individual. Those who have endorsed the group-reality position have believed that there is typically very little correspondence between group actions and the members’ preferences. Those advocating the individual-reality position have acknowledged the role of group influences on the individual, but have maintained that it is the individual who controls his/her own behaviors and, more importantly, that it is the individual who directs the course of the group’s actions.” (Allison & Messick 1987, 115.)
The notion of distributed cognitions can be seen as a serious attempt to balance the individualistic emphasis with more vigorous concern with the group level of analysis. However, even when characterized as distributed, there are different interpretations of 'distributed cognition' depending on the viewpoint.

### 3.3.2 The “individual-plus” view of distributed cognition

The “individual-plus” perspective of distributed cognition sees cognition as an individual phenomenon, but the importance of factors external to the individual is recognized. According to this view:

- Knowledge is something that individuals can possess, but sometimes that knowledge is distributed around different artifacts and other individuals. Socially shared knowledge can be added to the array of factors already known to influence individual thought. (Moore & Rocklin 1998, 102; Cole 1991, 399.)

- People process, represent, and remember in relation to each other and, therefore, researchers need to extend the scope of their intraindividual theory to include everyday activity and social interaction as well (Lave 1991, 66).

- Even when cognitive activity is fostered through processes of social communication, individual activity and reflection still play a critical role. Individuals often need to separate themselves from groups in order to seek the truth and groups often benefit and learn from individuals who have separated themselves in just this way. (Damon 1991, 392.)

- Individual and distributed cognitions are two different phenomena, but they exist in an interdependent dynamic interaction, and, therefore, studies should neither be restricted to the individual, nor controlled, artificial settings (Salomon 1993b, 120).

The “individual-plus” perspective captures much of the work being done in distributed cognition (e.g. Cranach, Ochsenbein, & Valach 1986; Derry et. al., 1998; Hinsz et. al., 1997; King 1998; Larson & Christensen 1993).
The view of distributed cognition that Moore and Rocklin (1998) have described as the "individual-plus" view, and Lave (1991) as the "cognition-plus" view is similar to Perkin’s (1993) notion of the "person-plus" view which describes a person plus the surround as the proper unit of analysis. These views do not challenge the principles of current cognitive psychology, but encourage the exploration of additional factors that might influence individual cognition (Moore & Rocklin 1998, 105; Perkins 1993, 89; Lave 1991, 66). Like Salomon (1993b) argues:

“Although it is undeniable that many human actions are socially and technologically distributed…it is also undeniable that not all cognitions, regardless of their inherent nature, are distributed all the time, by all individuals regardless of situation, purpose, proclivity, or affordance” (113, emphasis original).

3.3.3 The “social-only” view of distributed cognition

At the other end of the continuum there is what Moore and Rocklin (1993) call the “social-only” view of distributed cognition, and which Lave (1991, 67) labeled as “situated social practice”. This interpretation of distributed cognition argues that “learning, thinking, and knowing are relations among people in activity in, with, and arising from the social and culturally structured world” (Lave & Wenger 1991, 51). Therefore, cognition is always situated in the historical development of the ongoing activity. According to the “social-only” view, the concept of individual cognition is so thoroughly confused that it calls for a fundamental realignment of scientific effort. Most importantly, the “social-only” view argues that the human cognition consists of the interaction of individual, social, and cultural processes, and must be studied systematically in terms of all these aspects simultaneously. (Cole 1991, 399.) For example Lave (1988) suggests that the relationship between human thought, human action, and the environment is so tightly interwoven that the mind cannot be studied independently of that sociocultural setting within which people function. As Levine and Resnick argue (1993): “In this messy “real world” it is difficult to imagine any situation that is purely cognitive – devoid of emotions, social meanings, social interactions, and social
residues in the form of inherited roles and tools” (603, quotation marks original.) The methodological viewpoint within the “social-only” perspective is not the individual working in a group, but the group itself as a primary unit of analysis.

Despite the growth of the “social-only” position of distributed cognition, the effect of social and cultural variables upon cognitive processes has not proved a very popular topic among psychologists. Probably in part because no one is sure what the problems, paradigms, and methods of such a research enterprise might be (Schneider 1991, 553). When one tries to find cognitive research carried out from the “social-only” perspective, the findings are pretty scarce. For example, Hutchins (1995a) has analyzed the cockpit of an airplane as one sociotechnical system consisting of a pilot, a co-pilot, and the plane. He argues that the positioning of markers on a dial indicating the range of speed etc. while landing a plane constitutes the cockpit’s memory. He also presents a detailed study of navigating a US Navy ship (1995b). He considers navigation as a distributed task and argues that no single person can complete the navigation task; one person takes the bearing, another configures the chart, and so on. As the state of computation (i.e. the location of the boat) is not bound by an individual, it must move through a system of individuals (i.e. a group) and artifacts. The cognitive processes, therefore, involve "propagation of representational state across a series of representational media" (Hutchins 1995b, 117).

The different parties of distributed cognition can be seen as parts of the following quartet in which ”+ +” represents the individual-plus view of distributed cognition, ”- +” refers to the social-only view, ”+ -” refers to the individual-only view (discussed in chapter 4.1.3), and the ”- -” view sees the man in a very mechanistic way; as a machine.
To conclude, a major issue dividing the “individual-plus” and the “social-only” views of distributed cognition is whether all cognition is viewed as distributed, or whether only some cognition is distributed. There is research that treats individual mental activity as the central problem in cognitive science, considering interaction primarily as a stimulus to that private mental work. And, at the other end, there is research that treats the interacting group as the cognitive unit, unit of analysis, considering individuals primarily as contributors to the cognitive work of the group. Between these two extremes, several contributors appear to consider the implications of the notion of distributed cognition to be an open question. These researchers seek to extend our knowledge of human cognition through the investigation of the conditions of its sharing in concrete cases, having minimal concern with paradigmatic reform. (Cole 1991, 399.) As Salomon (1993b, 135) has pointed out, the psychology of individual competencies and that of distributed cognition ought to be accommodated within the same theoretical framework.
“No theory of distributed cognitions can do justice to the understanding of human activity…without taking into consideration individuals’ cognitions. The same applies to the flip side of this argument: No theory of individuals’ cognitions would be satisfactory without taking into consideration their reciprocal interplay with situations of distributed cognitions.” (Salomon 1993b, 135.)

I wish to adopt the idea of cognitions interacting in a spiral-like fashion like Salomon suggests:

“the ‘components’ interact with one another in a spiral-like fashion whereby individuals’ inputs, through their collaborative activities, affect the nature of joint, distributed system, which in turn affects their cognitions such that their subsequent participation is altered, resulting in subsequent altered joint performances and products” (Salomon 1993b, 122).

Salomon (1993b) also strongly addresses that psychologists have gone too far in dismissing the individual from analyses. Therefore, he stands on the "individual-plus" side of distributed cognition and argues that we cannot construct an adequate theory of distributed cognition without an explicit role for individual cognition. In other words, both of the aspects of cognition (individual as well as distributed) are taken under a detailed investigation in this research and they are both considered to be relevant in the processes of collaborative problem-solving and learning.
With the following figure (figure 10), I want to illustrate how individual-level cognitions and metacognitions as well as group-level cognitions and metacognitions interact in solving a problem in a collaborative mode.

Figure 10. Cognitive functions interacting during a collaborative problem-solving process.
3.4 Nature of learning in collaborative R & D processes

Each of the theoretical orientations presented in a current section are useful in thinking about problem-solving in a collaborative mode. Each is good for certain purposes, but not for all, and I will employ them for different needs in my analysis. For the purpose of investigating learning during the collaborative problem-solving process, another theoretical stepping stone is needed. Within the next section, I will take a closer look at the current theories of learning through the theories of human, intellectual, and social capital.

3.4.1 Producing human, intellectual, and social capital - a form of learning in a collaborative mode

3.4.1.1 Social capital: same term, multiple definitions

The term ‘social capital’ initially appeared in community research addressing the central importance - for the survival and functioning of city neighborhoods- of the networks of strong, cross-cutting personal relationships developed over time that provide the basis of trust, cooperation, and collective action in such communities (Jacobs 1965, in Nahapiet & Ghostal 1998, 243). During recent years, the concept of social capital has received growing interest among many theorists and many disciplines. One of the first systematic analyses of social capital was produced by a French sociologist Pierre Bourdieu who defined the concept as:

"the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance and recognition - or in other words, to membership in a group - which provides each of its members with the backing of the collectivity-owned capital, a "credential” which entitles them to credit, in various senses of the word” (Bourdieu 1986, 248, quotation marks original).
For Bourdieu, the central proposition of social capital is that networks of relationships constitute a valuable actual or potential resource, providing members of that network with collectively-owned capital "credentials". Bourdieu identifies these "credentials" as durable obligations arising from the feelings of gratitude, respect, and friendship, or from the institutionally guaranteed rights derived from membership in a family, a class, or a school (Bourdieu 1986, 249-250). Members in a social network can also gain privileged access to information and opportunities, which would otherwise be impossible (Nahapiet & Ghoatal 1998, 243). Also, social capital can be seen as a source of social status or reputation (Bourdieu 1986; Burt 1992).

The economist Glenn Loury (1977), on the other hand, defined social capital as naturally occurring social relationships to promote or aid the development of valued skills or characteristics. Loury’s definition of social capital stressed an individualistic strand of social capital, something essential also to the more recent work of Burt (1992). In this version, social capital begins to parallel human capital (Cooke & Wills 1999, 222).

Also Coleman addresses the relationship between social capital and human capital in his (maybe more refined) analysis of social capital, namely the role of social capital in the creation of human capital. Coleman uses social capital as a tool in explaining social action. It is his intention to find a common ground between the two main streams in describing and explaining social action; the sociologists’ view that sees the actor as socialized and the action as governed by social norms, rules, and obligations, and the economistic view that sees the actor as having goals independently arrived at, as acting independently, and as wholly self-interested. He is engaged in developing a theoretical orientation that accepts the principle of rational or purposive action, but only in conjunction with a particular social context. He begins his theorizing about social capital with the theory of rational action in which each actor has control over certain resources and interests in certain resources and events. He argues that "social capital constitutes a particular kind of resources available to an actor" (Coleman 1988, 98). Coleman defined social capital by its function. He writes:
"It (social capital) is not a single entity but a variety of different entities, with two elements in common: they all consist of some aspect of social structure, and they facilitate certain actions of actors - whether persons or corporate actors - within the structure" (Coleman 1988, 98).

Coleman emphasizes social capital as a resource for people. He argues that social capital comes about through changes in the relations among people who facilitate the action.

After Bourdieu, Loury, and Coleman, a number of researchers have published their analyses of social capital. For example, in 1990 Baker defined the concept as "a resource that actors derive from specific social structures and then use to pursue their interests; it is created by changes in the relationships among actors" (Baker 1990, 619). Schiff defines the term as "the set of elements of the social structure that affects relations among people and are inputs or arguments of the production and/or utility function" (Schiff 1992, 161). For Putnam, social capital means "features of social organizations, such as networks, norms, and trust, that facilitate action and cooperation for mutual benefit" (Putnam 1993, 35). This collective feature of social capital is presented in his work on Italian regions where he argued that the variation in prosperity between regional economies was highly and positively associated with variation in the degree to which strong social capital, civicism, and associationism were either present or absent. (Putnam 1993.) In a recent article of Nahapiet and Ghoshal, social capital is defined "as the sum of the actual and potential resources embedded within, available through, and derived from the network of relationships possessed by an individual or social unit. Social capital thus comprises both the network and the assets that may be mobilized through that network" (Nahapiet & Ghoshal 1998, 243).

To conclude, social capital is a form of capital that is produced in social interaction, networks and relations among people. It can be seen as an asset (something that people can use to pursue individualistic or mutual goals) for people within a certain social collectivity. However, there is at least one fundamental difference in the definitions described above. It is the question of the ownership: is social capital own by a single person, or it is own by a
collection of people? Researchers agree that social capital is produced in social interaction, relation within people, but can it be own by an individual? According to Nahapiet and Ghoshal (1998), social capital cannot be own by a single person alone. In this research, I follow the idea that social capital is collectively produced, and, therefore, it is also collectively own. In other words, social capital is social phenomenon, which cannot be detached from where it has been created. This does not mean that social capital cannot be used to pursue individualistic endeavors. But, even then, it is tied to a certain social milieu.

Within the next chapters, I will present attributes or characteristics of social capital found by other researchers.

3.4.1.2 Attributes of social capital

As a set of resources rooted in relationships, social capital has many different attributes. In studying social capital in the creation of intellectual capital, Nahapiet and Ghoshal (1998) consider different attributes of social capital in terms of three clusters: the structural, the relational, and the cognitive dimensions. By the structural dimension of social capital they mean the overall pattern of connections between actors – i.e. whom you confront and how. By the relational dimension of social capital they want to focus on the particular relations people have, such as respect and friendship that influence their behavior. The third dimension of social capital, which they label “the cognitive dimension”, refers to ”those resources providing shared representations, interpretations, and systems of meaning among parties” (244). I found this taxonomy quite explanatory and will use it to describe the different attributes of social capital.

Structural dimension of social capital

Networks

The fundamental proposition of the social capital theory is that relationships in networks provide access to resources (i.e. ”who you know” affects ”what you know”) (Nahapiet & Ghoshal, 1998, 252). Eventhough Coleman (1988) argues that information is important in
providing a basis for action, it is costly to gather. Nahapiet and Ghostal argue however, that social relations, often established for other purposes, constitute information channels that actually reduce the amount of time and investment needed to gather information. These information benefits occur in three forms: access, timing, and referrals (Burt 1992). Burt’s term ‘access’, in this context, refers to receiving a valuable piece of information and knowing who can use it, and it identifies the role of networks in providing an efficient information-screening and information-distribution process for members of those networks. ‘Timing’ refers to the ability of personal contacts to provide information sooner than it would become available to people without such contacts. ‘Referrals’ are processes providing information on available opportunities for people or actors in the network. While many (e.g. Coleman 1988; Putnam 1993) researchers emphasize the importance of dense networks as a necessary condition for social capital to emerge, for example Granovetter (1973) and Burt (1992) argue otherwise. In their view, it is the relative absence of ties that facilitate individual mobility. In his article “Economic Action and Social Structure: The Problem of Embeddedness” Granovetter claims that e.g. labor markets do not function by rational choice, but by embedded and even loose social relations and trust (Granovetter 1985).

**Cognitive dimension of social capital**

All social interaction requires at least some sharing of context between the parties of such relationship. Scholars widely recognize that innovation and product development generally occur through combining different knowledge and experience and that that diversity of opinion is a way of expanding knowledge. However, it has been unclear how this sharing comes about. Nahapiet and Ghostal (1998) suggest that it may come about in two main ways: 1) through the existence of shared language and vocabulary, and 2) through the sharing of collective narratives. They also suggest that these two elements constitute the facets of shared cognition.
Shared language and codes
Language is most often the way people interact with each other; they discuss, share information, and ask questions. When people share a common language, it facilitates their ability to gain access to other people’s information. Language also influences perception. Its codes organize sensory data into perceptual categories and provide a frame of reference for observing and interpreting the environment. Furthermore, a shared language enhances the combination capability. (Nahapiet & Ghostal 1998, 253-254.) Boland and Tenkasi (1995, 350) argue that the producing of knowledge in order to create innovative products and processes in knowledge-intensive firms requires the ability of ‘perspective-making’ as well as the ability to take the perspective of others into account (‘perspective-taking’). This takes us back to the discussion about distributed cognitions (discussed in pages 65-70) and stresses the importance of knowledge-creation in social interaction.

Shared narratives
Bruner (1990) proposed that there are at least two distinct modes of cognition: 1) the information processing (or paradigmatic) mode of cognition, and 2) the narrative mode of cognition. The contemporary way of understanding cognition has emphasized its information processing mode, particularly the rational analysis of data in a mental problem space. However, people narrativize their experiences almost continually as they recognize unusual or unexpected events and construct stories, which make sense to them (Boland & Tenkasi 1995, 353). Bruner (1986, 1990) argues that the narrative capability of humans is a fundamental cognitive process through which our cultural world and sense of self are constructed and maintained over time. These narratives are represented in synthetic narratives, such as fairy tales, myths, legends, good stories, and metaphors. Orr (1990), for example, has demonstrated how stories, full of seemingly insignificant details, facilitate the exchanging of practice and tacit experience between technicians, thereby enabling the discovery and development of improved practices. Like Nahapiet and Ghostal (1998) argue: “The emergence of shared narratives within a community enables the creation and transfer of new interpretations of events, doing it in a way that facilitates the combination of different forms of knowledge, including those largely tacit” (254).
The relational dimension of social capital

Trust
A reasonable amount of research has demonstrated that trust is an important feature of social capital. For example, Putnam (1993), Fukuyama (1995), as well as Ring and Van de Ven (1992) have shown that where relationships are high in trust, people are more willing to engage in social exchange in general, and cooperative interaction in particular. For Putnam (1993, 170), trust is the most important element for social capital to emerge. Ilmonen (2000, 22) agrees that trust is an important element of social capital, mainly because through trust, social capital becomes "a self-feeding" system, in which trust generates collaboration and eases the coordination between actions and communication. This, on the other hand, strengthens the reciprocal norms that, in turn, strengthens the sense of community and joint identity. Misztal (1996) has observed that "trust, by keeping our mind open to all evidence, secures communication and dialogue" (10). Misztal (1996) continues that trust may both open up the access to others for the exchange of intellectual capital and increase the anticipation of value through such exchange. For example, Nahapiet (1996) and Ring and Van de Ven (1992) have found support for this view in their research demonstrating that where there are high levels of trust, people are also more willing to take risks in such an exchange. As Nahapiet and Ghostal (1998) argue, there is a two-way interaction between trust and cooperation: "trust lubricates cooperation, and cooperation itself breeds trust" (255). A vast amount of trust may even become an exceptional asset while working with highly complex problems in a collaborative mode. Like Coleman (1988) argues: "a group within which there is extensive trustworthiness and trust is able to accomplish more than a comparable group without that trustworthiness and trust” (101).

Norms
Another characteristic of social capital are socially defined norms that exist when the socially defined right to control an action is held not by the actor but by others (Coleman 1990). Coleman argues that "where a norm exists and is effective, it constitutes a powerful, though sometimes fragile, form of social capital” (104). Norms of co-operation can become to have an important influence on exchange processes, opening up accesses to parties for the
exchange of knowledge and ensuring the motivation to engage in such exchange (Nahapiet & Ghostal 1998, 255). Starbuck (1992) stresses the importance of the social norms of openness and teamwork as key elements of knowledge-intensive firms. The willingness to value and respond to diversity, an openness to criticism, and a tolerance of failure are other norms of interaction that have been shown to be important features of social capital (Nahapiet & Ghostal 1998). While effective social norms can constitute a powerful form of social capital, they not only facilitate certain actions, but they constrain others. Those capabilities and values initially seen as a benefit may become, in time, a pathological rigidity (Nahapiet & Ghostal 1998, 255).

**Obligations and expectations**

When there is at least some level of trust in a relationship, there are almost ineluctably obligations and expectations among the parties. Coleman (1988) suggests that these obligations operate as "credit slips" held by A to be redeemed by B (cf. Bourdieu’s (1986) concept of credentials referred in page 72). Like Coleman writes:

"If A does something for B and trusts B to reciprocate in the future, this establishes an expectation in A and an obligation on the part of B. This obligation can be conceived as a credit slip held by A for performance by B. …These credit slips constitute a large body of credit that A can call in if necessary – unless, of course, the placement of trust has been unwise, and these are bad debts that will not be repaid." (Coleman 1988, 102.)

This form of social capital depends on two elements: the trustworthiness of the social environment concerning the repayment of obligations, and the actual amount of obligations held. Nahapiet and Ghostal (1998) suggest that such obligations and expectations influence both the access to parties in order to exchange and combine knowledge and the motivation to combine and exchange such knowledge.
3.4.1.3 Consequences of social capital

It has been argued that social capital increases the efficiency of action (cf. Kotarbinski). For example, Burt (1992) argues that networks of social relations increase the efficiency of information diffusion through minimizing redundancy. Putnam (1993) also argues that social capital reduces the costs of transactions. Some have also suggested that social capital, in the form of trust, diminishes the probability of opportunism and reduces the need for costly monitoring processes (Nahapiet & Ghoshal 1998, 245). Some researchers have also discovered that social capital encourages cooperative behavior, creativity, and learning (Fukuyama 1995, Putnam 1993).

Although the research literature of social capital strongly emphasizes its positive consequences, it is not a universally beneficial resource. Social capital can also be seen as functioning as a control mechanism by excluding outsiders, making demands on group members, restricting individual freedom, or setting tight norms (Portes 1998, 15). The phenomena of “collective blindness” can be seen as a representative of the negative effects of social capital (Janis 1982).

All that has been said about social capital so far can be summarized in the following way:

<table>
<thead>
<tr>
<th>Social Capital</th>
<th>Attributes of Social Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>* Produced in social interaction</td>
<td>Structural dimension</td>
</tr>
<tr>
<td>* An asset</td>
<td>* Networks</td>
</tr>
<tr>
<td>* Collectively own</td>
<td>Cognitive dimension</td>
</tr>
<tr>
<td></td>
<td>* Shared language and codes</td>
</tr>
<tr>
<td></td>
<td>* Shared narratives</td>
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<tr>
<td></td>
<td>Relational dimension</td>
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<td></td>
<td>* Trust</td>
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<td>* Norms</td>
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<td></td>
<td>* Obligations and expectations</td>
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</tbody>
</table>

Figure 11. Defining social capital.
Social capital can been conceived as produced capital, so can human and intellectual capitals. Physical capital, on the other hand, is usually conceived as naturally occurring or at least wholly tangible. The relationship between physical, human, social, and intellectual capital is discussed next.

3.4.1.4 Relationships between the four forms of capital: physical, human, social, and intellectual capital

There is an interesting parallelism between the four different kinds of capitals: physical (i.e. natural capital), human, social, and intellectual capital (i.e. produced capitals). Physical capital can be seen as embodied in tools, machines, and other productive equipment. Human capital, on the other hand, is usually conceived as an individual’s attributes, skills, and knowledge (OECD 2001, 17-18). In an OECD study on measuring human capital, it is defined as “the knowledge that individuals acquire during their life and use to produce goods, services or ideas in market or non-market circumstances” (Miller 1996, 22). The same way as physical capital is created by changes in materials to form tools that facilitate production, human capital is created by changes in people who bring about skills and capabilities that make them able to act in new ways. Thus, physical capital is usually conceived as wholly tangible, being embodied in observable material form, and human capital is usually conceived as less tangible, individual attributes like skills and knowledge (e.g. Coleman 1988, 100; Cooke & Wills 1999, 223). Social capital, on the other hand, is even less tangible, not own by any individual per se, but existing in the relations between people, and being a property of social interactions and networks (Coleman 1988, 100-101; Cooke & Wills 1999, 223; Burt 1992). Therefore, just as physical and human capital facilitate productive activity, social capital does the same. The relationship between social capital and human capital is well illustrated in the following passages by Coleman (1988):
"John Stuart Mill, at an age before most children attend school, was taught Latin and Greek by his father, James Mill, and later in childhood would discuss critically with his father and with Jeremy Bentham drafts of his father’s manuscripts. John Stuart Mill probably had no extraordinary genetic endowments, and his father’s learning was no more extensive than that of some other men of the time. The central difference was the time and effort spent by the father with the child on intellectual matters.” (Coleman 1988, 109-110.)

"In one public school district in the United States where texts for school use were purchased by children’s families, school authorities were puzzled to discover that a number of Asian immigrant families purchased two copies of each textbook needed by the child. Investigation revealed that the family purchased the second copy for the mother to study in order to help her child do well in school. Here is a case in which the human capital of the parents, at least as measured traditionally by years of schooling, is low, but the social capital in the family available for the child’s education is extremely high.” (Coleman 1998, 110.)

The conclusion that can be drawn out of these examples is the importance of social capital in the development of human capital. The fourth form of capital discussed here is intellectual capital. Traditionally, economists have examined physical and human capital as key resources for a company in facilitating productive and economic activity. However, it has been recognized that the hard assets like land, the plant, or equipment, and the individual skills or knowledge can not alone explain the success or failure of a firm. Just as social capital is an important factor in the development of human capital, it is also an important factor in the development of intellectual capital (Nahapiet & Ghoshal 1998, 245). But what do we mean by intellectual capital? In economic literature, the concept of ‘intellectual capital’ is often used when estimating the value of an organization’s intangible
assets (e.g. Edvinsson & Malone 1997; Stewart 1997; Darby, Liu, & Zucker 1999). Paul Strassmann (1998) presents a similar kind of idea in his definition of intellectual capital. According to his view, intellectual capital (or knowledge capital) is a source of economic value added by the organization, on top of its financial assets. Nahapiet and Ghostal (1998) take another kind of point of view and define the term ‘intellectual capital’ as ”the knowledge and knowing capability of social collectivity, such as an organization, intellectual community, or professional practice” (245). For them, intellectual capital is not so much about the organizational market asset, but a definition of the actual pool of knowledge and the knowing capability of an organization or any other kind of social collectivity of people. This is the definition of intellectual capital used in this research.

It seems evident that all of these four forms of capital play an important role in the knowledge creation of a group. Therefore, they also play an important role in a collaborative problem-solving process, which is one of the main interests of this research. With the following illustration, I want to explain the locus as well as the form of existence of each of the forms of capital. While physical capital exists in some material form, like land, a plant, or equipment, the other three forms of capital are not that evident. Human capital can be seen as being in the possession of an individual person, in form of knowledge, skills and attitudes, but intellectual and social capital are not possessed by any person alone. They are not even created by a single person alone. Both intellectual and social capitals are in the possession of a certain group of people, and they are created in that group. I also want to stress the importance of social capital in the creation of both human and intellectual capital: social capital facilitates the development of the other two. For example, whatever kind of human capital exists in an individual team member, the other team members do not profit from it if social capital is missing in the team. According to this view, social capital works as a mediator between the growth of both human and intellectual capital.
In a recent OECD report (OECD 2001), the existence of social capital is linked to the well-being of all peoples. The report argues that the existence of social capital correlates with better health, improves child welfare, lowers the rates of child abuse, and facilitates the transition to adult life. Strong social capital also correlates with lower crime rates, produces better government, and improves the well-being of all nations (52-55).
Now, back to the illustration presented in page 79. One more important element will be added into it: the element of social capital in the creation of human and intellectual capital.

**Social Capital**
* Produced in social interaction
* An asset
* Collectively own

**Attributes of Social Capital**
- Structural dimension
  - Networks
- Cognitive dimension
  - Shared language and codes
  - Shared narratives
- Relational dimension
  - Trust
  - Norms
  - Obligations and expectations

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![Diagram](image-url)

Figure 13. Elements social capital.

### 3.4.1.5 The meaning of knowledge and the level of analysis in the production of human, intellectual, and social capital

Two issues are of particular relevance when considering teams as a context for the development of social and intellectual capital. These are a) the meaning of explicit and tacit knowledge, and b) issues concerning the level of analysis, particularly the question of whether social or collective knowledge exists and in what form.

The question of what knowledge is, is arguably one of the most persistent themes in all science concerned with human beings. Therefore, there is no attempt to try and solve the
matter within this research. And, therefore, I am confine to a very superficial analysis. The most frequent distinction of the different types of knowledge scholars seem to make is between practical and theoretical knowledge. The former is based on experience, and the latter is derived from reflection and abstraction of that experience. Practical knowledge is also often labeled as "knowing-how", or procedural knowledge, and theoretical knowledge is labeled as "knowing-that", or "knowing-what", or declarative knowledge (Andersson 1981; Ryle 1949). Ryle’s “knowing-how” and “knowing-what” align with Polanyi’s (1962, 1967) distinction of tacit and explicit knowledge. Polanyi explains that explicit knowledge is like "knowledge about" in its abstractness while tacit knowledge is associated with experience. Polanyi’s notion of tacit knowledge reaches beyond conscious knowledge into the sub- and preconscious modes of knowing. His intention was to criticize the positivist norm of practicing “good science”, meaning that one should only interact with explicit rationalist and empiricist traditions by formulating clinical hypotheses and carrying out repeatable tests. For Polanyi, science was a process of explicating the tacit intuitive understanding, which is driven by the subconscious learning of the scientist. (Spender 1996, 50.) After Polanyi, many researchers (cf. e.g. Nelson & Winter 1982; Plotkin 1994; Nonaka & Takeuchi 1995) have argued that social organizations, firms, even species and societies evolve by adapting the body of knowledge shared by their members, and that much of that process takes place at the tacit level. Plotkin (1994, 231) sees that all evolved entities are true representations of the reality they have experienced. While the explicit knowledge is known to the individual, the tacit knowledge resides in the “genetic level” which lies beyond the individual’s conscious decision-making. In Nonaka and Takeuchi’s (1995) theory of organizational knowledge creation, the interaction of the explicit and tacit modes of knowledge is central. They define ‘tacit knowledge’ to be personal, embedded in individual experience, context-specific, and involving intangible factors, such as personal beliefs, perspectives, and value systems. Therefore, it is hard to formalize it and pass it on. ‘Explicit knowledge’, on the other hand, refers to knowledge that is transmittable in a formal, systematic language. The interaction between tacit knowledge and explicit knowledge between individuals is the core of their theory. As they write:
"Our dynamic model of knowledge creation is anchored to a critical assumption that human knowledge is created and expanded through social interaction between tacit knowledge and explicit knowledge. We call this interaction "knowledge conversion". It should be noted that this conversion is a "social" process between individuals and not confined within an individual." (Nonaka & Takeuchi 1995, 61, emphasis original.)

According to Nonaka and Takeuchi (1995), tacit knowledge has two elements: a cognitive and a technical. The cognitive elements include mental models, such as the schemata, paradigms, perspectives, beliefs, and viewpoints. These cognitive elements help individuals to perceive and define their world. The technical elements include concrete know-how, crafts, and skills.

Nonaka and Takeuchi (1995) argue that knowledge is created inside a company through four modes; socialization, externalization, combination, and internalization. Tacit knowledge transforms into tacit knowledge through socialization; tacit knowledge transforms into explicit knowledge through externalization; explicit knowledge is converted into explicit knowledge through a combination; and explicit knowledge transforms into tacit knowledge through internalization. Nonaka calls this knowledge creation model as the SECI model. Learning and knowledge creation are understood as the conversion of tacit knowledge into explicit forms in which it can be combined, followed by an internalization process during which this new knowledge becomes a part of the learner’s own knowledge structure.
Nonaka and Takeuchi argue that an individual can acquire tacit knowledge from others without using any language. This socialization process happens through observation, imitation, and practice. Nonaka and Takeuchi’s socialization mode of learning aligns with many current socio-cultural views of knowledge creation and learning. Lave and Wenger (1991), for example, see learning as a situational process in which less-skilled newcomer learns from a master in practice. I will study situated learning later in this section.

Externalization, on the other hand, is a process of articulating tacit knowledge into explicit concepts. In that process, tacit knowledge becomes explicit, taking the shapes of metaphors, analogies, concepts, hypotheses, or models. We try to express these using a language. This view of knowledge creation has a lot in common with the cognitive attribute of creating social capital. People use a shared language, codes, and narratives, which can be seen in the form of metaphors, for example, to create a common understanding and new knowledge, and by doing that, they gain commonly own social capital. Or, using Nonaka and Takeuchi’s ideas, a language in the forms of metaphors, analogies etc. transforms individually ”own” tacit knowledge into commonly ”known” explicit knowledge.

The third mode of knowledge creation, combination, is a process of systemizing concepts into a knowledge system. This involves combining different bodies of explicit knowledge through activities like sorting, adding, combining, and categorizing. Traditionally, the
contemporary cognitive psychology has focused on this kind of explicit knowledge creation by analyzing different cognitive activities involved in the knowledge creation of a single person.

The fourth mode of knowledge creation is internalization, which is a process of embodying explicit knowledge into tacit knowledge. Experiences, through socialization, externalization, and combination, are “internalized into individuals’ tacit knowledge bases in the form of shared mental models or technical ”know-how” and they become valuable assets” (Nonaka & Takeuchi 1995, 69.) One cannot help thinking about Vygotsky’s definition of internalization while considering Nonaka and Takeuchi’s use of the same term. Vygotsky’s suggestion was that higher mental functioning is dependent on the process of internalization. Socio-cultural theorists, whose master Vygotsky was, believe that all intellectual development appears twice, once socially with others, and later as independent problem-solving behavior. In other words, it moves from an external plane to an internal plane. In other words, internalization, for socio-cultural theorists, is the process of taking new information that was experienced or learned within a social context and developing the necessary skills or intellectual functions to independently apply the knowledge. (Bonk & Cunningham 1998, 36.)

As can easily be seen, there is nothing really new in Nonaka and Takeuchi’s model of learning or knowledge creation, but perhaps the key value of their theory lies on the dynamic nature of the model and on the stress it puts on the importance of tacit knowledge in the creation of new commonly-shared knowledge. The central idea is that new knowledge is created in the articulation of tacit mental models. During this process, tacit knowledge is converted into an explicit form “spirally”. As they write:
"Tacit knowledge of individuals is the basis of organizational knowledge creation. The organization has to mobilize tacit knowledge created and accumulated at the individual level. The mobilized tacit knowledge is "organizationally" amplified through four modes of knowledge conversion and crystallized at higher ontological levels. We call this the "knowledge spiral", in which the interaction between tacit knowledge and explicit knowledge will become larger in scale as it moves up to ontological levels. Thus, organizational knowledge creation is a spiral process, starting at the individual level and moving up through expanding communities of interaction, that crosses sectional, departmental, divisional, and organizational boundaries.” (Nonaka & Takeuchi 1995, 72, quotation marks original.)

Although, according to Nonaka and Takeuchi, new knowledge is, strictly speaking, created only by individuals, knowledge creation does not happen within a single individual, and a firm has the ability to know independently of its employees. As they write:

"By organizational knowledge creation we mean the capability of a company as a whole to create new knowledge, disseminate it throughout the organization, and embody it in products, services, and systems” (Nonaka & Takeuchi 1995, viii).

This takes us to the second important issue when considering a team as a context for the development of human, intellectual, and social capital; the issue of the level of analysis. This question concerns the degree to which it is possible to differentiate the concept of ‘collective’ or ‘social knowledge’ and how it is different from individual knowledge. As stated earlier, Nonaka and Takeuchi (1995) argue that a firm has the ability to “know” independently of its employees. This reveals the assumption that such a thing as ‘collective’ or ‘social knowledge’ exists. Also Nelson and Winter (1982) have stated that:
"The possession of technical "knowledge" is an attribute of the firm as a whole, as an organized entity, and is not reducible to what any single individual knows, or even to any simple aggregation of the various competencies and capabilities of all the various individuals, equipment and installations of the firm" (63, quotation marks original).

With a similar vein, Brown and Duguid (1991) argue that a community of practice is a construct where shared learning is inextricably located in complex, collaborative social practices. Nahapiet and Ghostal (1998, 246) acknowledge the significance of socially and contextually embedded forms of knowledge and knowing as a source of value differing from the simple aggregation of the knowledge of a set of individuals. However, there are others who do not believe that knowledge can exist in a social or collective mode. Simon, for example, has stated that:

"All organizational learning takes place inside human heads; an organization learns in only two ways: a) by the learning of its members, or b) by ingesting new members who have knowledge the organization didn’t previously have" (Simon 1991, 125).

Simon views an individual as the only entity in knowledge creation. Also, for example, Polanyi (1967) has argued that all human knowing is fundamentally personal. This is acceptable; all our knowing is built on top of meanings we construe, but this is only a half of the fact. The other half is that most of the “building-blocks” used by the knower are inherently social (Tuomi, 1999.) The confusion between the social creation of knowledge and the strictly individually created knowledge is evident and one of the most discussed topic among many disciplines dealing with human interaction, communication, problem-solving, and learning. There is confusion even within and inside single theories. Tuomi (1999), for example, criticizes Nonaka and Takeuchi’s SECI model for not clearly stating the roles of social and individual knowledge creation. As he writes:
"A problem with the SECI model is that it still lingers somewhere between a social and an individual point of view. Although Nonaka and Takeuchi emphasize that the process of knowledge conversion is "social,” their concept of knowledge is still individual and intrapersonal.” (Tuomi 1999, 333, quotation marks original.)

And he continues:

"The SECI model, therefore, combines in an interesting way a social view of learning and an individualistic conception of knowledge. In other words, it sees new knowledge as a collectively created novel design or fact, but it doesn’t see knowledge in relation to social practice. The process is social, but the result is not.” (Tuomi 1999, 335.)

"the SECI model could more accurately be described as a Moebius strip that ends where it starts - in an individual cognition" (Tuomi 1999, 334).

This argument between the social and the individual level of analysis in knowledge creation is the very same I have discussed earlier in this research when considering distributed cognitions. However, as also mentioned earlier, even if a researcher is in favor of the "Vygotsyan camp” and sees that all knowledge is first created at the social level, and only after this, it can become an object of individual reflection, he/she has not been able to watertightly show how this process actually happens in practice. However, in order to argue for or against either one of these views, one has to find a way to integrate both the individual and the social knowledge creation process at the explicit and tacit level of knowing.

Spender (1996) has created an interesting matrix of four different types of organizational knowledge, and Nahapiet and Ghostal (1998) have integrated these types into their
developing theory of intellectual capital. Both conscious knowledge (Spender) and individual explicit knowledge (Nahapiet & Ghostal) are typically available to an individual in the form of facts, concepts, and frameworks that can be stored and retrieved from the memory or personal records. The second element, automatic knowledge (Spender), or individual tacit knowledge (Nahapiet & Ghostal), can take different forms of tacit knowing, including the theoretical and practical knowledge of individual and the performance of different kinds of skills. The other two elements of intellectual capital are objectified knowledge (Spender) or what Nahapiet and Ghostal call social explicit knowledge, and collective knowledge (Spender) or social tacit knowledge in Nahapiet and Ghostal’s terms. Social explicit knowledge represents a shared body of knowledge. Social tacit knowledge represents the knowledge that is fundamentally embedded in the forms of social practices and that resides in the tacit experiences and enactment of the collective. As Nahapiet and Ghostal argue: ”For a given firm, these four elements collectively constitute its intellectual capital” (Nahapiet & Ghostal 1998, 247).

The different elements of organizational knowledge and intellectual capital can be illustrated with the following figure:

![Figure 15. Different elements of organizational knowledge and intellectual capital](image)

Eventhough it is assumable that both Spender and Nahapiet and Ghostal do believe that knowledge creation is social by nature, they are not explicit. Still, the question of the level of analysis remains.
Tuomi (1999) provides us with a “5-A model” of knowledge generation in human society. He argues that a consistent model of knowledge generation has to integrate both the individual and the social levels of knowledge generation, and that the basic constructs for knowledge generation should be “scale-invariant.” He continues that: “Within an organization, knowledge processes transpire on three fundamental and irreducible levels: those of human-in-society, community, and community of communities, i.e., a society” (Tuomi 1999, 347). In his “5-A model”, he distinguishes five modes of knowledge generation: articulation, appropriation, anticipation, accommodation, and action. Every one of these modes of knowing can appear at any level.

Tuomi illustrates his “5-A model” with the following figure:

![Diagram of the 5-A model of knowledge generation](image)

Figure 16. The “5-A model” of knowledge generation (Tuomi 1999).

For example, the articulation processes at the individual “human-in-society” level are processes that create nexus of meaning that can be reflected upon. In other words, these self-referential, non-collective processes can be defined as ‘thinking’, and when thinking leads to a new thought, we have articulated some meaning. Articulation at the “community level”, on the other hand, is based on dialogue and mutual understanding. The individual articulations are fused into collectively-formed concepts which, in turn, are appropriated as community-specific dialects. At the “community of communities” level articulation is born through language and the formation of social institutions and practices.
Appropriation at the “individual level” happens through imitation, the acquisition of knowledge through language and the systems of theoretical concepts, as well as through the development of models about social behavior. Appropriation at the “community level”, on the other hand, happens through the utilization of individually-generated innovations and interpretations, as well as through community-generated practices, tools, and dialects. Appropriation processes at the community of communities level have their source in the structural drift of society, or in the appropriation of knowledge created at the “individual” and “community levels”.

Anticipation, according to Tuomi, underlies all self-referential intelligent action. When the flow of action guided by tacit knowledge breaks down as a result of some kind of a surprise or unexpected situation, our knowledge becomes explicit. At the level of a community, anticipation occurs through the planning of coordinated action or by community routines. Following a similar vein, anticipation at the “community of communities level” consists of the social routines or thoughts of a particular ”collective mind”. However, as Tuomi points out, it is difficult to describe the ways such anticipation occurs at the social level because we do not know the thoughts of this “collective mind”.

Accumulation at the “individual level” produces memory and is the complement to anticipation. Like Tuomi writes: "Memory, as a capability to bring the past to bear on the present, consists of habits, experienced ontogenetic history and accumulated meanings that are used to interpret that history and to impregnate the present with meaning” (Tuomi 1999, 349). Accumulation at the “community level” includes practices, tools, stories, metaphors, paradigms, styles of thought, systems of concepts, and dialects. These are results of mutual coordination and emerge as articulations of a community experience. Accumulation at the “community of communities level” is born through cultural production and reproduction.

To conclude, Tuomi does not totally refuse the idea presented by some theorists and cited also in this study that the human knowing is personal by nature, but he strongly argues that all human knowledge creation fundamentally takes its shape and direction in social
interaction. Also, he is able to show theoretically how this process occurs between the individual and the social planes. Tuomi’s theory, although being more refined and detailed, is similar to what Salomon (1993b) has suggested. He represented the idea of cognitions interacting in a spiral-like fashion. In that model the individual and the social components interact with one another, and the individual’s inputs, through people’s collaborative action, affect the nature of the joint, distributed system, which in turn affects people’s cognitions so that their subsequent participation is altered, resulting in joint performances and products (see page 69). Tuomi also argues that the actual process gluing the various levels of analysis together is communication. This can be considered as somewhat confusing when looking at the figure 16 on page 93. According to the figure by Tuomi, the central process connecting all the other elements of knowledge creation is learning, but armed with quotation marks. Why is that? Is that because his theory is hypothetical in a sense that it has not been empirically tested in real-life situations? Or because he aligns communication and learning? I am not able to answer these questions, but within the following paragraphs, I will concentrate on the question of communication and learning in producing the human capital of a person and the social as well as the intellectual capital of a social collectivity.

Before doing that, I will add the dimension of knowledge creation and the dimension of the level of analysis in to the illustration of the elements of social capital presented in pages 79 and 84.
**Social Capital Attributes of Social Capital Producing Human, Intellectual, and Social Capital**

* Produced in social interaction
* An asset
* Collectively own

**Attributes of Social Capital**
- Structural dimension
- Networks
- Cognitive dimension
- Shared language and codes
- Shared narratives
- Relational dimension
- Trust
- Norms
- Obligations and expectations

**Producing Human, Intellectual, and Social Capital**
- Knowledge creation
- Explicit knowledge
- Tacit knowledge
- Level of analysis
- Individual
- Group/society

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**Figure 17. Elements of social, human, and intellectual capitals.**

### 3.4.1.6 Producing human, intellectual, and social capital

According to the researchers referred to in this section, social capital is seen as the origin and expression of the valuable resource embedded in social-network interactions or relationships, and its attributes are defined to be strong network ties, a shared language and codes, shared narratives, trust, norms, obligations, and expectations. Social capital also seems to have close connections to knowledge creation in social interaction, both at the explicit and the tacit level. However, this vast body of research does not give very clear answers to the following questions: How is social capital produced? How does it come about?

Either these questions are too trivial or the answers so evident, but many researchers seem to pass them pretty easily. Bourdieu (1986), for example, argues that while social capital
resides in relationships, these relationships are created through exchange. Nahapiet and Ghostal (1998) come to almost the same conclusion, stating that social capital is created by the exchange and combination of knowledge and experience. Coleman (1988), on the other hand, has stated that social capital comes about through changes in the relations among people. Even though researchers from various disciplines have found different attributes of social capital, the explanation of the mechanism how it actually is produced remains unclear.

After examining other researchers’ writings, it has become evident that social capital and, thus, human and intellectual capital are produced by communication, sharing, exchanging, and combining information. However, communication, sharing, exchanging, or combining are not enough if an individual or a group does not learn anything of what has been shared. Therefore, I venture to suggest that social capital comes about and is produced by learning. Like Kogut and Zander (1996) argue in their article “What firms do? Coordination, identity, and learning”: “Social interaction in groups facilitates not only communication and coordination, but also learning” (510). While engaging in social interaction, people share knowledge, experiences, ideas, and opinions of their own. I see this sharing either to be reinforced by such factors as high levels of trust and trustworthiness, commonly held norms, a shared language and codes, shared narratives, obligations, and expectations, or vice versa, the sharing can be hindered or it might be slower if there are low levels of trust or trustworthiness, vague norms, difficulties in understanding the language or other codes. I argue that all these different attributes are conditions under which social capital as well as human and intellectual capital are produced, but the actual mechanism of producing these capitals is learning by sharing distributed cognitions, both at the explicit and the tacit levels of knowledge creation.
3.4.2 A look at current theories of learning

Why do I need to find yet another definition for ‘learning’? Are there not enough learning theories already to choose from? Within the next few paragraphs, I will take a closer look at this problem by presenting some current theories of learning. By current theories of learning, I mean those that have risen out from the constructivist and/or socio-cultural approaches to human knowledge generation.

Before going into those, it is important to repeat that, within cognitive psychology, problem-solving has been viewed as the manipulation of problematic situations, comprising the appraisal of the problem, determining the initial and goal states of the problem, and creating the problem space (Newell & Simon 1972). Moreover, problem-solving is seen as being synonymous with learning (e.g. Newell 1980; Anderson 1993). Newell (1980) has even argued that all symbolic activity can profitably be treated as operation within a problem space. In socio-cultural literature problem-solving is viewed through selecting approaches and solutions which are viable within the social circumstances of its application (e.g. Lave & Wenger 1991). However, there is an important difference between learning through problem-solving and learning as problem-solving. In learning through problem-solving, learning results from solving the problem. Learning as problem-solving, however, implies that the goal itself is to learn, and there is something problematic about achieving this goal. (Bereiter & Scardamalia 1989, 364-365.) In the context of technological product development and collaborative problem-solving in that process, people do not often realize that they are learning while solving a problem. Their main goal is to get the problem at hand solved, and, therefore, it can be assumed that in this kind of a problem-solving process, people are learning through problem-solving.
3.4.2.1 Intentional learning

Bereiter and Scardamalia (1989) write about intentional learning and intentional learners. For them, learning, in order to be effective, is an intentional process of an individual. They use the term ‘intentional learning’ to refer to those cognitive processes that have learning as a goal, rather than it being an incidental outcome. Their scope lies in learning in educational settings, mainly in schools, and probably that is the reason why this view of learning is not very suitable in the context of this research. When it comes to technological product development and problem-solving in that process, people are not learning intentionally, they are intentionally solving a problem. The team or its members do not realize that they are learning while solving the problem. They simply learn through or while solving the problem, and learning can be seen as a “by-product” of the problem-solving process.

3.4.2.2 Socially-situated learning

Lave and Wenger (1991) see learning as situated in social action. They explain learning as legitimate peripheral participation, in which legitimate peripheral participators (newcomers) participate in a community of practice and slowly move toward full participation in that community through their engagement in community practices. They write:

"A community of practice is a set of relations among persons, activity, and world, over time and in relations with other tangential and overlapping communities of practice. A community of practice is an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage. Thus, participation in the cultural practice in which any knowledge exists is an epistemological principle of learning. The social structure of this practice, its power relations, and its conditions for legitimacy define possibilities for learning (i.e., for legitimate peripheral participation).” (Lave & Wenger 1991, 98, parentheses original.)
For Lave and Wenger, legitimate peripheral participation refers to both the development of knowledgeable skilled identities and the reproduction and transformation of the communities of practice. They give empirical examples of Yucatan midwives, Vai and Gola tailors, naval quartermasters, meat cutters, and Alcoholics Anonymous to stress the social nature of learning. This process has also been called ‘cognitive apprenticeship’ (cf. Collins, Brown, & Newman, 1989; Orr, 1990). Lave and Wenger (1991) argue that learning involves the whole person, not only in relation to certain activities, but also in relation to social communities of practice. According to them, learning occurs through participation in the ongoing social world. Situated learning as a model of learning and instruction has grown out of a general theoretical shift “from behavioral to cognitive to constructivist” learning perspectives (Ertmer & Newby 1993, 50). The proponents of situated learning argue that meaningful learning only takes place if it is embedded in the social and physical context within which it will be used (Brown et al. 1989; Lave & Wenger 1991).

### 3.4.2.3 The socio-cultural theory of learning

According to the socio-cultural theorists, an individual acquires new mental functions and patterns of thought through the mediational assistance of tools, signs, and human scaffolding when they are offered within his/her zone of proximal development (Salomon 1988; Wertsch 1991b). Vygotsky (1978) defined the ‘zone of proximal development’ (ZPD) as ”the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (86). Vygotsky’s main argument was that higher mental functions are first acquired on the social plane (external plane), and they become internalized only subsequently. He writes:
“Any function in the child’s cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category. This is equally true with regard to voluntary attention, logical memory, the formation of concepts, and the development of volition. We may consider this position as a law in the full sense of the word, but it goes without saying that internalization transforms the process itself and changes its structure and functions. Social relations or relations among people genetically underlie all higher functions and their interrelationships.” (Vygotsky 1981, 163.)

A key assumption here is that learning is not an exact copying process, instead, the learner appropriates or applies skills or information based on his/her own skills, needs, and experiences (Bonk & Cunningham 1998, 36).

This is also one of the main ideas of constructivism which is based on the fundamental assumption that people create knowledge from the interaction between their existing knowledge or beliefs and the new ideas or situations they encounter. Like Resnick (1989) argues: "First, learning is a process of knowledge construction, not of knowledge recording or absorption. Second, learning is knowledge-dependent; people use current knowledge to construct new knowledge: Third, learning is highly tuned to the situation in which it takes place.” (1, emphases original.) The idea that people construct new knowledge based on their previous understanding is also the main argument of the so called schema and mental models theories (cf. e.g. Anderson & Pearson, 1984; Norman 1983). These theories are often labeled as cognitive learning theories. The difference between this kind of constructivism (often called “traditional constructivism”) and socio-cultural constructivism lies on the assumption of the locus of knowledge. Within the former framework, an individual is considered to be the “meaning maker”, and the development of the individual’s
personal knowledge is the main goal of learning. Whereas, within the socio-cultural perspective, knowledge is seen as constructed by an individual’s interaction with the social milieu where he/she is situated, resulting in a change in both the individual and the milieu.

The other theoretical argument, outlined by Vygotsky, was the claim that all human mental action is mediated by tools (technical tools) and signs (psychological tools). The tools and signs a person is exposed to influence or mediate new patterns of thought and mental functioning (Wertsch 1991b). Vygotsky wanted to make a clear difference between technical and psychological tools. He also wanted to stress the importance of the both of them in human development, but actually wrote more about the latter one. He stated that:

"a tool...serves as a conductor of humans’ influence on the object of their activity. It is directed toward the external world; it must stimulate some changes in the object; it is a means of humans’ external activity, directed toward the subjugation of nature” (Vygotsky 1960, 125, in Wertsch 1985, 78).

A sign, on the other hand:

"changes nothing in the object of a psychological operation. A sign is a means for psychologically influencing behavior - either the behavior of another or one’s own behavior; it is a means of internal activity, directed toward the mastery of humans themselves. A sign is inwardly directed.” (Vygotsky 1960, 125, in Wertsch 1985, 78.)

Vygotsky also wanted to stress that psychological tools – signs - are social, not organic nor individual. They are social, first of all, because psychological tools, such as a language, various systems for counting, mnemonic techniques, and algebraic symbol systems, are the products of socio-cultural evolution. They are neither invented by each individual alone nor discovered in an individual’s independent interaction with nature. They are also social because they are not inherited in the form of instincts or unconditional reflexes. Instead,
individuals have access to psychological tools by virtue of being a part of a socio-cultural milieu. (Wertsch 1985, 80.)

While Lave and Wenger’s legitimate peripheral participation and Vygotsky’s socio-cultural theories stress an apprenticeship arrangement in learning, they implicitly agree that there is always someone how “knows better” than the other. However, if learning is seen as a problem-solving process, this view does not hold within a technological product development team. When solving highly complex, ill-defined problems in a collaborative mode, it is often unlikely that there is always someone in the team that knows something better than the others.

3.4.2.4 The process models of learning

There are many process models of learning that see learning as a cycle-like process in which the phases of learning follow each other. Maybe one of the most influential models of adult learning has been proposed by Kolb (1984). In this model, which Kolb calls ”the experiential learning model”, learning occurs through a sequence of phases in which concrete experiences generate an opportunity for observation and reflection which, in turn, lead to the creation of new concepts and models that are then tested in new situations.
According to Kolb, learners need four types of skills to make the learning cycle effective. First, they have to be able to engage openly and without prejudice in new experiences. Secondly, they need to reflect (cf. Schön 1983, 1987) and observe their experiences from many points of view, and, thirdly, they have to create concepts that integrate the observations into logically sound theories, and, finally, use these theories in decision-making and problem-solving. (Kolb 1984, 30.)

Another learning cycle model referred to here is Engeström’s learning cycle. Engeström’s (1999) model inherently incorporates the idea that learning is a social process. In his model, the first step is questioning. A problem emerges that requires a solution. Next, the problem is analyzed, and based on the created understanding of the problem, a solution model is produced, its characteristics are examined, and a promising solution is implemented. After the implementation, the whole process is reflected on and new practices are consolidated.
When comparing these two learning models, one fundamental question must be asked: Who is it that learns? Is it the individual, or can it be possible that groups, teams, or organizations learn? Kolb’s model has been very widely used by organizational practitioners. However, the unit of analysis is vague in his model. It has been used to explain individual, team, and organizational learning. Miettinen (1998) has criticized Kolb’s model by saying that it is only a collection of theoretically unrelated concepts. Engeström’s model, on the contrary, is not intended to be a model of individual learning, instead, learning is assumed to be related to a change in social practices already at the beginning. His model describes learning in groups, teams, or whole organizations. This means that the distributed cognition view is built-in in the model.

This takes us back to the question discussed earlier, the question of the unit of analysis. This question is so fundamental that it can be called an argument. While, for example, Simon (1991) stresses that organizations do not learn, only their members do, there are others that argue otherwise. In a camp that can be called ”human-learning-is-inherently-social”, researchers quoted in this research (e.g. Vygotsky, Lave, Wenger, Collins, Brown, Duguid,
Orr, Engeström and Tuomi) argue that individual learning is impossible without social interaction. As Tuomi (1999) writes:

"The individual learner is not a solitary identity, who absorbs and internalizes existing "knowledge" in the learning process. Instead, the individual, as a learner and an identity, is fundamentally constructed through the same social process that makes the individual a member of a community. We are who we are through membership in such communities. One could say that although we are individual bodies, in some biological sense, our identity is not inside our bodies but exists in the social world. Our intelligence constructs the world around this identity, and therefore our perception and thinking rest on collective basis.” (313-314, quotation marks original.)

3.4.3 Learning through problem-solving in a collaborative mode - producing human, social, and intellectual capital

The constructs of human, social, or intellectual capital would not be valid if learning was only seen as an individual process. I see that the basic idea of these concepts is the acceptation of the social nature of human interaction, knowledge creation, and learning. The construct of human capital, even though being an attribute of an individual, is also dependable on the social dimension of human interaction. Therefore, in my developing framework of cognitive and collaborative problem-solving, learning is seen as a formation of both human capital (as skills, knowledge, and attributes of a single person) and intellectual capital (as the knowledge and knowing capability of a social collectivity). It is also seen as the production of social capital of a particular team of problem solvers. This is tied to the outcome or the product of the collaborative problem-solving process at the cognitive level. I argue that the product of a collaborative problem-solving process (at the cognitive level) is, at the individual level, human capital of a person, and, at the social level, intellectual and social capital of a collaboratively working group of people. Now, it is possible to add the fourth and the last dimension to the figure of different elements of social
capital presented in pages 79, 84 and 96. This dimension stresses the importance of learning in the production of all three forms of capital: human, intellectual, and social.

Figure 20. Elements of social, human, and intellectual capitals.
The dimension of producing human, intellectual, and social capital by learning is the answer to the question of what is being learned. In other words, an individual in a group learns something about the subject matter at hand, but also new skills, and, finally, he/she gains other personal attributes. The group, instead, gains knowledge and knowing capacity that is collectively own. It also gains some of the so called "knowing-who” knowledge, which is own by that certain collectivity of people.

3.5 An novel approach to cognitive and collaborative problem-solving and learning

The ultimate goal of this research is to capture the characteristics of a cognitive and collaborative problem-solving and learning processes embedded in the technological product development processes of R & D teams. As already argued earlier in this research, all problem-solving is carried out in some problem space. This space was taken under detailed investigation through theoretical lenses described and developed within this section. Based on the theoretical orientations described, I have developed six theoretical stepping stones according to which to outline the overall problem space, formulate the research questions, and analyze the empirical data.

The six components of this developing theory of cognitive and collaborative problem-solving and learning process are: 1) a problem, 2) practical tools, 3) cognitive tools, 4) human capital, 5) intellectual capital, and 6) social capital.

The whole process of learning through problem-solving in a collaborative mode with its implications (i.e. is what is being learned) can be illustrated with the following figure:
First, a problem must exist. After identifying the problem, the definition of the problem itself, the problem situation, and the possible constraints is made. In order to solve the problem, some practical as well as cognitive tools are being used. The fundamental cognitive outcome of the problem-solving process is a three-veined learning process, creating capital surplus of human, intellectual, and social capital.
CONDUCTING THE RESEARCH

4.1 Research problems

The main goal of this research is to develop a novel approach to cognitive and collective problem-solving and learning processes. In order to capture this phenomenon, the processes of collaborative problem-solving and learning taking place in technological product development are investigated. To be able to capture the cognitive and collaborative problem-solving and learning processes embedded in technological product development, in all their glory, it is necessary to study all aspects of the joint problem space simultaneously. My developing framework for conceptualizing the cognitive and collaborative problem-solving and learning processes is influenced by five theoretical viewpoints: 1) the information processing approach, 2) the theory of efficient action, 3) the metacognitive nature of cognitions, 4) the interacting nature of distributed cognitions, and 5) the production of human, intellectual, and social capital by learning.

As this research is both theory and data-driven, the research problems also arise from both – the theoretical construct presented in the earlier sections and the empirical data gathered for this research. The research question is:

**How do the processes of cognitive and collaborative problem-solving and learning occur in technological product development?**

In order to find an answer to this question, the following sub-questions must be asked:

1. What are the characteristics of an R & D problem and the problem-solving situations of R & D processes?
2. What practical tools are used by problem solver(s) in solving R & D problems?
3. What cognitive tools are used by problem solver(s) in solving R & D problems?
4. What kind of learning takes place in a collaborative problem-solving process?
The most fundamental ontological question that needs to be asked when considering the epistemological as well as the methodological orientation of this research is the question of language and cognition. Are we able to rely on the assumption that the meanings we express in words are direct and true reflections of our cognitions?

This question has been argued for and against by several researchers. For example, Mandler (1975), Miller (1962), and Neisser (1967) have proposed that we may have no direct access to the higher-order mental processes involved in problem-solving. Miller (1962) has stated that: "It is the result of thinking, not the process of thinking, that appears spontaneously in consciousness" (56). Neisser (1967), on the other hand, writes: "The constructive processes themselves never appear in consciousness, their products do" (301). Similarly, Mandler argues that: "There are many systems that cannot be brought into consciousness, and probably most systems that analyze the environment in the first place have that characteristic. In most of these cases, only the products of cognitive and mental activities are available to consciousness." (245.) Despite these rather judgmental statements (which they really are because of the lack of supporting data), a vast amount of qualitative research on human behavior and cognitive processes is conducted with the underlying assumption that there is thought in a language. As argued at the beginning of this research, research on collaborative human problem-solving and learning processes must be conducted within real-life situations in which people solve real work-related problems with minimum interference from the researcher. Emphasizing these premises, the only possible ontological explanation would be that language is, at least, the nearest to cognitions and perhaps the only access to higher-order cognitive processes. Like Cranach et al. (1986) have stated:

"...the relationship between conscious cognitions and language, it is certainly close. We are well aware of the fact that the linguistic representation is not identical with the represented underlying cognition. Still it is so isomorphic that ideas can be translated into utterances; it is the nearest to cognitions that we can get at all." (206.)
The often quoted phrase, "the end justifies the means", is especially true when considering the epistemological and methodological orientation of this research. It is my strong belief that when studying human behavior of any kind, the epistemological and methodological decisions made before and during the research process should serve the ultimate goal: finding a true answer to the particular research problem. Not vice versa. Furthermore, neither epistemological nor methodological orientation should be followed blindly, but one should carefully consider the epistemological as well as the methodological decisions keeping in mind the ultimate goal of finding the true answers. As the ultimate goal of this research is to understand the cognitive and collaborative problem-solving and learning processes embedded in the technological product development process within real-life problem-solving situations, the most appropriate and epistemologically-justified research approach is an empirical as well as a qualitative inquiry. This approach aims for real and true understanding by describing and explaining the phenomenon under study as well as by using empirical data gathered in real-life circumstances to proof its arguments (Puolimatka 1995, 11). Although there are many definitions of qualitative research available in literature, I confine to one:

"Qualitative research is multimethod in focus, involving an interpretive, naturalistic approach to its subject matter. This means that qualitative researchers study things in their natural settings, attempting to make sense of or interpret phenomena in terms of the meanings people bring to them. Qualitative research involves the studied use and collection of a variety of empirical materials – case study, personal experience, introspective, life story, interview, observational, historical, interactional, and visual texts – that describe routine and problematic moments and meaning in individuals' lives."

(Denzin & Lincoln 1994, 2.)

When conducting a qualitative study and, even more so, when defending its reliability by answering questions like "What is competent reasoning?" and "What is logically true?", the
question of research logic becomes important. There are at least three ways of approaching this subject matter: deductively, inductively, or abductively.

If the argumentation logic of this research was deductive, it would mean that the phenomenon under study as well as the research problems are approached through some already existing theory. A researcher then, applies an actual theory through which he/she collects the empirical data and analyzes it. The purpose of the investigation would be to test and verify the explanatory power of a certain theory against a certain phenomenon. In deductive argumentation, the verification of a phenomenon is carried out within the limits of an approved margin of error, and the sampling criteria are often determined as representative. However, in qualitative research, it is relatively cumbersome and often unnecessary to use a representative sample (with the exception of overall sampling). (cf. e.g. Grönfors 1982; Niiniluoto 1983.) In human science, rigorous deductive argumentation as a research logic significantly narrows the overall functional space where people act and a researcher carries out his/her investigation.

Induction as research logic, on the other hand, points out the importance of the research subject or subjects. A purely inductive inquiry constructs (usually through a qualitative analysis) a theory based on the collected data. The ultimate goal of inductive argumentation is to discover the essential characteristics of a certain phenomenon and to express how these characteristics are organized in reality. The theory is formulated from the collected data with the help of a comprehensive analysis. In other words, with an inductive research logic, the researcher tries to ensure that all aspects of the phenomenon can be taken under consideration and that the formulated theory really describes the phenomenon studied. (cf. e.g. Strauss & Corbin 1990; Grönfors 1982.) Purely inductive argumentation has been criticized because of the impossibility of "theory-less" perceptions. Like Grönfors (1982) argues:
"...pure inductive argumentation is hardly possible. If a researcher had no preconceptions and assumptions about the phenomena under study, and the relations between those phenomena, he would end up only to describe his observations, which is equally impossible without some selective processes based on some preconceptions." (36.)

Thus, a researcher always holds some preconceptions and presuppositions about the phenomenon under study. The development of the research question and the collecting and analyzing of the data are always based on some assumptions about the reality. The case being so, we cannot talk about inductive argumentation anymore.

The abductive research logic places itself between deductive and inductive argumentation. While deductive argumentation proceeds from general to particular, and inductive from particular to general (eventhough these lines of reasoning are not generally accepted among theorists), abductive argumentation proceeds both ways. Abductive argumentation, which was first introduced by the American philosopher Charles Pierce (1839-1914), is based on the idea that new scientific discoveries are possible only when they are based on some guiding principles. A new theory will not accrue based on observation only, like inductive argumentation supposes. The guiding principle in abductive argumentation can be either a rather indefinable and intuitive conception of some phenomenon or a sound hypothesis. With the guiding principle in mind, observations can be concentrated on some matters or circumstances, which are believed to produce new ideas and wisdom (Pierce 1958, 96-97). How do guiding principles arise then? According to Grönfors (1982), they can arise from the data, previous research findings, or theory. The process of analyzing the research data is a continuous dialogue between the data, previous research findings, the theory, and the researcher's intuition. The guiding principle can be abandoned or changed to another one during the course of the research. There can also be many guiding principles, and abductive argumentation enables unusual and surprising things to be considered during the course of a particular research.
However, there are no unambiguous instructions for abductive argumentation. This situation is typical of all qualitative research; there are no "ready-made recipes" which to follow when conducting qualitative research. Thus, the research methods as well as the analyzing techniques must be tailored for each study. When following abductive research logic, the researcher must be familiar with his/her own presupposals, values, and beliefs. He/she must also overcome these presupposals to be able to see and understand the phenomenon under study. Making use of abductive research logic also means that the researcher collects, codes, and analyzes the empirical data all the time. In this way, abductive research logic aligns with inductive logic. In abductive research orientation, the data collection and analysis form a circle, but the influence of the theoretical framework is more openly present than in the inductive research orientation. (Alasuutari 1989.) In other words, when acknowledged, the theoretical framework connects the theory and the empirical observations together in a meaningful manner. The theory and empirical findings are parallel, not separate processes.

Like stated earlier, my developing theoretical framework for conceptualizing collaborative problem-solving and learning processes is influenced by five theoretical viewpoints: a) the information processing approach, b) the theory of efficient action, c) the metacognitive nature of cognitions, d) the interactive nature of distributed cognitions, and e) the production of human, intellectual, and social capital by learning. However, it is not the intention of this study to deductively test these theories, but to use them as theoretical stepping stones when analyzing the empirical data and developing a novel approach to cognitive and collaborative problem-solving and learning processes. Still, the theoretical framework of this research brings about some methodological considerations that affect the way the research is conducted. First of all, while people are understood as individuals who work, learn, and solve problems in collaboration with others, and the individual is a single entity but exists in interaction with other people, the following methodological aspects must be acknowledged and admitted:

- The researcher understands the research subject through his/her own knowledge structures.
- The research subject understands the researcher and the research methods through his/her knowledge structures.
The presupposals and prejudices of both the researcher and the research subject are unavoidable as well as necessary.

There are no clear criteria for the interpretation of the research findings.

Both the researcher and the research subject learn during the research process, and this leads to a change in the knowledge structures of the both of them.

Secondly, these methodological aspects have an impact on the research logic: while formulating the research questions, collecting and analyzing the empirical data, the researcher is forced to carry out a tight dialogue between the theoretical framework and the empirical data collected for the particular research. This dialogue is the only way for the researcher to keep up with the effects of the above mentioned methodological aspects during the course of the research. The dialogue is the only way the researcher is able to find the guiding principles which to follow. With the abductive research orientation, it is possible to avoid studying the phenomenon from a too narrow, beforehand-chosen theoretical perspective, and, on the other hand, to avoid the illusion that previous theoretical knowledge would not affect the course of the research.

With the following illustration, I shall show the interaction between the ontological, epistemological, and methodological orientations as well as the research methods used in this study. None of these aspects should function separately, but they should interact during the research project. I call these orientations the underlying assumptions of this research.
Figure 22. The interactive nature of the underlying assumptions of this research.
4.3 Research subjects and methods

The empirical data of this research was gathered in two phases. In the first phase, twelve engineers from the fields of industrial design, planning engineering, and teaching were interviewed using the theme interview method. The length of the interviews varied from one hour to three hours.

During the second phase of the data gathering, in order to identify the practical and cognitive tools used in technological problem-solving, 46 problem-solving episodes were observed and videotaped by the researcher. The episodes were gathered using the case study method. The case study method is the preferred strategy when “how” or “why” questions are being posed, when the researcher has minimal control over what happens, or when the focus is on a contemporary phenomenon within some real-life context (Yin, 1994, 1). In this research, the “how” question is being asked. The observed and videotaped data was gathered in real-life problem-solving events which the researcher had no control over what so ever. The cases under study were chosen from two R & D teams working in real-life problem-solving situations.

Team Y worked at a relatively large (turnover 5,5 billion FIM in the year 2000) Finnish construction company which can also be called “a low-tech” company. This team consisted of five civil engineers, all men. They were all employed in the company. The youngest was 27 years old, and the oldest had just turned 50. The average age was 37,2 years. Their working experience ranged from three to 24 years. The average working experience was 14,4 years. Four out of five had received their graduate diploma from a technical university, and one had got it from a technical college. The task of team Y was to create a new house-building model for their region.

Team B worked at a growing medical technology company which can also be labeled as a "high-tech" company. This company is an affiliate company with the parent company located in the United States. Team B consisted of four people, two men and two women. The youngest was a 25-year-old production engineering student doing her thesis required
for the university diploma. One was a 30-year-old material engineer working at the University of Technology. The two others were actual employees of the company. Both were graduated mechanical engineers. The oldest was 39 years old, and the average age was 32.8 years. The working experience among this team ranged from one year to 15 years, and the average working experience was 8.5 years. The task of team B was to create a new package and a new packing line for some of their products.

4.4 Research design

As already mentioned, 12 engineers from different fields were interviewed in the first phase of the data gathering. The purpose of these interviews was a) to find answers to the first research question of what the characteristics of a R & D problem and problem-solving situation in R & D process are, and b) to get an idea of possible answers to the second question. The interview themes were the following:

- Who solve R & D problems?
- What are the common characteristics of R & D problems?
- What are the constraints of R & D problems?
- What are the common features of the technological problem-solving process?

After transcribing and analyzing the data gathered from these interviews, two cases - team Y and team B - were studied. In both of the cases, the data gathering started with interviews, and every team member was interviewed separately. The first purpose of the first interview was to get background information about the company, the interviewee, and the R & D project under investigation. The second purpose was to find answers to the first research question about the characteristics of R & D problems as well as problem-solving situations occurring in technological product development processes. The common themes in the first interview were the following:
• Background information about the interviewee
• Background information about the company
• Background information about the R & D project under study
  • The definition of the R & D project
  • The problem statement of the R & D project
    (initial state, goal state, and constraints)
    • The proceeding of the R & D project
    • Specific rules of the R & D project
    • Agents of the R & D project
    • Responsibilities of the R & D project
• Individual as a team member
  • Responsibilities of the individual
  • What does the individual already know about the problem?
• Developing teams
  • The composition of the team
  • Why and how was the team developed?
  • By whom was the team developed?

After the so called orientation interviews, the researcher observed and videotaped team meetings. During this period, so called reflective interviews were made. These interviews were made a) in order to verify the researcher’s interpretations, which were based on direct observations made during team meetings, and b) to build a deeper understanding of the problem-solving and learning process from an individual’s point of view. The common themes of the second interview were the following:
• Verifying the researcher’s observations of the practical tools used in the problem-solving process
• The individual’s prior knowledge and skills in the area concerning this particular R & D project
• What kind of new knowledge or skills did the individual acquire during this project?
• How did the individual proceed in this R & D project?
• Did the individual know if he/she was doing the right things, and how did he/she know that?
• How did the individual know when the problem was solved?
• Has the individual learned something during the process?

The purpose of the direct observation of the team meetings was to find answers to the second research question: What practical tools are used by problem solver(s) while solving R & D problems? During team meetings, the researcher marked down every practical tool used either by an individual or by the team that seemed to help either the individual or the team to reach better understanding of the problem at hand. The researcher’s direct observations were later verified by the team members during the second interviews. The observations were not used to analyze how well or poorly the team or its members were functioning.

In order to answer the research question number three about what cognitive tools are used by problem solver(s) while solving R & D problems, videotaped team meetings were transcribed and analyzed using thematic analysis. Thematic analysis is a process that can be used to encode qualitative information (Boyatzis 1998, 4). In this research, thematic analysis was used as a way to systematically analyze qualitative information, and it was done in two phases. First, thematic coding was done to discover both the individual cognitive and metacognitive functions used in collaborative problem-solving as well as the distributed cognitive and group metacognitive functions used in collaborative problem-solving. All these processes can be labeled as higher cognitive functions. Secondly, every statement was defined based on the kind of elementary (or lower) cognitive function it expresses.

To investigate what kind of learning takes place (the research question number four) in a collaborative problem-solving process, the videotaped and transcribed team meetings as well as the transcribed interviews were analyzed.
An overview of the empirical data gathered for this research can be illustrated with the following table:

<table>
<thead>
<tr>
<th>Interviews</th>
<th>12 engineers</th>
<th>1-3 hours/interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>Case Y</td>
<td>Case B</td>
</tr>
<tr>
<td></td>
<td>(low-tech company)</td>
<td>(high-tech company)</td>
</tr>
<tr>
<td>Videotaped Team Meetings</td>
<td>3, appr. 6 hours</td>
<td>4, appr. 10 hours</td>
</tr>
<tr>
<td>Observations</td>
<td>appr. 6 hours</td>
<td>appr. 10 hours</td>
</tr>
<tr>
<td>Interviews</td>
<td>10 (2 interviews / team member)</td>
<td>8 (2 interviews /team member)</td>
</tr>
</tbody>
</table>

Table 2. An overview of the empirical data.

4.5 Unit of analysis, unit of coding, and development of the analysis matrix

In order to discover the cognitive tools (both individual and distributed) used in collaborative problem-solving processes, videotaped team meetings were transcribed and analyzed using a thematic analysis method. Each videotaped team meeting can be seen as consisting of several problem-solving episodes. The episode is a problem-solving event in which the team deals with one problem statement. Within the episode, each utterance is individuated by content cues so that whenever there is a shift in a person or a topic, a new utterance is instantiated. Therefore, the unit of coding is an individual, but the actual analysis is not detached from the discussion context. The discussion context is particularly important here. Like Bakhtin (1986) has argued: "Utterances are not indifferent to one another, and are not self-sufficient; they are aware of and mutually reflect one another" (91). Therefore, every coded utterance and its reflected meaning is analyzed based on the discussion context. By discussion context I mean the overall discussion generated by individual voices. Let the following example explain:
Case B
Part of episode 1.4.

Hilkka: "What are the requirements of the product itself, why does it need to be packed?"

Kari: "Well, the requirements are..."

Hilkka: interrupts: "Of course, a part of the reason is that, in a moist body, the product will dissolve, but the product retains its solidity in a dry, dark, and cool atmosphere."

Miisa: "The package itself won't regulate the temperature..."

Hilkka: "No, that's right."

Hilkka: "But the package will provide a moist block, a light block."

Kari: "Here we come to the point which we have discussed earlier, the storing temperature, how can we store the product?"

If the cognitive tools used in this example were analyzed without considering the discussion context, just taking a single utterance under analysis, the result would be the following:

Hilkka: "What are the requirements of the product itself, why does it need to be packed?"

asking

Kari: "Well, the requirements are..."

answering

Hilkka: interrupts: "Of course, a part of the reason is that, in a moist body, the product will dissolve, but the product retains its solidity in a dry, dark, and cool atmosphere."

answering

Miisa: "the package itself won't regulate the temperature..."

answering

Hilkka: "No, that's right."

agreeing

Hilkka: "But the package will provide a moist block, a light block."

explaining
"Here we come to the point which we have discussed earlier, the storing temperature, how can we store the product?"

asking

However, if the context of discussion is considered, and the discussion is understood as formed by utterances that have a tight relation to the other utterances and speaking voices, the example can be analyzed more deeply:

"What are the requirements of the product itself, why does it need to be packed?"

Understanding that the problem exists (individual higher cognitive functioning) and asking (individual elementary cognitive functioning), and sharing understanding (distributed cognitive functioning)

"Well, the requirements are..."

Sharing the perception that a problem exists (distributed cognitive functioning) and answering (individual elementary cognitive functioning)

interrupts: "Of course, a part of the reason is that, in a moist body, the product will dissolve, but the product retains its solidity in a dry, dark, and cool atmosphere."

Sharing information about a possible solution (distributed cognitive functioning) and answering (individual elementary cognitive functioning)

"The package itself won't regulate the temperature..."

Understanding the limitation (individual higher cognitive functioning), and sharing information about a limitation of the problem-solving (distributed higher cognitive functioning) and answering (individual elementary cognitive functioning)

"No, that's right."

Understanding the limitation (individual higher cognitive functioning), and sharing the limitation (distributed higher cognitive functioning) and agreeing (individual elementary cognitive functioning)

"But the package will provide a moist block, a light block."

Understanding the solution (individual higher cognitive functioning), and sharing information about the possible solution (distributed higher cognitive functioning) and explaining (individual elementary cognitive functioning)
"Here we come to the point which we have discussed earlier, the storing temperature, how can we store the product?"

Representing the problem (individual higher cognitive functioning), asking (individual elementary cognitive functioning), and knowing what has been discussed earlier (group's metacognitive functioning)

As can easily be seen, the consideration of the discussion context while analyzing empirical data is a necessary premise for a rich and true analysis. Analysis made to all problem-solving episodes follows the line of reasoning presented above. It must also be noted that the categories are not disjunctive: a single utterance can fall into more than one category. An overview of the problem-solving episodes and utterances coded in this research is presented with the following table:

| Case  | Problem-solving Episodes | Utterances | | | |
|-------|--------------------------|------------|------------|------------|
|       |                          | Total      | Most/Episode | Least/Episode | Average/Episode |
| Case B| 25                       | 746        | 95          | 8           | 30             |
| Case Y| 21                       | 691        | 79          | 6           | 33             |

Table 3. An overview of the problem-solving episodes.

Each utterance was individually coded according to a scheme that consisted of four broad categories: (a) individual cognitive functions, (b) distributed cognitive functions, (c) individual metacognitive functions, and (d) the group's metacognitive functions. Within these broad categories, each utterance was analyzed with a more specific focus. Non-relevant talk (off-task talk) includes non-serious comments, jokes, etc. The analysis matrix used for coding the transcribed team discussions was the following:
Table 4. The analysis matrix used for coding the transcribed team discussions.

The analysis matrix was partly developed based on the findings of previous research and theories of human problem-solving, and partly by further elaborating the existing theories as well as inductively based on the empirical findings of this particular research. The creation of each thematic code is described in detail in the next section.

The coding was carried out by the researcher. A measure of stability for the coding was obtained by coding the transcripts twice, half a year apart. The congruence between all of the coded problem-solving episodes was 95.6% (for case B) and 97.8% (for case Y). The compositions of all of the coded episodes for both cases can be seen in appendices 1 and 2. Also, two examples of the coded problem-solving episodes for both cases can be seen in appendices 3, 4, 5, and 6.

To help the reader to differentiate the information source (i.e. phase I or phase II) of the empirical data gathered through interviews and videotaped team meetings, every utterance quoted in this research is provided with the following information:
1. The information source: either an interview or a videotaped team meeting.
2. The first name of the informant (if two or more people have the same name, the first initial(s) of his/her last name is given).
3. If significant, the title of the informant is notified.
4. If the informant belongs to either of the R & D teams studied, the case is notified (i.e. case B or case Y).
The language used during the interviews and team meetings was Finnish. Therefore, all pieces of interviews as well as the transcripts of the team meetings quoted in this research have been translated from Finnish to English by the researcher.

4.6 The joint performance of the theoretical framework, research problems, research methods, and the empirical data

With the following illustration, I wish to describe how the theoretical framework (discussed in section 4), research methods (discussed in the current section), and the empirical data gathered for this research combine. The theoretical framework can be seen as “a lens of a magnifying glass”. Through this “lens”, and with the help of the research methods, the empirical data was managed, processed, and finally analyzed.
A PROBLEM
Columns 1, 2, 3, 4

HUMAN CAPITAL
Column 7

SOCIAL CAPITAL
Column 7

COGNITIVE TOOLS
Column 6

PRACTICAL TOOLS
Column 5

INTELLECTUAL CAPITAL
Column 7

<table>
<thead>
<tr>
<th>Research question #1</th>
<th>Research question #2</th>
<th>Research question #3</th>
<th>Research question #4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Column 1</strong></td>
<td><strong>Column 2</strong></td>
<td><strong>Column 3</strong></td>
<td><strong>Column 4</strong></td>
</tr>
<tr>
<td>Research methods: theme interview (Phase 1) case study (Phase 2) Research techniques: interviewing, transcribing videotaped team meetings</td>
<td>Research method: case study (Phase 2) Research techniques: observing team meetings, verifying interviews</td>
<td>Research method: case study (Phase 2) Research technique: transcribing and coding videotaped team meetings = thematic analysis</td>
<td>Research method: case study (Phase 2) Research techniques: transcribing videotaped team meetings, interviewing</td>
</tr>
</tbody>
</table>

Figure 23. The interactive model of the theoretical framework, research problems, research methods, and the empirical data.
The main goal of this research was to capture the problem-solving and learning processes of a collaboratively working technological product development (R & D) team. In order to reach the goal, the overall space where the actual problem-solving takes place must be investigated.

Within the information processing theory of human problem-solving, one of the most important constructs is the definition of ‘problem space’. All problem-solving takes place in some problem space. This problem space refers to the whole problem-solving process and includes: 1) an information processing system (which can e.g. be person or a computer); 2) a task environment which refers to the problem statement which, in turn, includes the initial and the goal state of the particular problem, but also physiological as well as problem-specific constraints under which the problem must be solved. Within this problem space, the information processing system solves a problem using different strategies and operators (see figure 4 in page 25).

The theory of efficient action, praxiology, sees the human problem-solving process more or less similarly to what was just described. Both Kotarbinski and Meloe talk about the information processing system as an agent (or, simply, ‘X’ in Meloe's terminology) actually solving the problem. The problem statement, or ‘Y’ in Meloe's terms, and ‘product’ or ‘result’ in Kotarbinski's terms, on the other hand, is the object of the problem-solving activities (see figure 5 in page 32).

In order to investigate the overall problem space, the main research task has been decomposed into four research questions. The purpose of this section is to answer the first question: What are the characteristics of problems and problem-solving situations in technological product development processes?
5.1 The characteristics of problems and problem-solving situations in technological product development

In order to reveal the overall nature of the problem space in technological product development, the following aspects of this space are investigated in this section: the information processing system/agent/X, the task environment, including the characteristics of technological problems, the characteristics of the problem-solving situation, the initial and the goal state of the problem, as well as the characteristics of the problem constraints of technological product-development-related problems. All aspects are investigated qualitatively through interviews carried out for this particular research as well as through observed team meetings.

5.1.1 Who solves problems?

The first step in revealing the overall nature of the problem space in technological product development is the answering of the “who” question. Who is the information processing system/agent/X who solves problems in technological product development process?

The interviewees were asked if they carried out their work alone or in a group. All except one worked with a group of people. The reason for doing team-work was very clear: in order to be successful in today's R & D world, people must co-operate. Co-operation is an essential part of the R & D process mainly because one person, no matter how well-educated and experienced, cannot by him/herself manage all areas of expertise required in the R & D processes. The following comment illustrates the situation well:

"...all products have become kind of 'cross-technical', so they demand the mastering of different parts of technology, and very seldom can one person master all of them. So that's why we need to do team-work." (an interview Juha J.)
To conclude, in technological product development, the information processing system, or the agent, or the X carrying out the actual problem-solving is not a single person, but a group of people working together. This real life phenomena arises from the argument discussed earlier in this research. In section 4, the contemporary psychology's as well as information processing theory's way of approaching human cognition and problem-solving in particular was blamed for conducting laboratory research that does not reveal the real-life circumstances of human cognition and problem-solving behavior. Furthermore, it does not realize the collaborative nature of human cognition and problem-solving activities. In today's R & D processes, the information processing system is not a single person, but a group of people working together. Therefore, the notion of collective action and co-operation in Kotarbinski's theory of efficient action becomes valuable (presented in Chapter 2.4.2). For Kotarbinski, co-operation is an essential part of effective action of whatever kind. He also realizes the double-edged nature of co-operation because he argues that it can be both positive and negative. Co-operation is positive if the agents working together help each other and work toward the same goal. It is negative if the agents hinder each other from reaching the goal. The presence of co-operation became evident during the course of this research. However, if most R & D processes are carried out in collaboration with others as a team, how are these teams drawn together, and on what basis do certain people form a team?

During the first interview, every team member was asked why they think they belong to the R & D team. The answers were convincing. Every member of both of the teams saw that their belonging is based on their position in the hierarchy of the company as well as their duties. Here are a few examples of the answers:

"I can communicate about customer opinions with other team members and contribute the team that way."
(an interview, Petri, Customer Service Engineer, case Y)

"I belong to this team because purchasing is my responsibility."
(an interview, Mikko, Purchase Manager, case Y)
"It is my duty to make sure that we follow the quality demands."
(an interview, Hilkka, Quality Manager, case B)

"My duty is to bring in new knowledge about different kinds of packages."
(an interview, Mika, researcher, material specialist, not a permanent employee, case B)

The members of both of the teams were also asked about the basis of how members of different R & D projects are mainly chosen in both of the companies involved in this research. The answers indicated that R & D teams are mainly gathered based on people’s positions in a particular company, but also based on their expertise, knowledge, and skills. Also the so called personal chemistry plays a role while choosing individuals to different R & D teams. Personal chemistry issues are discussed in more detail later in this section (Chapter 5.1.4). These examples illustrate the situation well:

"It is based on a person's knowledge and skills, and that we know that a certain individual knows pretty much and can handle the project, and then we see if he or she has time."
(an interview, Kari, case B)

"In every project, there must be people from certain departments...we collect enough expertise into every project."
(an interview, Mika, case B)

"We try to gather people who represent every sector...marketing, selling, customer services, production..."
(an interview, Jari, case Y)

"Yes, this kind of a representativeness of different functions is a clear argument. And the other one is that together we think of peoples that are active and progressive buddies."
(an interview, Timo, case Y)

A strong emphasis on team-work and co-operation can also be seen in the composition of an R & D team. It can also change during the particular R & D process. If people originally signed to a team do not have certain knowledge or competence required during the problem-solving process, other experts are called for advice. These experts can be either employees
of the company or people outside the company. The following excerpts from the team discussions reveal the situation well:

**Case B1**

Mika: "Can we use outside help during this project? It just came to my mind that Matti Seppo seems like a nice guy, he has been working with CM-packing."

Kari: "Do you mean at Crysant?"

Mika: "Yes, he might have some ideas about how to do the package design and how to do the inside of it."

Hilkka: "We must use outside help."

Kari: "If you have good suggestions, we will discuss those within this group, and if this group agrees, we will fulfill those, do you think this is a good way to do it?"

Hilkka: "Yes, because, otherwise, we redo the wheel again, eventhough Nokia produces it already."

Kari: "You make suggestions and we consider them. So, we can use outside consultation if needed."

Hilkka: "Yes."

**Case Y 1**

Jari: "Ducts are black service water radiators."

Antero: "But Juha told me that they are right ones, that's what he told me."

Mikko: "Should we write down that they are service water radiators for wet areas?"

Timo: "Yes, we'll specify this to service water radiators."

Antero: (calls Juha) "Hi, is there a possibility of making a mistake with these wet area radiator? You sometimes fought with those types. If Jasuterm [the name of the product] is decided upon, but can they send us a radiator that rusts away?...All right then, there is no possibility of making a mistake. Thanks, bye."

All in all, the information processing system, or the agent, of carrying out problem-solving activities in technological product development is usually a group of people, an R & D team. However, this team is not unchangeable, the composition of a team can change during the problem-solving process according to the knowledge, skills, and expertise needed during that particular process. The individuals constituting the team obtain their right to belong to the team according to their position and duties in the company. Also, personal abilities as well as personal chemistry affect how teams are composed inside the company.
5.1.2 What kinds of problems?

In chapter 3.1.2 the nature of problems in technological product development was discussed theoretically. There, I argued that problems in all R & D processes have the following characteristics: they are large in size and complex by nature (the problems are open-ended and ill-structured), they need to be decomposed, and there are no right nor wrong answers to these product-development-related problems. During the data gathering, these arguments about the nature of problems in technological product development were tested in several ways.

First, the interviewees were asked to identify the frequency of the occurrence of different kinds of problems in technological product development in the first phase of the data gathering. They were given seven different alternatives by the researcher. The interviewees were asked to consider the occurrence of the following problems in technological product development and to put them into order based on frequency. The following alternatives were given:

1. Problems which are completely new.
2. Problems caused by the break down of the existing technology.
3. Problems caused by the further development of the existing technology.
4. Problems caused by the imbalance of the existing technology. The innovation itself works, but causes problems somewhere else.
5. Problems caused by previous failures.
6. Problems caused by the need to decrease insecurity.
7. Problems concerning technology itself forcing to achieve better innovations.

According to the interviews, the most common kind of a problem occurring during the technological product development process is a problem that is caused by the further development of the already existing technology or the need to decrease the insecurity of the already existing technology. Also, both of the case teams studied in this research were
concerned with problems that have been caused by the further development of the already existing technology.

Maybe the result cannot be generalized to all R & D work, but it seems rather interesting that most problems occurring in technological product development are caused by the further development of the existing technology and the need to increase the security of the already existing technology. One could assume that R & D teams in high-tech companies are always dealing with completely new problem, emerging in a continually innovative atmosphere. On the contrary, the interviewees strongly emphasized that they were confronted by absolutely new problems only very rarely. The following statements illustrate the situation well:

"Quite few [new problems], most often we just develop the existing product a little further. And that's it!"
(an interview, Matti V.)

"Completely new problems, at least those are extremely rare, maybe it varies according to the field one works in, but usually there are no new problems."
(an interview, Pertti)

As an interesting nuance, all of the interviewees argued that there are no such problems in technological product development that are caused by technology itself forcing continually to achieve better results (alternative number 7). Therefore, the existence of technological determinism was strongly denied, and everyone stressed that people are in charge of the development of technological innovations.

Another interesting phenomena arose when the team members were asked about their opinions about the duration of the present R & D process. Eventhough the members of both of the teams were able to estimate the duration of the R & D process at hand, one of the most common answers was that the process is a never-ending one. Here are a few of the answers I got:
"This process will take about one year, but, basically, this never ends."
(an interview, Mika, case B)

"This will last for one year, but the project will continue even long after that."
(an interview, Miisa, case B)

"I cannot tell, but this won't be finished by the summer and, in principle, this is somehow never-ending."
(an interview, Mikko, case Y)

"One year is realistic…but this won't be one-hundred-per-cent-done ever."
(an interview, Jari, case Y)

"In summer…but it is never completely done."
(an interview, Petri, case Y)

This particular feature of technological problem-solving processes correspond with the earlier findings (see Chapter 3.1.2) of the types of the most frequently occurring problems in technological product development. On the basis of this research it can be stated that, most often the problems in technological product development are not new, but those that already exist, and for some reason they have been taken under consideration again. Therefore, the never-ending nature of technology-related problem-solving is evident. The results also imply the other stated feature of technology-related problems; the argument that problems occurring in technological product development are large in size and complex by nature. If this was not the case, problems would be solved fast and permanently. Because the problems are large and complex, they are hard to handle at once. Therefore, the need to decompose the problems into smaller problems is also evident. For example, both of the teams under study realized the overall problem they were concerned with, but approached the problem by decomposing it into smaller tasks. This example from team B's discussion explains the situation well:
Case B1

Hilkka: "Is the goal clear?"
Kari: "Of course."
Hilkka: "So?"
Kari: "The goal is to pack these wildly increasing amounts [of the company's products] with the packing machine, we need to make sure that it is applicable to packing this kind of a product, find out materials we can use, and consider the design of the package, too. So with what and how we pack."

Hilkka: "And we need to choose a machine and build a manufacturing line."
Kari: "And then we must consider the adjustments and make some kind of a preliminary validation plan."

Miisa: "My master's thesis needs to have a further-development plan."
Kari: "These kinds of broad goals."
Miisa: "And then we talked about the layout of the machine environment, and how the material flow goes."

5.1.3 In what kinds of situations?

There are different kinds of problem-solving situations in technological product development. According to the theoretical framework of this research, the problem-solving situations in technological product development have the following characteristics: problem-solving is not a random act, it is tied to some constraints; the cost of being wrong can be very high; there is no genuine feedback from the world during the actual problem-solving process; it is usually carried out by a cooperatively working group of people; and the produced artifact is required to function independently.

In phase I of the data gathering, the following problem/solution “quartet” was introduced to the interviewees. They were asked to evaluate what kind of problem-solving situations occur most often during the technological product development processes. Furthermore, they were asked to consider every situation based on its overall occurrence. Based on the interviews, all these hypothetically-created problem-solving situations do occur during R & D enterprises. First of all, there are situations in which the problem is known, and so is the solution (+/+). Only the means for actually solving the problem are missing. In other
situations, the problem is well-known, but the solution as well as the means for finding the solution are missing (+ / -). There are also problem-solving situations were both the actual problem and the solution are not known, but there is a need to do something (- / -). In other words, in technological product development, type (-/-) situations occur when the initial and/or the goal state of the problem appear as a need, but the actual appearance of a problem or a solution is missing. There are also situations in which the solution is known, but the actual problem unknown (+/-). The following “quartet” illustrates the problem/solution combination in any kind of problem-solving activity:

<table>
<thead>
<tr>
<th>Problem Known</th>
<th>Problem Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Known</td>
<td>- / +</td>
</tr>
<tr>
<td>Unknown</td>
<td>- / -</td>
</tr>
</tbody>
</table>

Figure 24. Problem/solution “quartet”.

On the basis of this research, the most common problem-solving situation in a technological product development process is a situation where the problem or the problem-solving task is known but the solution and the means to reach the solution are missing (-/+). So, the actual problem-solving activities taken by the problem-solver/solvers are acts of finding the means to reach the solution.

Both of the cases involved in this research dealt with type -/+ problems. In other words, the problem was already known, but the means to solve the problem as well as the actual appearance of a solution were missing. However, the initial and the goal state of the problem were known.
In case Y, the problem or the problem-solving task was to create a new house-building model for the region. The initial state was the experienced confusion about the overall way the company is building its product today. The goal state of the problem was a situation in which there is a systematic model for building houses. However, the actual solution of the form and other features of the model were missing.

In case B, the problem or the problem-solving task was to create a new package for the company's products as well as a new packing line. The initial state of the problem was the situation they were experiencing at that moment: they realized that with the existing package and packing system they will not be able to pack their products as fast and economically as they are ought to in the future. The goal state of the problem was the situation of having a new and functional package as well as a packing line. However, the actual solutions of the material, form, etc. of a new package, as well as the actual appearance of a new packing line were missing.

All members of both of the teams were well aware of the initial state of the problem, the problem itself, and the goal state. However, they often phrased them according to their own background and position in the company. This tacitly implies that in any problem-solving activity carried out in cooperation with others, people create their own problem statements according to their personal previous knowledge and experience which have been formed over the years of schooling as well as the positions they have had during their working life.

The following quotations describe the situation and the person-relatedness concerning the understanding of the initial state of the problem:

"When our volumes increase, this traditional way of packing our products, which has been designed and sized for considerably smaller product volumes... Now when our volumes increase, this is not a proper way of packing. This is extremely slow, personnel-consuming, and there are quite a lot of unsure matters."  (an interview, Kari, Product Manager, case B)
"The customer feedback and, on top of that, a bottleneck in production, meaning that the packing is very clearly a bottleneck."
(an interview, Mika, Researcher, case B)

"The starting-point is the situation which we have now. Our product is not standardized, it is not clear in a way that these are the 'Lego blocks' that our house is built of. We need to find those out. In other words, what our product is, in fact. There are many variations, there are many ways to do things, many ways to do a design...but now we are trying to pull them more together." (an interview, Jari, Development Manager, production, case Y)

"In recent years, there have been all kinds of technical problems with damp-resistance and mold, and so on. Now we want to make sure that we make the right choices, and that our products are durable. When a customer buys a product, we do not have to be afraid that we need to have a lawsuit because of these matters...And another point of view is that we believe that we have some kind of a conception about the costs in this construction business, we buy construction products on a daily basis, so we know better how much they cost. Now, when we are able to choose these products, we will make an economic summation, an economic choice." (an interview, Timo, Project Engineer, case Y)

"Well, when we use many different planning firms, I mean all kinds of planning, not just architects. And those firms might have ten different designers so, of course, the result is very multiform. This makes our job difficult, it makes building hard. Therefore, we need to standardize. And, of course, we are always at construction sites..." (an interview, Antero, Construction Manager, case Y)

One of the fundamental features of Kotarbinski's praxiology is the idea of conscious actions. He argues that people do not act randomly, but are well aware of their actions. I found this argument very interesting and wanted to ask the interviewees’ opinions about the randomness of their actions during the problem-solving process in technological product development. The question asked was very straightforward: "Do you know what you are doing all the time?" The answers were straightforward as well. About a half of the interviewees replied that they are aware of their actions all the time and do not act randomly, and the other half told that they are not aware all the time and sometimes act randomly. However, when observing the team meetings, random actions were not evident. There were no such comments like "let's try if this works" or "we are not sure if this is the
right way to do it, but let's find out". Instead of just trying some solution, the teams discussed about testing the solution or building a model or a prototype before making a decision or being sure that the solution works. The majority of the interviewees also evaluated the solvability of the problem at the very beginning or before beginning the product development process. These are a couple of the comments on the evaluation of solvability:

"Of course we need to evaluate it [solvability] right away the problem has been brought under consideration. And we often make a decision already at that point about whether to go into that problem or not."
(an interview, Pertti)

"Of course [we evaluate the solvability] before we accept the task, it would be a catastrophe for us if we could not do anything to that matter."
(an interview, Matti Kuu)

Also another point supporting the notion of conscious actions became evident during the interviews. The interviewees were very well aware of the fact that, in technological product development, the costs of being wrong or making wrong decisions can be very high. There were comments like: "if you do not know what you are doing, you won't be a Design Engineer for long." and "this is business, we cannot just try anything, it is too risky".

An important notion to make is that the randomness of actions and being either right or wrong are not the same things. One can be well aware of his/her actions, but at the same time he/she might make wrong decisions. The proposition made earlier in this research (Chapter 3.1.2) that there are no right nor wrong answers to problems occurring in technological product development in general finds support from the interviews made for this research, too. Let the following statements speak for themselves:

"Like we discussed earlier, nothing is sure, we just have to be prepared for fixing. So if it [the final product] is not good, we'll fix it...that's the way it goes on in the world, we fix a great number of things, a great number."
(an interview Heikki)
"In practice, these are complicated machines, there is no such designer or design system which won't make mistakes, there will always be things to fix, and in making a prototype, we fix them."
(an interview, Harri)

To conclude the findings about the nature of the problem-solving space in technological product development so far, the questions of who solves, what kinds of problems, in what kinds of situations are being asked and answered. The constraints under which problems must be solved are discussed in detail next.

5.1.4 Under what kinds of constraints?

When solving a problem of whatever kind, we need to consider the constraints or obstacles that hinder or limit the actual problem-solving activities. These constraints or obstacles can be characteristics of both the problem-solver and the problem situation. Earlier in this research, Goel and Pirolli's definition about the nature of constraints in design-making was mentioned. They (Goel & Pirolli 1989; Goel 1995) divide these constraints in two broad categories. They talk about nomological constraints that are basically natural laws that are hard, absolute, and nonnegotiable. They also talk about social, political, legal, economic, and cultural constraints, which are set by human beings, they are not definitional, and they can be changed and negotiated. Niiniluoto (1983, 80), on the other hand, writes about the philosophy of technology and points out six rather broad issues which have to be considered while developing and using new technologies. Traditionally, technological development has focused on the issues of effectiveness and economics, but today more and more stress is put on esthetic, ergonomic, environmental, and ethical issues (Niiniluoto’s “six E’s”). When collecting the empirical data for this research, I particularly asked, while interviewing about issues that constraint technological problem-solving and product development. I also gathered this kind of information while observing teamwork. The qualitative analysis of the research question of the nature of constraints in technological problem-solving was carried out both deductively and inductively. First, Niiniluoto's six E's were used as definitional stepping stones while mapping the constricting elements of technological problem-solving. Secondly, as my data goes beyond these “six E's”, I inductively added six more factors that
can be seen as constraining technological problem-solving and product development activities. The composition of the different factors has been gathered into the following table:
<table>
<thead>
<tr>
<th>Problem constraints</th>
<th>Label</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
</table>
"Of course we have quality frames, too." (An interview, Mikko, case Y)  
"Yes, to be able to illustrate the cost curve, we could use hours or get delivery cycle times, how many hours it takes to produce the product. And then we would know this so called non-refining time and get out the automatization potential." (Videotaped team meeting, Tapio, case B)  
"We are expressly interested in time...we are interested in the increment potential..." (Videotaped team meeting, Kari, case B) |
| Economic            | Financial resources are limited. | "We need to think about our choices in terms of money all the time. It is true that we know many ways to do this better than we actually do, but it costs." (An interview, Timo, case Y)  
"The first [constrain] is money; good and cheap, those are two different things." (An interview, Juha J.)  
"The most economical balcony, that is the number one." (Videotaped team meeting, Antero, case Y) |
| Esthetic            | The produced product must be functional as well as pleasing to touch and look at. | "It really sticks out if there is a drain coming from the roof, and a gray drain would fit the milieu well, but now it is orange, damn!" (Videotaped team meeting, Antero, case Y)  
"Not black, just normal colors." (Videotaped team meeting, Jari, case Y)  
"Noponen insisted on those curves, they look terrible, now we are just waiting to see how they have survived the winter." (Videotaped team meeting, Antero, case Y) |
| Ergonomic           | The produced product must be functional as well user-friendly. | "If the packer is here, there must be room on each side so, if the packer is either left or right-handed, he/she can reach the product anyway." (Videotaped team meeting, Miisa, case B)  
"The package must be user-friendly." (An interview, Hilkka, case B)  
"We talk about product ergonomy which means that the product is physically pleasant, it does not give you back pain, your eyes won't get tired, and, for example when planning an airplane, it is extremely important that the information is shown clearly, so if something happens, you see it clearly, you do not need to start to look for meters on the sealing or the floor..." (An interview, Jorma P.) |
<table>
<thead>
<tr>
<th>Category</th>
<th>Explanation</th>
<th>Quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental</td>
<td>Environmental laws, regulations, and other such issues must be taken under consideration while planning, producing, selling, using, and disposing of the product.</td>
<td>&quot;For us they [environmental issues] are not a sales asset, and that's why we do not automatically go along.&quot; (An interview, Timo, case Y)  &quot;Environmental issues come from the customer. Of course we do the kind of package that we can sell and that does not encounter resistance from the customer.&quot; (An interview, Mika, case B)  &quot;I wonder when they will start to require the manufacturer to take used packages back, perhaps it will happen one day.&quot; (Videotaped team meeting, Mika, case B)</td>
</tr>
<tr>
<td>Ethical</td>
<td>Conscience choices of an individual or a group of people.</td>
<td>&quot;Of course I speak only for myself, and would say that, yes, they [ethical issues] do restrict me. I won't do whatever, I think about how this product will be used if I manage to create it; will it be used to kill people, or will it be used to something else.&quot; (An interview, Jorma P.)</td>
</tr>
<tr>
<td>Natural</td>
<td>Natural laws which are absolute, hard, and non-negotiable.</td>
<td>&quot;Natural laws are absolute…we cannot build a nuclear reactor on top of a seismic area.&quot; (An interview, Jorma M.)</td>
</tr>
<tr>
<td>Legal</td>
<td>Regulations set by laws, standards, rules, and authorities.</td>
<td>&quot;It must be [medically] agreed, so we do not need to be worried that there is some pigment that will get into our product…&quot; (Videotaped team meeting, Miisa, Case B)  &quot;We need to be able to proof to authorities that this is a safe package, sterile, the product will stay sterile, and it will remain unchanged while in storage...&quot; (An interview, Miisa, case B)  &quot;The authorities demand, and we demand that there are wells...&quot; (Videotaped team meeting, Timo, case Y)  &quot;Laws and EU-directives, we Finns are very eager to follow those.&quot; (An interview, Kauko)</td>
</tr>
<tr>
<td>Internal</td>
<td>Organizations' internal regulations, norms, and resistance against change.</td>
<td>&quot;Internal resistance must be overcome, and we need to &quot;sell&quot; our product inside this company, too.&quot; (An interview, Timo, case Y)  &quot;We have a so called nation-wide [the company has many regional offices] method card index. On the other hand, it is a restriction but also a possibility.&quot; (An interview, Timo, case Y)</td>
</tr>
</tbody>
</table>
| External | Customer expectations and demands. | "The problem of knowing what the customer's exact problem to be solved is."  
(An interview, Ilkka)  
"The wishes [of the customer] were pretty contradictory, first they wanted that the cardboard box would be stiff, but, on the other hand, after it [the product inside the cardboard box] is used, there should be all kinds of tear-off strips, so that it [the cardboard box] would go flat and be easy to destroy or recycle."  
(Videotaped team meeting, Mika, case B) |
| --- | --- | --- |
| Product-related | Product-based qualities or demands. | "But there is always a little inconsistency, we can reduce the amount of waste if we pack hardly at all, but this product demands at least double packing because they [products] can be brought to the sterile section of the operating room only if they look a certain way."  
(Videotaped team meeting, Hilkka, case B) |
| Personal | Personal restrictions like knowledge, skills, and courage.  
Personal chemistry. | "Of course personal knowledge, skills, and working methods set limits."  
(An interview, Jorma P.)  
"The most important restrictive factor is personal knowledge, everything you can do stays in those mental limits you personally have."  
(An interview, Pertti)  
"Personal restrictions, which mean that, even though you would like to do something, you do not have the courage to try, it is easier to stay in the old, even though you know it is not good."  
(An interview, Matti Ku.)  
"It is so that if you know somebody better than someone else, you ask him/her to join your own projects."  
(An interview, Mika, case B) |

Table 5. Factors constraining problem-solving in technological product development: Constraint label, definition, and examples from the empirical data.
Efficiency and economic issues constraining problem-solving in R & D processes

Here, efficiency-related constraints mean tight timetables and such quality demands that constrain problem-solving activities in technological product development. Very often R & D teams work under enormous time pressure, but are still required to do high-quality work. Efficiency and economics are treated at the same time because, in most R & D practices, they tend to go hand in hand. Efficiency is an important attribute of economics, and vice versa. In order to be effective, an R & D process must be fast and economic. Fast in a sense that there is a deadline when the task of the R & D team must be finished. And economic considering the money (e.g. salaries) to be invested in the actual product development and problem-solving process. The following statement illustrates this situation well:

"It is time and money, meaning that the implementation [of the product] cannot cost more than is ordered, it [the product] must be functional and feasible in a certain time frame." (an interview Matti Kuu)

However, tight timetables or financial limits are not only seen as negative factors. They also provide the R & D process and the members of that process a sort of framework within which the team can plan its activities and proceedings. Otherwise, the development process could take too long. The following two passages illustrate this situation well:

"Designers are such meticulous patrons that it [the design] is never done. On the contrary, they would like to do it over and over again, but then money determines, and the time is up." (an interview Ilkka)

"Often, there is a feeling that we could do better, but then there is no time nor money to do it any better." (an interview Heikki)

Setting limitations on time and money can be seen as a way to economize the actions of an R & D team. As Kotarbinski (see pages 33-34) argues, the economization and instrumentalization of action, as well as the preparation of actions are the key elements in producing effective action. When the actions are economic, they are also more cost-saving or productive. In other words, technical efficiency is tied to cost efficiency in a
technological product development process. The action preparatories, on the other hand, make certain actions possible or easier, or enable or facilitate their better execution. A specific action preparatory Kotarbinski mentions is planning. He argues that a plan should be purposive, easy to use, uniform, continuous, flexible, and future-oriented. Therefore, planning is seen as a preparatory tool for more efficient work. A plan can also be seen as a positive constraint for problem-solving, especially for collaborative problem-solving. A plan sets rules and norms for group work. It also clarifies the proceedings, roles, and goals of a certain R & D team.

The studied case B followed a project folder made for the better execution of all R & D projects of the company. It was the duty of a certain person (Miisa) to follow the folder and keep record of every team meeting. Also, every member had a certain, clearly-defined formal role in the group. The group members also had a pretty similar understanding about the duration of the particular R & D process. They also knew to whom they need to report about the proceeding of their work and to whom they are responsible.

Case Y, on the other hand, had not made any formal planning about the proceedings, rules, roles, goals, etc. of the particular R & D project. When asked about the issue, they replied:

"This is not that kind of a thing, we are familiar with these kinds of projects. This [project plan] is written down in our result-oriented management rules, allocation, areas of responsibilities, etc. So it comes naturally, we do not need to really arrange it."
(An interview, Antero, case Y)

"There are no written rules, but we have discussed things verbally."
(An interview, Jari, case Y)

"Actually, the only “rule” is the timetable."
(An interview, Petri, case Y)

Despite the lack of formal planning, all members of team Y knew what was expected of the team as a whole, and of them as individuals. They also knew to whom they were responsible.
All in all, Kotarbinski's demand for very exact planning did not really come true in either of the studied cases, eventhough planning was somewhat more formal in case B than in case Y. The way (either orally or formally) the team arranged its planning did not seem to affect its overall work. However, the duration of the data gathering was too short in order to verify the consequences of pour planning for the overall success of the R & D processes studied.

**Environmental issues constraining problem-solving in R & D processes**

Environmental constraints are environmental laws, regulations, and other such issues which should be taken under consideration while planning, producing, selling, using, and disposing of any kind of product or process. One would expect that environmental issues played a very important role in today's R & D activities. However, according to the collected data, environmental issues are not respected unquestioningly, but are balanced with other important questions. Like one interviewee stated:

"Environmental regulations are like a sort of scales. Like radiotherapy is given to those having a cancer because it relieves pain, but, at the same time we know that it also does a lot of damage. So the same applies here too. If we reach a proper use and are able to guarantee the product safety, it is, of course, more important a factor than a package that is made of paper and will decompose in a year or two." (An interview, Hilkka, case B)

Generally, environmental issues are noticed and practiced if a) they are directed by laws or other regulations, b) the company receives financial benefits for following them, or c) if the customer demands for environmentally-friendly products. This is very well illustrated in the following three examples:
Case Y2

Timo: "For example, in yesterday's news they said that the obligation to collect organic waste will drop to having five apartments per a block of flats, now it is ten apartments."

Jari: "In Jukola [name of an apartment building], the problem was that it was designed according to the old practice."

Timo: "This must be written down into the material information, or in fact..."

Antero: interrupts: "The costs are not too high."

Timo: "Yes, it is just buying."

Antero: "Is it an authority demanding this cold room for waste, or isn’t?"

Mikko: "I think so."

"Any company cannot function if it does not do business. Here you can see that these environmental issues offer a company a possibility to do business. People buy products which can be composted." (an interview, Pertti)

Case B3

Mika: "There have been all kinds of experiments, but often they come up against logistical problems. There should be a lot of plastic waste before it can be put to use."

Miisa: "However, this is a thing that we need to consider here. It is a big thing because they [customers] ask, when buying the product, how it can be wasted, if we have made a life-span analysis, and these kinds of things. Hospitals are interested, at least here in Finland and in Europe, I do not know about the US."

Legal issues constraining problem-solving in R & D processes

Constraints and restrictions set by laws, regulations, standards, and different authorities were very well noticed and taken seriously among the R & D teams under study. Legal matters act as boundaries inside which problem-solving activities of an R & D team are carried out. Therefore, laws, regulations, standards, etc. do not constrain problem-solving negatively. However, they give limits inside which problems must be solved.

Case Y2

Antero: "Then we have these doors between the floors. Are they allowed to open inside?"

Petri: "No, it can not be like that."

Timo: "Because of the fire regulations."
Case B1
Hilkka: "Have you changed any standards between you two, what type of packing materials can we use for packing sterile products in general?"
Mika: "I gave all the material I had to Miisa."
Hilkka: "So Miisa has them?"
Miisa: "Yes."
Hilkka: "Because there are standards about packing materials, surprisingly many. But there is no such standard that would say how to pack our company's products, that were too easy."

Ergonomic and esthetic issues constraining problem-solving in R & D processes

Ergonomic and esthetic issues are tied to the final outcome of the R & D process. The produced product or process must be functional, it has to fill its purpose, work properly, and be reliable. However, at the same time, it should be pleasant to use, look at, and touch (sometimes even to smell or taste). Of course, there are differences in the importance of ergonomic issues or the esthetic appearance of products or processes, but these issues are no longer overlooked in technological product development. Pretty often the teams under study discussed the constraints caused by ergonomic or esthetic demands. These are examples of those discussions:

Case B4
Miisa: "If the packer is here, there must be room on each side so, if the packer is either left or right-handed, he/she can reach the product anyway."
Kari: "Or a shelf up there."
Miisa: "It is one possibility. It is, of course, better than this."
Kari: "Reversible, it strains less."

Case B1
Kari: "There was a good idea, I do not remember who presented it, but, about the furniture we have in the operation room, those are usually white, why cannot we use some black pads so we could see the product better?"
Hilkka: "Yes, there should be a contrast..."
Case Y2

Antero: "I really would like to know the customer opinion about the shaded frame and the white door. But, if the product sells, that is all right."

Petri: "They have liked it so far."

Antero: "You see all kinds of adjustments out there, however, if we paint the walls first with a color similar to the wallpaper’s, the white paint won't show through."

Mikko: "It is an additional cost, however."

Case Y1

Petri: "About the fuse panel, the door phone, and the air condition control. In Pellava [a name of an apartment building], they were all in different walls, and in Torni [a name of an apartment building], they were close to each other. The electrical wiring designer should think a bit about where to put them, if they are all placed in three different walls in the hallway, there is no place to hang the mirror, and the customers will be angry."

Ethical issues constraining problem-solving in R & D processes

Ethical constraints are defined as being conscience choices an individual or a group has to make when developing a new product or process. Ethical issues constraining technological problem-solving were not mentioned by any of the interviewees of this study without specifically asking. One can only guess about the reasons for this, and the result might have been different if I would have observed an R & D process in some army-related laboratory, for instance. In the observed team meetings, ethical issues were discussed only randomly. Here are a couple of examples:

Case Y3

Antero: "They [playgrounds] must be safe."

Mikko: "Those are so called safe products, there are no places where you can hurt your fingers, you can even eat them."

Petri: "Nowadays, they have a warning sign which says that “do not climb with your bicycle helmet on”.

Antero: "Then we only use sand boxes."

Timo: "If we go to environmental issues, the amount of fresh water is diminishing alarmingly in the world. And if we spread water and advise to spread it on the grass, this is not ecologically lasting."
Natural issues constraining problem-solving in R & D processes

Natural constraints are natural laws that are absolute, hard, and non-negotiable. Technological product development is based on natural laws. In the videotaped team discussions, natural laws came up only occasionally, they were not very lively discussed nor argued among the team members. These are examples of the discussions in which natural laws were mentioned:

**Case Y1**

Timo: "In my understanding, the problem with row houses has been the surface waters, now we have been trying to solve this..."
Antero: interrupts: "If the altitude level of the building is right, we can solve this so that it [water] does not puddle."

**Case B1**

Hilkka: "How about a product that is little bit electric?"
Kari: "Yes, it could be that, too."
Hilkka: "We get some of that [electricity] already."
Miisa: "What do you mean by electric?"
Hilkka: "In production, first we counted that there were 50, and then we went to another point, someone had taken the safety-lid off, and there were only 48 left."
Kari: "They are like fleas."
Hilkka: "Yes, they jump like fleas."
Mika: "They have been grinned with metal bits."
Hilkka: "That's right."
Kari: "Sometimes tension generates induced electricity, that's the reason."
Mika: "And the final product is so light."
Hilkka: "Yes, it is."
Internal and external issues constraining problem-solving in R & D processes

By internal constraints, I mean an organization's and/or a team's internal regulations, norms, and resistance against change, which can prevent the problem-solving and the product development processes, or at least hinder them. Organization's internal regulations, norms, and internal resistance have been the target of many investigations, particularly when studying group decision-making and problem-solving. Substantial organizational research, for example, suggests that organizational cultures significantly affect how groups in organizations perform tasks (cf. e.g. Weick & Roberts 1993). Even though organizational culture was not a target of this research, and the research design did not serve this purpose, it became evident that the organization's internal regulations, norms, rules, and resistance against change had their effect on the work of a particular person or a team.

"True understanding is important. The quality management system is a good example, many think that it is a heavy system because they need to fill in papers. Those are not extra papers. When the bunch understands that, they think that it is just normal work, and then it is ok."
(An interview, Jari, case Y)

"It just came to my mind that this is an odd situation because we should tell about this project to others, but it has not been the culture in this company."
(An interviewee, Jari, case Y)

"Internal resistance must be overcome, and we need to “sell” our product inside this company, too."
(an interview, Timo, case Y)

"It [the project plan the team is working on] has reached people [other employees of the company], but it is very typical that I have only got one feed-back comment."
(Videotaped team meeting, Timo, case Y)

Very often, research findings concerning organizational culture emphasize the negative effects of organizational rules, norms, and other regulations (cf. e.g. Janis 1982). However, according to the findings of this research, internal regulations and norms have their
advantages, too. Because of them, the employees know what is expected of them and others, how they ought to do their work, how to collaborate etc.

"I'm held responsible for this project because everyone in this company has so called “key results” of their own. And that's how we realize our responsibilities."
(an interview, Jari, case Y)

Case Y2
Timo: "What about the balcony, I do not know if the method card index [the company's internal index] gives advice, or some other instruction, do they talk about balconies?"
Jari: "It was quite complicated."
Timo: "I have it on my shelf."
Antero: "So do I."

"We have a so called nation-wide [the company has many regional offices] method card index. On the other hand, it is a restriction, but also a possibility.
(An interview, Timo, case Y)

External constraints, on the other hand, are those customer expectations and demands that restrict problem-solving in R & D processes. Like the empirical data of this research shows, it is often the customer or the final user of the product or process that determines the path of the discussion and problem-solving activities of an R & D team. The customers' expectations and demands become constraints when they do not know what the actual problem is that they want to be solved, or when the customers' wishes are so contradictory that they are impossible to fulfil. The following example of a discussion of team B explains the nature of external constraints.

Case B3
Mika: "Nurses wish all kinds of things, but often they are contradictory wishes. If we make a large and clear opening spot, the package cannot be small because human hands are what they are."
Miisa: "I agree, the wishes are very contradictory."
Mika: "And first, before the use, the package must be as stiff and solid as possible and stay in shape when in storage. But after the product is used, the package should go flat, become small, and be easy to dispose of."
Miisa: "That's right."
Hilkka: "It should vanish about the same time it is opened."
Kari: "We need to weigh the wishes because they are clearly contradictory."
Product-related issues constraining problem-solving in R & D processes

In technological product development, the product or process under design can have qualities and demands of its own that restrict the actual problem-solving process. The intended solution has to be abandoned if the product under design itself "rules" it out.

Case B2
Miisa: "Can we provide the moisture and light block with this kind of a package if the cap's top is sterile? And if we think that destructibility is important, and with the aluminum bag it is not possible."
Hilkka: "But how do we normally make the moisture and light block? With metal, and that's aluminum."

Case B2
Mika: "What about if it is pure aluminum, then it could be just wrinkled and recycled."
Hilkka: "But then we loose the breaking block, it would be like a folio. It won't last..."
Kari: interrupts: "The seaming doesn't work."
Hilkka: "Yes, the seaming doesn't work, and if there is any little cut somewhere, it will break it."
Mika: "That's right."
Kari: "Yes, that's right."

Personal attributes constraining problem-solving in R & D processes

Personal attributes are personal knowledge, skills, and attitudes, which affect how an individual approaches the problem-solving task given to the R & D team, and how a team can benefit from its members' abilities. According to the present interviews, these personal abilities are very often seen as the most important constrain of problem-solving. If you do not know, if you cannot do, and if you do not have the right attitude, you are no use to your team. Like one interviewee stated:

"The most limiting thing is the designer's own personal knowledge, everything depends on those personal resources."
(an interview, Pertti)
However, during the observed team discussions, personal abilities were not discussed in any negative way. Here is one example:

Case B
Miisa: "I thought that if I would first draw some kind of molds with Pro [a computer program], it is very handy, and then we can try to fit the product into it."
Kari: "Yes, it could be, can you do it?"
Miisa: "Yes, last winter I used it to design our motor".
Kari: "With Pro! This was great news. I have heard that there are not too many who can use Pro, it is so new."

Personal chemistry, on the other hand, constrains problem-solving when it, for example, determines who joins the team, who is accepted, and whose opinions are valued by others. Personal likes and dislikes are very human emotions, which have their effect on every circumstance. However, based on this research, personal chemistry is a matter of knowing more than liking people. Simply, you work with people you know best.

Case B1
Mika: "Can we use outside help during this project? It just came to my mind that Matti Seppo seems like a nice guy, he has been working with CM-packing."
Kari: "Do you mean at Crysant?"
Mika: Yes, he might have some ideas about how to do the package design and how to do the inside of it."
Hilkka: "We must use outside help."

"Surely there is personal chemistry in a way that if we know someone from the Marketing Department or Quality Assurance Department, we ask him/her to join our own projects."
(An interview, Mika, case B)

Concluding the empirical findings concerning problem constraints

As was mentioned at the beginning of this chapter, constraints or obstacles related to technological product development and problem-solving can be either characteristics of a person solving a particular problem, or they can be features of the actual problem-solving
situation. They can also be characteristics of a particular team of problem-solvers or society as a whole. Twelve different attributes of constraints were found in this study, and can be divided into three categories. The first category consists of natural constraints, which actually give an absolute frame within which a particular problem can be solved. The other two categories are rather broad and can be labeled as a) society/situation-related constraints and b) person/group-related constraints. However, these categories are not exclusive. For example, ethically can be a characteristic of both the person and the group of people, as well as the particular situation or the whole society. Also efficiency and economical constraints can be attributes of both. Either society or the situation in which the problem-solving activities take place value or demand effective and economic actions, or the person/persons doing the actual problem-solving work set timelines and monetary goals for themselves. Very often the efficiency and economical issues are valued by both categories. Even product/process-related constraints can be seen as a part of developing society or personal knowledge. Not too long ago, cars used only leaded gasoline, until researchers realized it has harmful environmental effects, and society started to demand cleaner fuel, so technological product development carried out by engineers produced a car engine that was able to use unleaded gasoline.

However, environmental, ergonomic, esthetic, external, and legal constraints are clearly society/situation-related issues. Laws, regulations, standards, and other rules set by different authorities are agreements of a particular society at a certain time. Environmental and ergonomic issues are valued today more than ever before in history. Also external, customer-related issues and esthetic issues are considered more carefully.
Table 6. Factors constraining problem-solving in technological product development: three categories.

<table>
<thead>
<tr>
<th>Nature-related constraints</th>
<th>Society/situation-related constraints</th>
<th>Person/group-related constraints</th>
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</thead>
<tbody>
<tr>
<td>Natural laws</td>
<td>Efficiency</td>
<td>Efficiency</td>
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<tr>
<td></td>
<td>Economic</td>
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<td></td>
<td>Ergonomical</td>
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<td>Product/process</td>
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The problem constraints in technological problem-solving are many and diverse. The actual challenge of technological problem-solving does not seem to be finding the initial or the goal state of a particular problem, but finding the means of getting to that goal in a thick and heavy "jungle of constraints". On the other hand, it is important to notice that not all constraints are constraints in a negative way, just hindering the actual problem-solving. But some constraints actually assist the problem-solving process by offering valuable regulations, limits, and advice. The following line of one of the team members (case B) illustrates this situation well:

"Now we have many things to consider. We need to consider the different priorities, which the customer's needs and opinions are, ecology, meaning recycling and so on, and then we have our own production, costs, efficiency, timelimit, competitiveness, and above all, the ability to bring new products fast to the market."
(videotaped team meeting, Tapio, case B)
The task of this section was to identify the characteristics of the problems and problem-solving situations as well as the problem constraints in technological product development, and all major findings are gathered into the following figure:
|-------------|-------------------------|-----------------------------|----------------------------------|
| - R & D team  
  - The composition may change during the process.  
  - The members are chosen by their position and duties in the company, as well as by their personal knowledge, skills, and attitudes. | - Problems which are large and complex -> They need to be decomposed.  
  - Problems caused be the further development of the already existing technology or by the need to increase the security of the already existing technology.  
  - Problems with no right nor wrong answers.  
  - Problems that are "never-ending" by nature. | - In situations in which the problem is known but the solution and the means to reach the solution are missing (-/+).  
  - In situations in which the initial as well as the goal state of the problem is known, but phrased according to the person's own previous knowledge and experience.  
  - In situations in which people do not act randomly, but test, model, and evaluate the solvability of the problem.  
  - In situations in which the costs of being wrong can be very high. | - Efficiency  
  - Economic  
  - Environmental  
  - Legal  
  - Ergonomic  
  - Esthetic  
  - Ethical  
  - Natural  
  - Internal  
  - External  
  - Product-related  
  - Personal |

Figure 25. The nature of the problem space: Who solves, what kinds of problems, in what kinds of situations, under what kinds of constraints.
Most often, cognitive problem-solving is aided by tools of some kind. Kotarbinski talks about instrumentalization when referring to the aids one uses to be able to act more economically than without them (discussed in Chapter 2.4.2). For example, the use of a computer program can be seen as an instrumentalized action in which the computer program serves as an aid for the better and more economical execution of a certain task. Therefore, for Kotarbinski, tools appear as concrete instruments or artifacts, which are easy to perceive and name. On the other hand, Kotarbinski talks about free impulse, referring to a necessary prerequisite for active and conscious acts causing a certain event (in Raivola 1996). Kotarbinski's idea of efficient action and the role of free impulse in this process can be understood in the following way:

![Diagram of simple act as a basic operation](image)

Figure 26. Simple act as a basic operation (adapted from Raivola 1996).

Here, an agent's free impulse serves as a precondition for the execution of an act. Like Raivola (1996) argues: "It is of the essence that praxiology sees expertise as a practical skill and a solution to a problem, not as a disposition dominated by mental operation but as
actualized and furnished by them" (5). Kotarbinski also argues that every impulse is directional and intentional, it is aimed at something (1965, 18). Being a necessary premise of action, a free impulse can be understood as a tool aiding the problem-solving process of an individual or a group. Without the agent's free impulse, the problem-solving act would not proceed.

Also Vygotsky (see Chapter 3.4.2.3) argued that all human mental action is mediated by tools, either technical or psychological. By technical tools, Vygotsky means tools that are concrete and directed toward the visible world (cf. Kotarbinski's instruments). By psychological tools, on the other hand, Vygotsky means tools (or signs) which are internal and invisible, such as languages, various systems of counting, mnemonic techniques etc. He also argued that psychological signs are social, they are products of the socio-cultural evolution, not individual. They are not invented by an individual nor discovered in an individual's own interaction with nature, but they are symbols with definite meaning that has evolved in the course of the history of culture. The other concept that makes Vygotsky's reasoning important here is the idea of mediation. Mediation is a socio-cultural concept or principle with a fundamental message. Within the socio-cultural theory (or social constructivistic theory), all human development, including learning and problem-solving, is dependent on the institutions, settings, and cultural artifacts in one's social milieu. Therefore, the tools and signs one is exposed to mediate new patterns of thought and mental functioning (Wertsch, 1991a). These mediatinal tools or signs can be languages, mathematical symbols, diagrams, artwork, or other culturally-formed constructs.

Vygotsky's main argument was that human mental development can not be explained on the basis of principles that had formerly accounted for the genesis of psychological processes (in this case, the principles of Darwinian evolution). Instead, human mental development in Vygotsky’s theories incorporates natural and cultural principles. As Vygotsky and Luria argued:
"We think that the turning point or critical moment in the behavior of apes is the use of tools; in the behavior of primitives it is labor and the use of psychological signs; in the behavior of the child it is the bifurcation of lines of development into natural-psychological and cultural-psychological development" (in Wertch 1985, 23).

A fundamental distinction that underlines Vygotsky's line of reasoning about human mental development and the role of mediation in this process is the distinction between "elementary" and "higher" mental functions (1978, 39). Vygotsky's general idea was to examine how mental functions like memory, attention, perception, and thinking first appear in an elementary form and then change into a higher form. He argued that natural (or elementary in his other writings) development produces functions in their elementary forms, whereas cultural (or social) development converts the elementary into higher mental processes. (Wertch 1985, 24; Davydov & Radzikhovskii 1985, 53.) Vygotsky (1978) used four criteria to distinguish between elementary and higher mental functions: 1) the shift of control from the environment to the individual (the emergence of voluntary regulation), 2) the emergence of conscious realization of mental processes, 3) the social origins and social nature of higher mental functions, and 4) the use of signs to mediate higher mental functions.

Vygotsky argued that voluntary control, conscious realization, and the social nature of higher mental processes all presuppose the existence of psychological tools, or signs, that can be used to control one's own and others' activity. The notion of a sign as a psychological tool made it possible for Vygotsky to modify the traditional behavioristic two-part scheme (stimulus-response) of analysis of mind into a three-part scheme, introducing a psychological tool as an intervening link. He understood thought and speech as instruments for the planning and carrying out action. He writes:
"Children solve practical tasks with the help of their speech, as well as with their eyes and hands. This unity of perception, speech and action, which ultimately produces internalization of the visual field, constitutes the central subject matter for any analysis of the origin of uniquely human forms of behavior." (Vygotsky 1978, 26.)

The work of Vygotsky and other Russian psychologists (e.g. Rubinshtein, Leont'ev and Luria) begun in the 1920's. They formulated a rather revolutionary theoretical concept to transcend the prevailing understanding of psychology. This new orientation, nowadays known as activity theory, was a model of artifact-mediated and object-oriented action, further elaborated by other (e.g. German, French, British, American and Finnish) scholars. The basic principles of activity theory include the hierarchical structure of activity, object-orientedness, internalization, externalization, tool mediation, and development. The principle important in this research at this point is tool mediation. Activity theory emphasizes that human activity is mediated by tools in a broad sense, i.e. action is mediated by technical tools as well as by psychological signs.

However, neither technical tools nor psychological signs alone would amount to much. Following Vygotsky's reasoning, there is a way to turn around upon one's thoughts, to see them in new light, to get to "higher ground". He explains that human mental development happens or is achieved through the zone of proximal development (discussed in Chapter 3.4.2.3) in which a less knowledgeable or a less skilled person (the child in Vygotsky's writings) is brought to an environment where that person can reach “higher ground” from which to reflect. However, as discussed earlier in this research, the occurrence of these ZPD's is often unrealistic when solving highly complex problems in the course of an R & D process. Therefore, in this research, Vygotsky's reasoning about the existence of technical tools as well as psychological signs, and their mediational function in bringing mental action from the elementary level to the higher level is treated as theoretical construct. However, applied in a situation where constructs like ZPD's are often unrealistic. In this research, mediational tools are divided into two categories: first, there are mental
mediational tools which refer to Vygotsky's psychological sings and Kotarbinski's free impulse, and secondly, there are instrumental mediational tools which refer to Vygotsky's technical tools and Kotarbinski's instrumentalized action. Both tools are treated as aids for more efficient execution of the collaborative problem-solving process. I admit that the notion of tool is used in rather broad sense in this research. However, there are two reasons that justify this. First of all, tools (or devices) that aid an individual or a group to bring their mental actions from the elementary levels to the higher levels of cognitive functioning are both; mental and instrumental. These functions should be understood widely, they are not merely rules, norms, instruments, or division of labor (cf. Engeström 1987, 78), in other words instrumental tools. But also psychological functions that aid the cognitive functioning of an individual or a group. These functions are called mental mediational tools in this research. And they should not be understood as always being intentionally used. Secondly, I strongly believe that the overall scientific reasoning going around and about in many disciplines should be simplified. The beauty of science lies on parsimonious theories.

The existence of both mental and instrumental mediational tools became evident in the course of this research. Human cognitive functioning, in this case problem-solving in groups, is enabled by the intervening nature of both technical and psychological tools. Without mediational tools such things as experience and knowledge would not become evident in group situations; the discussion in a group would be just a comment after another, not a real dialogue. Also, without instrumental mediational tools, the group work would be inefficient, time-consuming, and ponderous. The tools are also highly situation-dependent. For example, a mental mediational tool of an individual experience of formal education can be retrieved from the memory if the situation "hints" the need or someone asks a question that "awakes" the memory.

Within this research, the goal was to inductively (data-driven) reveal the overall spectrum of mediational tools that in some way aid the actual problem-solving process of a collaboratively working R & D team. Some of them are more cognitive by nature and others more practical by nature, but all of them serve the same pragmatic purpose: the better
execution of the problem-solving task at hand. A more profound meaning of mediational tools is that as their usage advances to alter other culturally-formed constructs, the available mediational means that can impact cognitive functioning also change (Wertch, 1991b).

In this section, the nature of practical mediational tools (including mental and instrumental mediational tools) used in technological problem-solving by R & D teams are examined. Cognitive tools are examined in the next section.

By observing the team meetings and verifying my subjective interpretations during the second interviews made to every of the teams member afterwards, I was inductively able to find 30 practical mediational tools used while solving a complex technological product-related problem in a collaborative mode (see appendix 7).

Practical mediational tools can be divided into two categories: 1) mental mediational tools which originate from individual experience or from the experience of others, or from knowledge acquisition through written/visual/audio material, or through testing the product or part/s of it, or building a prototype or a model and 2) instrumental mediational tools which are concrete methods or artifacts used to aid problem-solving, but also easily perceivable to others outside the team. However, a mediational tool of 'knowledge acquisition through testing and building a model or a prototype' can be understood as belonging to both categories.
## PRACTICAL MEDIATIONAL TOOLS

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5.2.1 Mental mediational tools

Mental mediational tools serve as intervening links between elementary and higher cognitive functions, and, by doing so, they aid problem-solving and individual as well as group mental development. Elementary cognitive functions, on the other hand, serve as impulses to higher cognitive functions.

Individual experience

According to the findings of this research, a precondition for the higher cognitive function of memory retrieval or reflection (i.e. the usage of individual experience) is an elementary cognitive function of asking, listening, observing, etc. In a certain situation, an individual needs the information he/she has gathered through formal education, during the course of his/her working life, or life in general. Therefore, a person uses his/her experience as a tool for aiding or promoting the problem-solving task at hand. The usage of this particular tool is very situation-dependent. There has to be some kind of “a hint” from the environment before memory retrieval or reflection occurs. This “hint” can be a question from another team member or a discussion of others that “awakes” the personal memory. Here is one example of a team discussion in which the elementary cognitive function of asking serves as an impulse to the higher cognitive function of memory retrieval, and in which the mental mediational tool of ’experience acquired through working life' serves as an intervening link between these two mental processes.
Case B2

Miisa: "I'm about to receive that ISO-11607 standard."
Kari: "WHAT?"
Miisa: "Iso-11607."
Kari: "What?"
Miisa: "Wait a second, what was its name again."
Hilkka: "It is a packing standard and something."
Miisa: "Did I have it here?"
Kari: "So it is some kind of a collection, or what?"
Hilkka: "No, it is..."
Kari: "Or is it just..."
Miisa: "It is a packing standard for terminal medical device."
Hilkka: "That's right."
Kari: "OK."

In the next example, an elementary cognitive function of listening serves as an impulse to the higher cognitive function of memory retrieval, and a mental mediational tool of 'experience acquired through life in general' serves as an intervening link between these two mental processes.

Case Y2

Mikko: "How about the mailbox, is it painted and can it be filled up on top?"
Jari: "I think we do not need to put up a big jury for this matter."
Antero: "How about locks?"
Mikko: "Yes."
Timo: "I have lived in a row house for 20 years, and I only have a Cortex [the name of the mailbox manufacturer] plastic mailbox without a lock. Nobody has touched it, at least that I would know of it. I would not rate that locking possibility very high, the Finns are so honest."

Experience of others

The experience of other people plays an important role in collaborative problem-solving. Other people's experiences serve as informants, as tools, which enable the higher cognitive functions of understanding, learning, planning, revising, etc. to occur in both an individual or a group. This process is stimulated by elementary cognitive functions like asking, answering, listening, and observing. An interesting observation is that the modes of asking vary according to the situation and the need at the moment. On the basis of this research,
colleagues inside the company and experts outside the company are asked if they are known to be more knowledgeable and experienced (cf. transactive memory, meta knowledge, and mental models discussed in Chapter 3.2.4), and when an exact question needs to be answered. On the other hand, less knowledgeable colleagues or non-experts outside the company are used as informants (or tools) if the situation is more opinion-like, not if an exact piece of knowledge or a fact is needed. Here is an example, in which the higher cognitive functioning of becoming more knowledgeable (i.e. learning) is stimulated through the elementary cognitive functions of asking, answering, and listening. Also, a more experienced colleague serves as a mediational tool or an intervening link between these two cognitive processes:

**Case Y1**

Petri: "How big of an expense is that dry well?
Antero: "It is not a big one. But a bigger problem is whether there is enough room to build it in."
Timo: "So, in the floor on the top of the hollow vault."
Antero: "Yes." (leaves the room)
Jari: "How about the water in the sauna then?"
Timo: "But if we lift the floor, then the water gets out, too."
Mikko: "At certain point it will be more expensive to lift that floor than what is the actual cost of that dry well. How much do we need to lift that floor in order to install that dry well?
Timo: "Of course, if we do it in one place, it is not expensive, not even in a hundred, but obviously this is something we need to think about..."
Antero: Comes back to the room and interrupts: "There has been that kind of a margin already. The well for the washing machine lifts the floor already, so it [the dry well] is possible to attach, Riki [a more experienced colleague] said this."

In the next example, the competitor's development serves as a mediational tool between the elementary cognitive functions of asking, listening, and observing, and the higher cognitive function of learning from a competitor's experience.
Case B2, situation in which the team is observing and testing another company's packages.

Miisa: "Here we have these Wipak's packages. When we tried these out, we noticed that they are pretty difficult to open so that you get it [the product] out of the package, if it stays like this so..."

Hilkka: "Yes, then it must be pulled pretty strong."

Miisa: "Yes, it is pretty difficult to get out."

Hilkka: "Yes, it can get stuck."

Miisa: "So then this is too big [for our products]. This we need basically to...Are there any unopened ones?...So when you start to open this, and you want to keep the product sterile..."

Hilkka: "Yes, you need to get it like..."

Miisa: "Like this."

Hilkka: "You have to do it like that, and now someone else can take it."

Mika: "This is a little bit like poking."

Hilkka: "Yes, it is."

Knowledge acquisition through written, visual, or audio material

Knowledge acquisition through written, visual or audio material also serves as a mental mediational tool, and it is most often used by individuals alone. The knowledge acquisition through written, visual or audio material enables the higher cognitive functions of understanding, learning, planning, revising, etc. to occur. This process is stimulated by more elementary cognitive functions like reading, observing, and listening. Then, the actual mediational tool is the object of reading, watching, or listening, like a scientific article, the TV, a magazine etc. The following examples illustrate situations in which the mediational tools (i.e. the object) are a scientific journal (in the first example) and a magazine (in the second example), the elementary cognitive function is reading and the higher cognitive function is the memory retrieval of a learned piece of knowledge stimulated by the comments of other team members:
Case B2
Mika: "I wonder when they start to require the manufacturer to take back used packages, perhaps it will happen one day."
Hilkka: "Yes."
Kari: "Yes."
Mika: "There was an article in the Medical Device Technology journal about this issue. It [the journal] came from here to me, or where did it come from?"
Hilkka: "Yes."
Mika: "There are contradictory practices, the journal wrote. In Germany, they give discount from recycling charges, in France, they do not need to recycle medical packages at all. It is very country-dependent..."
Hilkka: Interrupts: "Yes, it is."

Case Y3
Antero: "How about that ADP-network, what is it, is it "the thing" in the future?"
Timo: "Well, I read yesterday's Aamulehti [a newspaper], somebody wise wrote, or was it Kauppalehti [a business magazine], that in less than three years, there will be some kind of a mega-connection in every apartment."

While mental mediational tools are used to reflect on either one's own or others' experience or to gather information through written, visual, or audio material, they also enable the usage of tacit, explicit, individual, as well as group knowledge. For the concepts of tacit and explicit knowledge, see Chapter 3.4.1.5. They have been in the interests of many researchers, and the common conclusion about the nature of these two modes of knowledge is that, in order for tacit knowledge to be useful in practice, it must be converted into explicit form (cf. e.g. Nonaka and Takeuchi's learning and knowledge creation cycle in page 87). However, Cook and Brown (1999) have argued that tacit as well as explicit forms of knowledge are both distinct forms of knowledge, and neither is a variant of the other, each does the work the other cannot, and that neither form cannot be made out of or changed into the other (384). In other words, both of the forms of knowledge are needed in knowledge creation and the knowing of both an individual and a group.

Another interesting feature of tacit/explicit knowledge discussion is the question of the locus of knowledge and knowing; whether it is only an individual who knows, or an organization, or both. This problem has also been studied earlier in Chapter 3.3.1. Cook and
Brown both belong to the camp, which believes that group can "know" on its own. They write:

"...we propose that individuals and groups each do epistemic work that the other cannot. So, for example, while only individual physicians know how to diagnose nephritis using palpation (groups do not have hands), the knowledge of what constitutes acceptable and unacceptable practice in nephrology is possessed by nephrologists as a group...part of what is known about a given domain is possessed by individuals, part by group." (1999, 386.)

Cook and Brown call this interaction between tacit, explicit, individual, and group forms of knowledge and knowing a "generative dance" in which each form of knowledge is brought into play by knowing, and knowledge is used as a tool in interaction with the world. In other words, when considering team-work, the interaction between team members entails the usage of the team members' various bits of knowledge as tools in order for the team to function successfully.

Even being unique and quite parsimonious, Cook and Brown's theory leaves questions behind. First of all, they strongly argue that tacit and explicit knowledge are both separate forms of knowledge; one cannot be converted into the other. However, constructs like reflection-in-action and metacognition can be understood as mental processes in which a person's inner (or tacit) thoughts (including knowledge and emotions) are converted into explicit ones. The most often heard definition of reflection-in-action is by Schön (1983) who argues: "...we sometimes think about what we are doing. Phrases like "thinking on your feet," "keeping your wits about you," and "learning by doing" suggest not only that we can think about doing but that we can think about doing something while doing it." (54, quotation marks original.) Metacognition, on the other hand, refers to the mental process of being aware of one's own thoughts (see Chapter 3.2.2). Probably the most common way of investigating mental processes has been a method in which people are reflecting (i.e. telling verbally or by behavior) what they are thinking or doing. Now, Cook and Brown argue that
tacit knowledge cannot be converted into explicit knowledge. How can it be investigated, then? They explain that each form of knowledge can be used as an aid in acquiring the other. They give an example of a riding bicycle:

"If you know how to ride, for example, you might use your tacit knowledge to ride around in a way that helps you discover which way you turn when you begin to fall. Likewise, if a novice is told how to turn to avoid a fall, that explicit knowledge could be used while learning to ride as an aid in getting a feel for staying upright. However, neither tacit nor explicit knowledge can be used by itself to acquire the other: one must also, at the very least, get on a bicycle…"

(Cook and Brown, 1999, 385.)

In other words, there must be a mechanism with the help of which a person riding a bike becomes aware of his/her tacit knowledge, and with the help of which he/she is able to pass it on to others. On the basis of this research, I argue that the interplay between the elementary cognitive functions, mental mediational tools, and higher cognitive functions produces the mental actions of an individual as well as a group. In this process, mental mediational tools serve as mechanisms, which allow both cognitive functions as well as tacit, explicit, individual, and group knowledge to interplay and generate. This process can be illustrated with the following figure:
Mental mediational tool as an intervening link

Elementary cognitive function as an impulse
• Asking
• Answering
• Reading
• Listening
• Observing
• Etc.

Higher cognitive function
• Cognitive functions
• Metacognitive functions

Human mental action ~knowing
• Tacit knowing
• Explicit knowing
• Individual knowing
• Group knowing

Figure 27. The interplay between elementary cognitive functions, mental mediational tools, and higher cognitive functions in the production of human mental actions.

In this model, mental mediational tools serve as intervening links between elementary and higher cognitive functions. By doing so, the mental mediational tools serve as the mechanism for passing on tacit, explicit, individual, and group knowledge. In other words, the tacit and explicit forms of individual as well as group knowledge are not considered as two separate types of knowledge, but mutually constituted knowledge in which explicit knowledge is always grounded on a tacit component (Tsoukas 1996, 14). Therefore, both types of knowledge aid the process of producing human mental actions.

A second pitfall of Cook and Brown's theory is their concentration only on rather "hands-on" examples, like a riding bicycle and a making flute. While doing so, a very important part of today's team-work is left untouched. Nowadays, a lot of team work is carried out in so called knowledge intensive firms where people work with knowledge, and not so much with physical objects, like hands or machines. In other words, there are not very many skills one could pass to others, but there is a lot of knowledge that needs to be revealed and created in order to work successfully. Like Frances Horibe (1999) has summed up in his monograph "Managing Knowledge Workers":

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• The driver of success in the New Economy is knowledge.
• The demand for knowledge workers is great and growing.
• A knowledge worker is one who uses his/her head more than his/her hands to produce value.
• About 60 per cent of all jobs are knowledge-based. (Horibe 1999, xvii.)

5.2.2 Instrumental mediational tools

Instrumental mediational tools, on the other hand, are tools, like methods or artifacts, which are more clearly perceived and concrete. Nevertheless, they also aid problem-solving making it more efficient and productive. For example, the usage of professional jargon makes the discussions of teams more fluent and efficient. One does not need to explain things in a thorough way, but the others understand him/her with fewer words filled with special definitions and codes special to that particular group of people. The following two examples illustrate the situation well:

Case B4
Miisa: "The 25 millimeter screws would fit in the same box with the Menisk [the name of the product], and then, for example, from 30 to 70."
Mika: "Yes, we need to start from the first one and then do the multipliers."
Miisa: "Would it be the smallest one then?"
Mika: "Well, let's put 25, 50, and 100 in addition."
Miisa: "150 possible. Is 110 the longest?"
Kari: "Yes."
Miisa: "And then we have plates [the type of the product], those are big ones. Have we made them already?"
Kari: "No, or the first ones have been made, but not packed."
Miisa: "Is there any idea how we pack them?"
Kari: "No."
Miisa: "They do not fit in any of those."
Kari: "But we have those stent [the type of the product] bags."
Miisa: "Yes, those stent bags. They are 25 times 50 and 50 times 50."
Case Y1
Timo: "Where were we? We processed those radiators without the K-value. And we accepted those. Under the dropped ceiling, massif wood 2 times 45 degrees. What about this?"
Mikko: "Massif?"
Antero: "Does it mean that it is 87 degrees, or what?"
Jari: "About."
Timo: "When coming from the neighbor's, the dropped ceiling, that fold."

Two other instrumental tools often used in collaborative problem-solving seem to be the distribution of tasks between the team members and the distribution of tasks to some people outside the team. Here is one example of the usage of both of those tools:

Case Y2
Timo: "When it comes to the extent of the revetment, I think we need to point out a person who is in charge of it and who can give us feedback after the sales are done."
Antero: "I could be in charge because I must follow those sales, anyway."
Mikko: "Matti must also follow those. I could pass this job to Matti who could also check the revetment types, and we will know how much they cost."
Antero: "Yes, we can work together, then."

Making use of external presentations, i.e. drawing sketches, testing a product or part/s of it, or building a model or a prototype are also very common characteristics of the work of an R & D team. These external presentations can be seen as instrumental tools aiding the problem-solving and learning process of a team. The following example of a team discussion illustrates how drawing a sketch is used as an instrumental tool:

Case Y2
Timo: "It could be a good principle [covering an area from a garage to the front door with blacktop or rock material]."
Antero: "It is the same with Punahilkka [name of an apartment building], it makes no sense."
Petri: "And then we have Jukolankoti [name of an apartment building]."
Jari: drawing a sketch: "But, in my opinion, it is clear that if we have the front door here and we have a garage right here, at least this area should be covered with rock material or blacktop."
Knowledge acquisition through testing and building a model or a prototype

Testing and building a model or a prototype are very essential mediational tools used in technological product development. Through testing, information about the functionality of the product is gathered. Therefore, the mediational function of testing and building a model or a prototype is twofold. First of all, the testing and building of a model or a prototype have the characteristics of instrumental tools: testing and building a model or a prototype are external presentations, which easy to perceive and name. On the other hand, their purpose is knowledge acquisition and learning about the functionality of the product under development. In this sense, they serve as mental mediational tools, which aid the problem-solving process by promoting understanding and learning (i.e. higher cognitive functions).

The twofold nature of testing and building a model/prototype can be illustrated with the following example:

Case B4
Miisa:  "How about when we heat it [a package] first while we do it, but is it chilled by the time it comes to the point where the product is put inside?"
Mika:  "Yes."
Miisa:  "I need to test it when we go to Kiromat [a package line manufacturer]."
Mika:  "I tested it already."
Miisa:  "Was it [warm]?"
Mika:  "They [the packages] were not warm anymore, they were just pretty thin. I tested one because I saw that they were left a little crumpled, and I straightened it, so that's how I realized that it was not warm.
Kari:  "That's probably right, but we need to keep that in mind."
Miisa:  "And our pace time is already so that we can assume that when a packer places a product in the package, it will be chill by that time."
5.2.3  Concluding the major findings

The task of this section was to find an answer to the research question number two: What kinds of practical tools are used by problem solver(s) in solving R & D problems?

According to the findings of this research, in technological product development of a collaborative mode, practical mediational tools used to aid the problem-solving process are: 1) mental mediational tools which serve as intervening links between elementary and higher cognitive functions, and 2) instrumental mediational tools which are concrete and perceivable methods or artifacts aiding the problem-solving process making it more efficient and productive. Both of these tools are used either by an individual alone or by a team. Both are also very situation-depended, but targeting the same goal: the better execution of the problem-solving task at hand as well as gaining new patterns of thought and mental functioning for both the individual and the group.

5.3  Elementary and higher cognitive tools used in collaborative problem-solving in technological product development processes

As argued in the previous chapter, human mental action (i.e. knowing) takes place through a three veined-process. First, there has to be an elementary cognitive function, which serves as an impulse to a higher cognitive function. However, this process is not straightforward. A mental mediational tool serves as an intervening link between the two cognitive functions and is a precondition for a higher cognitive function to occur. Within the previous chapter, these practical tools used in collaborative problem-solving were examined. The task of this chapter is to examine what those cognitive tools are, both elementary and higher cognitive functions, used in collaborative problem-solving. They are called "tools" for the reason of their aiding nature in cognitive and collaborative problem-solving processes of R & D teams.
5.3.1 A look back at the theoretical framework

According to the information processing theory and its numerous descendants, the human problem-solving activity is a series of steps a problem-solver takes in a problem space during the problem-solving process. In the information processing theory, these steps are called 'states' and 'operators'. 'States' are like sub-goals on the way to the solution of the problem. 'Operators' are actions or strategies a problem-solver must apply in order to move from one state to another (discussed in Chapter 2.3). In other words, the human cognitive activity during a problem-solving process consists of identifying the problem and its initial and goal state, representing the problem in a problem space, and solving the problem using different strategies, like trial and error, means-ends analysis, and heuristics, as well as understanding what solution might be possible under certain limitations (cf. e.g. Newell & Simon 1972; Voss 1989; Baron 1994; Davidson et al. 1994).

Praxiology, the theory of efficient action, on the other hand, explains any action (including problem-solving) to be an effect caused by the agent's free impulse (discussed in pages 29 and 162-163) and an act (discussed in page 28). In other words, the problem-solver's free impulse causes an act that produces a solution (cf. Kotarbinski 1965; Meloe 1983).

Other important elements while studying individual cognitive functioning are the occurrence of metacognitive functions which enable an individual to be aware of him/herself as a cognitive agent (i.e. metacognitive knowledge, discussed in Chapter 3.2.2) and the occurrence of metacognitive skills that enable a person to plan, monitor, and revise his/her progress in a cognitive enterprise (discussed in Chapter 3.2.3). These individual metacognitive functions have been investigated by many researchers (cf. e.g. Flavell 1979, 1985, 1992; Brown 1978, 1987; Stenberg 1981, 1986; Kluwe 1987).

Both the information processing theory and metacognitive research have concentrated heavily on the research of individual cognitive functioning. However, when problem-
solving occurs in a collaborative mode within a group of people, two cognitive constructs become important. First, when working collaboratively, people share information. They share information about the subject matter at hand, they share information about the possible solution as well as limitations under which the problem must be solved. They also create shared representations of the problem. But like Cole (1991) has argued, sharing is a "Janus-headed" concept. On one hand, it refers to receiving, using, and experiencing together with others. On the other hand, it also means dividing or distributing something between oneself and others. Both of these aspects of sharing with respect to distributed cognition (discussed in Chapter 3.3.4) are relevant for this research. In a collaborative problem-solving practice -because each actor does not possess the entire knowledge to accomplish the task- the demand to share knowledge becomes necessary. The actual realization of the problem-solving task at hand goes through the common sharing of knowledge, i.e. building up distributed cognition. Each actor of the particular problem-solving process disposes a part of the information, thus, it is the necessity of sharing information that causes co-operation. Shared knowledge is a feature of distributed cognition that enables the monitoring of the ongoing activity by other knowledgeable participants (Decortis, Noirfalise, & Saudelli 2000). Now, the question is how this feature (shared knowledge) of distributed cognition comes about in collaborative problem-solving processes. Like Brown and Cole (2000) argue: "No two people can ever entirely experience a situation or use a tool in exactly the same way, even as they are cognizant of the fact (which they may communicate to each other) that there are aspects of their experience which can be said to be shared in the sense of held in common" (parentheses original). Therefore, and even though, in a collaborative activity -like team problem-solving- the distributed cognition "arrives" at the scene of collaborative problem-solving as strings of spoken words and becomes "shared", it is highly unlikely that it is understood exactly the same way by each actor at that scene. Therefore, we cannot equate sharing with mutual understanding. However, we can equate sharing with individual understanding, i.e. to be able to share knowledge or information, one has to understand it. We can also equate sharing with dividing or distributing knowledge or information to others. Thus, only ideas that are shared by one individual and attended to by others (for example discussed) have the
potential to modify distributed cognition. Moreover, as all members of both teams studied in this research had a history of working together (i.e. teams were gathered for a certain purpose, but team members had worked together in different projects in the past) it can be assumed that both teams formed a community of practice in the particular organizational setting (see Chapter 3.3.1.1). Therefore, the construct of tacit knowledge (discussed in Chapters 3.4.1.5 and 5.2.1) becomes relevant while speculating about the concept of shared knowledge. It can be assumed that the tacit individual as well as group knowledge formed in the past, aids the process of sharing in all future collaborative activities.

Secondly, when working together, people create metacognitive knowledge and skills, which are collectively created and "own". The very same way an individual is able to plan, monitor, and revise his/her cognitive functions, a group as a whole is able to plan, monitor, and revise its cognitive functions. I call these group's metacognitive skills. Furthermore, as an individual is aware of his/her way of approaching a cognitive task and the usage of certain cognitive strategies, a group is aware of the total pool of information within the group, it is aware of the areas of expertise, formal roles, and information gathering activities of other group members (discussed in Chapter 3.2.4). I call this group's metacognitive knowledge.

5.3.2 Developing themes and codes for higher cognitive tools

In order to find an answer to the research question number three of what cognitive tools are used by problem solver(s) in solving R & D problems?", the videotaped team meetings were transcribed and analyzed using a thematic coding method. A good thematic code captures the qualitative richness of the phenomenon. It can be used in the analysis, interpretation, and presentation of the research. There are three different ways of developing a thematic code: (a) theory-driven, (b) prior-data or prior-research driven, and (c) inductive or data-driven. All of these approaches move the researcher toward the development of the theory. However, they differ in the degree to which the thematic analysis starts with a theory (researcher's own or someone else's) or raw information. In theory-driven code
development, the researcher begins with his/her theory of what occurs and then formulates indicators of evidence that will support this theory. The elements of the code are derived from the elements of the theory. (Boyatzis 1998, 29, 33.) The value of the theory-driven code is highly dependent on the theoretical sensitivity of the researcher (Strauss & Corbin, 1990). Boyatzis defines the prior-research-driven code development as using codes developed by other researchers or creating codes based on other researchers' findings or hypotheses. In the first case, the researcher is building on prior research that has established valid codes. In the latter case, researcher uses prior research as a guideline for what to look for. Data-driven codes, on the other hand, are developed inductively from raw information. It is a task of the researcher to interpret the meaning after obtaining the findings. (Boyatzis 1998, 30.) As this research is both theory and data-driven, all three ways of thematic coding have been used.

**Developing themes and codes for individual cognitive and metacognitive tools**

The thematic code for individual cognitive and metacognitive functions occurring during the problem-solving processes is developed based on earlier theories. The individual cognitive functions –theme is developed based on the information processing theory initially developed by Newell and Simon (1972). This theory argued that, in order to solve a problem, an individual must first identify the problem, represent it, and understand the constraints under which the problem must be solved. However, and despite of, the information processing theory's strong emphasis on problem-solving strategies or methods, they were left untouched during the thematic coding of the problem-solving episodes. The reasons for doing this arose from two viewpoints: first, this is not a strategy research, and the importance of the so called problem-solving strategies or teachable methods has been doubted throughout this research.
## Theme

### INDIVIDUAL COGNITIVE FUNCTIONS

<table>
<thead>
<tr>
<th>Category</th>
<th>Code definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>A person identifies a problem.</td>
<td>Coded when a person presents a problem for the first time.</td>
<td>&quot;What are the requirements of the product itself, why do they need to be packed?&quot;</td>
</tr>
<tr>
<td>A person understands what kinds of solutions are likely.</td>
<td>Coded when a person proposes a solution or agrees/disagrees with a proposed solution.</td>
<td>&quot;Of course, a part of the reason is that, in a moist body, the product will dissolve, but the product will remain its solidity in a dry, dark, and cool atmosphere.&quot; &quot;Yes, that's right.&quot;</td>
</tr>
<tr>
<td>A person understands the limitations under which the problem must be solved</td>
<td>Coded when a person proposes a limitation or agrees/disagrees with a proposed limitation.</td>
<td>“The package itself won’t control the temperature.” “No, that's right.”</td>
</tr>
<tr>
<td>A person represents a problem or divides it into a sub-problem/s.</td>
<td>Coded when a person represents a problem or divides it into a sub-problem/s.</td>
<td>“How can we store the product?” “The problem is how we get the indicator on the side of the package.”</td>
</tr>
</tbody>
</table>

Table 7. Theme number 1: Individual cognitive processes during problem-solving.

The thematic code for individual metacognitive functions is build on earlier theories concerning individual metacognitive knowledge, initially developed by Flavell, Friedrichs, and Hoyt (1970), Flavell (1979), and on earlier theories of metacognitive skills developed by Brown (1978). As addressed earlier, metacognitions are "second-order" cognitions: thoughts about thoughts, knowledge about knowledge, and reflections about actions. However, problems arise when one tries to apply these rather general definitions to specific
instances. Metacognitive functions are difficult to verify in a problem-solving situation as they are rarely manifested or intentionally expressed by the solver. When studying individual metacognitive functions, the researcher usually asks the subjects to think out loud or to describe, verbally or in writing, the operations they would normally accomplish mentally. These means of collecting data about the mental activities of problem-solvers were not available in this research. However, the examination of a team discussion during the problem-solving can be a valuable source of information on metacognitive activities. These discussions cannot be expected to reveal the totality of metacognitive functions, but they can offer information well worth considering.
## Theme

<table>
<thead>
<tr>
<th>Category</th>
<th>Code definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>A person plans his/her cognitive strategies or actions</td>
<td>Coded when a person schedules his/her own cognitive strategies or actions.</td>
<td>“Should I contact someone who manufactures packing pads?”</td>
</tr>
<tr>
<td>A person monitors his/her cognitive progress, strategies, or actions.</td>
<td>Coded when a person checks or evaluates his/her own cognitive progress, strategies, or actions.</td>
<td>“I tried to think how this process goes, so I think that, as early as possible, I should make the decision about the different levels.”</td>
</tr>
<tr>
<td>A person revises his/her cognitive strategies or actions</td>
<td>Coded when a person changes his/her own cognitive strategies or actions.</td>
<td>“No, at this point I have to go to the water-operating plan because it is drawn there.”</td>
</tr>
<tr>
<td>A person is aware of him/herself as a cognitive agent.</td>
<td>Coded when a person makes comments about him/herself as a cognitive agent.</td>
<td>“There is so much information coming, and when my working style is so that it is often impossible to apply.”</td>
</tr>
<tr>
<td>A person is aware of his/her way of approaching a cognitive task.</td>
<td>Coded when a person makes comments about his/her way of approaching a cognitive task.</td>
<td>“Now, I cannot remember.”</td>
</tr>
<tr>
<td>A person is aware of using a cognitive strategy.</td>
<td>Coded when a person makes comments about a cognitive strategy he/she is using or about to use.</td>
<td>&quot;When I tried this approach in the past, it worked.&quot;</td>
</tr>
</tbody>
</table>

Table 8. Theme number 2: Individual metacognitive processes during problem-solving.
Distributed cognitive functions and a group's metacognitive tools

The thematic code for the distributed cognitive functions occurring during the collaborative problem-solving process is built based on the idea of cognitions, both individual and shared, interacting in a spiral-like fashion, mentioned by Salomon (1993). Following this idea, it is assumed that individual cognitive functions of identifying and representing a problem and understanding the limitations under which the problem must be solved, as well as understanding the possible solutions, do have group-level counterparts. The thematic code for 'sharing problem-relevant information' is developed inductively from the data collected for this research.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharing a perception that a problem exists.</td>
<td>Coded when a group member agrees with the proposed problem.</td>
<td>“Yes, I think so, too, because those requests we have sent were a long time ago.”</td>
</tr>
<tr>
<td>Sharing problem -relevant information.</td>
<td>Coded when a group member presents a problem-related question, answers a question, or shares problem-related information.</td>
<td>“We have a price range…these are costs, not the selling prices, right?” “Yes, that is what we pay.”</td>
</tr>
<tr>
<td>Sharing information about possible solutions.</td>
<td>Coded when a group member shares information about a solution or proposes a solution.</td>
<td>“It must be described in Material-99.” “And also in the architect’s design guideline.”</td>
</tr>
<tr>
<td>Sharing information about the limitations under which the problem must be solved.</td>
<td>Coded when a group member shares information about a limitation or proposes a limitation.</td>
<td>“The package itself will not control the temperature.” “It [the padding] must also be medically agreed.”</td>
</tr>
<tr>
<td>Creating a shared representation of the problem.</td>
<td>Coded when a group member agrees with the proposed representation of the problem (sub-problem) and/or defines it more closely.</td>
<td>&quot;Yes, and in which products will we use it, or do we use it in all our products?&quot; &quot;Yes, that is a very important question.”</td>
</tr>
</tbody>
</table>

Table 9. Theme number 3: Distributed cognitive functions during problem-solving.
The thematic code for the group's metacognitive functions applied during collaborative problem-solving is built on earlier research that treated metacognition as an individual process, and also on prior research that hypothesizes about group metacognitive knowledge calling it transactive memory (Wegner 1987), meta-knowledge (Larson & Christensen 1993), or shared mental models (Cannon-Bowers et al. 1993). Therefore, it is assumed that the individual metacognitive skills of planning, monitoring, and revising one's cognitive functioning do have group-level counterparts. However, the metacognitive knowledge of a group is somewhat different from individual metacognitive knowledge. Metacognitive knowledge at group-level is more like being aware of the information within the group, being aware of the information gathering activities of other group members, and being aware of the areas of the expertise and the formal roles of other group members.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning group’s cognitive strategies and actions.</td>
<td>Coded when a member of a group plans the group’s cognitive strategies or actions.</td>
<td>“We could ask them to provide us with certain kind of information, and once we get that, we can ask for more information from those that seem to be the most appropriate.”</td>
</tr>
<tr>
<td>Monitoring group’s cognitive progress, strategies, and actions.</td>
<td>Coded when a member of a group checks and evaluates the group’s cognitive progress, strategies, or actions.</td>
<td>“We still have a lot to do.” “We also need to consider the position of those pieces inside the package.”</td>
</tr>
<tr>
<td>Revising group’s cognitive strategies and actions.</td>
<td>Coded when a member of a group revises the group’s cognitive strategies or actions.</td>
<td>“Should we now start from a scratch again, so that we send a request for material to all importers?”</td>
</tr>
<tr>
<td>Metacognitive knowledge of a group.</td>
<td>Coded when group members are aware of the formal roles, area of expertise, and the information gathering activities of other group members or the total pool of information in the group.</td>
<td>“Then Timo as a Project Manager will decide which pattern we use.” “Mikko has come up with an idea…” “You have read it, haven’t you?”</td>
</tr>
</tbody>
</table>

Table 10. Theme number 4. Group's metacognitive functions during problem-solving.
5.3.3 Developing themes and codes for elementary cognitive tools

At the second phase of analyzing the problem-solving episodes, elementary (lower) level cognitive functions used by individuals during the collaborative problem-solving process were discovered using the data-driven thematic coding method. The elementary cognitive tools –theme was coded inductively based on the kind of elementary cognitive function each individual utterance seemed to reveal.
<table>
<thead>
<tr>
<th>Category</th>
<th>Code definition</th>
<th>Example of Case B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asking</td>
<td>Coded when a person asks a question.</td>
<td>&quot;Didn't Lea say that some products have been contaminated because of too slack a package?&quot; person A3</td>
</tr>
<tr>
<td>Commenting</td>
<td>Coded when a person makes a comment.</td>
<td>&quot;That's new, that slackness.&quot; Person B2</td>
</tr>
<tr>
<td>Answering</td>
<td>Coded when a person answers to a question someone presents.</td>
<td>&quot;Yes, the package should be more firm.&quot; Person D4</td>
</tr>
<tr>
<td>Expressing an opinion</td>
<td>Coded when a person expresses a personal opinion.</td>
<td>&quot;Of course it should be more firm.&quot; Person C5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;We should ask how they have handled the packages.&quot; Person B6</td>
</tr>
<tr>
<td>Proposing</td>
<td>Coded when a person proposes a problem, a sub-problem, solution, or limitation.</td>
<td>&quot;The whole package breaks, the packages are too slack.&quot; Person A1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;But if there is a bubble inside, doesn't it give enough protection?&quot; Person A8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;A deep drawn package would be more firm.&quot; Person B12</td>
</tr>
<tr>
<td>Agreeing</td>
<td>Coded when a person agrees with a proposed problem, subproblem, solution, limitation, or opinion.</td>
<td>&quot;Yes, of course the lid won't give enough protection.&quot; Person A10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&quot;Yes.&quot; Person C13</td>
</tr>
<tr>
<td>Disagreeing</td>
<td>Coded when a person disagrees with a proposed problem, sub-problem, solution, limitation, or opinion.</td>
<td>&quot;Yes, for the other side of the bubble, but not for the lid.&quot; Person C9</td>
</tr>
<tr>
<td>Defining/Explaining</td>
<td>Coded when a person defines or explains a proposed problem, sub-problem, solution, limitation, or limitation closely.</td>
<td>&quot;And smaller, too.&quot; Person B14</td>
</tr>
<tr>
<td>Repeating</td>
<td>Coded when a person repeats either his/her or someone else’s statement.</td>
<td>&quot;The lid won't give enough protection.&quot; Person B11</td>
</tr>
</tbody>
</table>
The following two cognitive tools did not appear within the above example, but in other problem-solving episodes:

| Reading                          | Coded when a person reads aloud. | "Lawn and plants, see report number 203.#
Case Y, epis. 2.1., person A, utterance 44 |
|---------------------------------|----------------------------------|---------------------------------------------|
| Assisting others                | Coded when a person assists other/s to remember or complete an activity. | "What else is in here, I only see those trees."
Case Y, epis. 2.1., person F, utterance 38
"And three birches."
Case Y, epis. 2.1., person c, utterance 39
"And lawn."
Case Y, episode 2.1, person F, utterance 40 |

Table 11. Theme number 5: Individual elementary cognitive tools.

With the same logic proposed earlier, the individual metacognitive functions of planning, monitoring, and revising, as well as group's metacognitive functions of planning, monitoring, and revising could be seen as elementary cognitive tools. However, I have reserved the concept of 'elementary tool' for the elementary cognitive functions of an individual. So have many done before me (cf. e.g. Newell & Simon 1972). Therefore, in "a hierarchy" of cognitions, metacognitive functions are not elementary by nature, but higher cognitive functions.

5.3.4 Conclusion: elementary and higher cognitive functions aiding the collaborative problem-solving process

The higher cognitive functions that occurred in the collaborative problem-solving processes of the teams under study here can be illustrated in percentages in the following table:
<table>
<thead>
<tr>
<th>Theme</th>
<th>Code</th>
<th>Case B</th>
<th>Case Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual cognitive functions</td>
<td>Identifying the problem</td>
<td>2.7%</td>
<td>2.8%</td>
</tr>
<tr>
<td></td>
<td>Understanding what kinds of solutions are likely</td>
<td>26.0%</td>
<td>23.0%</td>
</tr>
<tr>
<td></td>
<td>Understanding the limitations under which the problem must be solved</td>
<td>4.9%</td>
<td>3.0%</td>
</tr>
<tr>
<td></td>
<td>Representing the problem/dividing the problem into sub-problem(s)</td>
<td>4.3%</td>
<td>2.9%</td>
</tr>
<tr>
<td></td>
<td><strong>∑</strong></td>
<td><strong>37.9%</strong></td>
<td><strong>31.7%</strong></td>
</tr>
<tr>
<td></td>
<td>Sharing a perception that the problem exists</td>
<td>2.7%</td>
<td>2.8%</td>
</tr>
<tr>
<td></td>
<td>Creating a shared representation of the problem</td>
<td>2.9%</td>
<td>1.9%</td>
</tr>
<tr>
<td></td>
<td>Sharing problem-relevant information</td>
<td>20.1%</td>
<td>32.0%</td>
</tr>
<tr>
<td></td>
<td>Sharing information about possible solutions</td>
<td>26.0%</td>
<td>23.0%</td>
</tr>
<tr>
<td></td>
<td>Sharing information about the limitations under which the problem must be solved</td>
<td>4.9%</td>
<td>3.0%</td>
</tr>
<tr>
<td></td>
<td><strong>∑</strong></td>
<td><strong>56.6%</strong></td>
<td><strong>62.7%</strong></td>
</tr>
<tr>
<td>Distributed cognitive functions</td>
<td>Planning individual cognitive strategies, actions</td>
<td>0.8%</td>
<td>1.0%</td>
</tr>
<tr>
<td></td>
<td>Monitoring individual cognitive progress, strategies, actions</td>
<td>0.2%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Revising individual cognitive strategies, actions</td>
<td>0%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Metacognitive knowledge of a person</td>
<td>0.3%</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td><strong>∑</strong></td>
<td><strong>1.3%</strong></td>
<td><strong>2.3%</strong></td>
</tr>
<tr>
<td>Individual metacognitive functions</td>
<td>Planning the group’s cognitive strategies, actions</td>
<td>2.5%</td>
<td>2.9%</td>
</tr>
<tr>
<td></td>
<td>Monitoring the group’s cognitive progress, strategies, actions</td>
<td>0.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td></td>
<td>Revising the group’s cognitive strategies, actions</td>
<td>0.08%</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Group's metacognitive knowledge</td>
<td>2.0%</td>
<td>1.1%</td>
</tr>
<tr>
<td></td>
<td><strong>∑</strong></td>
<td><strong>5.4%</strong></td>
<td><strong>4.6%</strong></td>
</tr>
<tr>
<td>Group's metacognitive functions</td>
<td>Non-relevant talk</td>
<td>0.3%</td>
<td>0.7%</td>
</tr>
<tr>
<td></td>
<td><strong>∑</strong></td>
<td><strong>100%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Table 12. A summary of the individual cognitive, metacognitive, distributed cognitive, and the group's metacognitive processes.
Based on the findings of this research, one of the most important cognitive functions people expose during a collaborative problem-solving process is the distributed cognitive function of sharing information. People share facts, experiences, opinions, and comments, as well as gain knowledge by asking, listening to, and observing others. They also share their acceptance and disagreement. Moreover, during a collaborative problem-solving process, people share their understanding about the possible solutions to a problem, as well as possible limitations under which the problem must be solved. However, while sharing understanding about the possible solutions as well as limitations, people, at the same time, express their individual cognitive functioning. As can be seen in table 12, the percentages of both 'understanding what kinds of solutions are likely' (individual cognitive functions) and 'sharing information about possible solutions' (distributed cognitive functions), as well as 'understanding the limitations under which the problem must be solved' (individual cognitive functions) and 'sharing information about the limitations under which the problem must be solved' (distributed cognitive functions) are the same. Therefore, I argue that in sharing knowledge about any subject matter in a group, this matter needs to be understood by the sharing subject (i.e. an individual group member). However, to avoid the failure of circular reasoning (due to the coding scheme) and to be able to distinguish the distributed cognitive functioning from the individual cognitive functioning, as well as to avoid the misunderstanding that sharing always equates with understanding, it is necessary to take a closer look at the actual studied team discussions that went on during the collaborative problem-solving enterprises. In order to illustrate this, I quote a piece of a problem-solving episode of case B (the whole episode is reported in appendix 4). Here, it has to be remembered that all utterances might hold information, which will be coded into several categories (to review the categories, see e.g. table 12 in page 195).
**Case B**  
Part of the episode 4.12. (the team tries to find a solution to the problem of which machine providers to contact and how)

**Mika:** "Multivak and Kiromat are clear, they have the machines, but the best way to reach the smaller companies is to call and ask them."

*Mika proposes a solution (individual elementary cognitive function), he also understands the solution (individual higher cognitive function), but also shared it with the others (distributed cognitive function). He also plans a cognitive strategy "to call and ask" (group's metacognitive function).*

**Miisa:** I guess I don't have to send the requests in writing, but if I call them and tell them that I want this kind of information, so will they send it to me?"

*Miisa continues to build a solution based on Mika's proposition (individual elementary cognitive function), she also understands the solution (individual higher cognitive function), but also shares it with the others (distributed cognitive function). She also monitors her own metacognitive strategy: "I don't have to send…if I call them and tell" (individual metacognitive function).*

**Kari:** "Well, it might be so."

*Kari agrees with the strategy (individual elementary cognitive function), he also understands it (individual higher cognitive function), and shares his understanding with the others (distributed cognitive function).*

**Miisa:** "For example this Brennen gives that kind of a feeling, when I sent them..."

*Miisa shares her previous experience with the others (distributed cognitive function) by explaining (individual elementary cognitive function).*

**Kari:** "When we ask for information, we could mention to them that we don't have any previous experience of this kind of technology, and we would need information on how to pack these kinds of small products."

*Kari continues to build the solution based on Mika's and Miisa's previous propositions (individual elementary cognitive function), he also understands the solution (individual higher cognitive function), and shares his understanding with the others (distributed cognitive function).*

**Miisa:** "The brochures really don't tell you everything, they just tell you that you can use this machine to make nice bubbles."

*Miisa shares her previous knowledge with the others (distributed cognitive function) by explaining (individual elementary cognitive function).*

**Mika:** "Well and fast."

*Mika shares his previous knowledge with the others (distributed cognitive function) by commenting (individual elementary cognitive function).*
Miisa: "We could ask them to provide us with certain kind of information, and once we get that, we can ask for more information from those that seem to be the most appropriate.

Miisa continues to build the solution based on Mika's, Kari's and her own previous propositions (individual elementary cognitive function), she also understands the solution (individual higher cognitive function) and shares her understanding with the others (distributed cognitive function), as well as plans a strategy "we could ask, once we get that, we can ask" (group’s metacognitive function).

Kari: "Multivak and Kiromat, and maybe a third one, too."

Kari continues to build the solution based on Mika's, Miisa's and his own previous propositions (individual elementary cognitive function), he also understands the solution (individual higher cognitive function) and shares his understanding with the others (distributed cognitive function).

Mika: "Yes, there might be others, too."

Mika agrees with the solution (individual elementary cognitive function), he also understands it (individual higher cognitive function) as well as shares his understanding with the others (distributed cognitive function).

In this example, the final solution is built based on the cognitive process where the members of the group share some of their ideas about the problem-solving task as well as process ideas shared by the others. Therefore, this example demonstrates well how individual cognitive functions (both elementary and higher) interact, and, thereby, produce distributed cognitive functions possessed by a group of people. The analysis concerning all of the collected problem-solving episodes follows the line of reasoning presented above.

Therefore, the hypothesis of cognitions (both individual and distributed) interacting in a spiral-like fashion (during which individuals' inputs, through their collaborative activities, affect the nature of the joint cognitive system) first proposed by Salomon (1993b) proofs its explanatory power. Eventhough, as argued at the beginning of this research, it was not the intention (nor was it possible) of this research to find universal model defining how a complex and collaborative problem-solving process proceeds, the author dares to propose an illustrative metaphor of cognitions interacting like a spiral adapted from Salomon (1993b) and develop it further based on the findings of this research.
While solving a problem of whatever kind, the problem must first exist, and it must be identified. This can be seen as the starting point of the spiral (point A). After identifying the problem, the spiral starts to expand and develop toward a problem solution (point B). The speed of the enlargement and development of the spiral varies, and, against all mathematical laws, the development of the spiral can occasionally decline. However, in the same way as a spiral is never-ending by nature, so is problem-solving in technological product development processes. The never-ending nature of problem-solving processes in R & D became evident while investigating the characteristics of problems occurring within the R & D functions (discussed in Chapter 5.1.2).

The development of the spiral can also be seen as a maturing process in which cognitions, both individual and distributed, aid the way to the better execution of a task. Like one interviewee stated:

"It [the collaborative problem-solving process during the R & D process] is a very odd process. We discuss with one another and acquire information. It might be a sort of a maturing process, first we do not know anything and then, little by little, we get more knowledge. It is like from zero to 100 percentage, first, it is zero and then, hopefully, we reach 100, but not necessarily, sometimes we can be wrong. Or sometimes the solution is not 100 percent, but 80 percent. This happens often, very rarely the solution is 100 percent, but sometimes it can be even above 100, we succeeded better than we though we would. It is some kind of a maturing process, a growing process." (an interview, Kari, case B)
An important nuance that became evident with both cases is the finding of solution-oriented problem-solving. On the basis of this research, the cognitive activities of both of the R & D teams concentrated more on finding a solution to the problem at hand than finding constraints that limit the problem-solving process. Both of the groups also concentrated on the subject matter at hand very well, and the amount of non-relevant talk in both of the groups was very low (0.3% in team B and 0.7% in team Y). However, the low proportion of non-relevant talk reported in this study might result from two things. First of all, as explained in page 122 each videotaped team meeting was seen as consisting of several problem-solving episodes, where an episode was a problem-solving event in which the team deals with one problem statement. Therefore, only problem-solving episodes were coded, not the talk which took place between problem-solving episodes and therefore concerned some other (non-relevant) issues, like company's market position, allocating money or people to other projects, and negotiating about the next team meeting. However, while not including this kind of talk into coded episodes the proportion of non-relevant talk within the episodes is still very low. Therefore, the next possible reason for this might be the observation procedure itself. It is always possible that team members did not behave as they would have without the researcher's presence. This problem will be discussed further in Section 6.

It is also worth noticing that the amount of shared problem-relevant information is higher with team Y (32.0%) than team B (20.1%). Based on the analysis carried out, all explanations given for this phenomenon are only speculative First of all, the size of these particular R & D teams differed. Team Y had five members, whereas team B had four. The need for information exchange is more crucial when the actual size of the team grows. However, in this case this might not be the most plausible explanation. Instead, as the nature of the problem-solving tasks differed between these two R & D teams, teams need for information exchange differed as well. Team Y worked on a so called "low-tech" problem, in which the solutions are often based on previous knowledge and experience possessed by the group members. In other words, the members of the team Y had alot of previous knowledge and experience to share. The team B, on the other hand, worked on a so called "high-tech" problem, in which none of the team members had very much previous
knowledge or experience. Another plausible explanation can be based on the existence of previous knowledge and experience as well. While comparing the average amount of working experience between these particular R & D teams, we find that the average working experience within the team Y was 14,4 years, whereas within the team B it was only 8,5 years. Members of the team Y were also older in age (average 37,2 years) than members of the team B (32,8 years). Based on these rather speculative notions it can be argued that both, the nature of the problem-solving task as well as the amount of working experience acquired, do affect the quantity of the information exchange within the collaborative problem-solving process.

Another issue that grazes the analysis is the question of the source of the cognitions. Where do cognitions originate from? Even though this question was not specifically presented at the beginning, it became quite evident in the course of this research that the source of cognitions can be either individual or distributed. A cognition expressed in a collaborative problem-solving process can originate from a person's past experiences (formal education, working life, life in general) or knowledge base (knowledge acquired through written/visual or audio material, or knowledge acquired through testing, building a model or prototype), or, in other words, it can originate from the person's memory. Cognition can also be created in a particular situation in which the cognitions of group members interact and create new cognitions in some people (i.e. learning, discussed in the next section). Moreover, cognitions can originate on the basis of the group's metacognitive knowledge possessed by the whole group working together.

When taking a closer look at the metacognitive functions that occurred during the collaborative problem-solving processes, the result is quite clear. The amount of cognitive functions occurring during the collaborative problem-solving processes is much higher than the amount of metacognitive functions. When distributing all higher cognitive functions between the cognitive and metacognitive functions of both an individual and the group, the division looks like this:
Table 13. The distribution of cognitive and metacognitive functions of individuals and groups.

<table>
<thead>
<tr>
<th>Case</th>
<th>Individual and distributed cognitive functions</th>
<th>Individual and group's metacognitive functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case B</td>
<td>93.0 %</td>
<td>6.7 %</td>
</tr>
<tr>
<td>Case Y</td>
<td>92.4%</td>
<td>6.9 %</td>
</tr>
</tbody>
</table>

One could argue that the metacognitive functions that occurred during the collaborative problem-solving processes are so few that they are hardly worth mentioning. However, although the metacognitive functions that occurred during the collaborative problem-solving processes are few in numbers, their presence is still evident. One of the results of this research show that groups do plan, monitor, and revise their cognitive functions. In fact, the most often-occurring metacognitive function was the cognitive function of planning the groups' cognitive strategies and actions. Also, the presence of the groups' metacognitive knowledge became evident. However, individual metacognitive functions do not play an important role in the course of a collaborative problem-solving process. The explanation for this can be as simple as the nature of group work itself. During a collaborative enterprise, an individual belongs to a group of people and mirrors his/her metacognitive functioning more through the group than him/herself.

To conclude, and, as argued at the beginning of this section, both elementary and higher cognitive functions only aid the collaborative problem-solving process of an R & D team. As argued in page 175, the interplay between elementary cognitive functions, mental mediational tools, and higher cognitive functions produces mental actions of individuals as well as groups. Now, the figure presented in page 176 can be expressed in more detail:
All cognitive functions, eventhough being perhaps the most important preconditions in getting a problem solved, are only one part of an ensemble of the construct of the problem space. Now, it is possible to continue to formulate the overall construct of a problem-solving space where all problem-solving takes place. This formulation is a continuation to the figure presented in page 161, in which the following parts of the entire problem space were illustrated: who solves, what kinds of problems, in what kinds of situations, under what kinds of constraints? Based on the findings of the previous section as well as the section at hand, two other parts of the problem space can be dealt with:
With what kinds of practical tools? | With what kinds of cognitive tools?
--- | ---
- Mental mediational tools  
- Individual experience  
- Experience of others  
- Knowledge acquisition through written/visual/audio material  
- Knowledge acquisition through testing and building a prototype  
- Instrumental mediational tools | - Higher cognitive tools  
- Individual cognitive functions  
- Individual metacognitive functions  
- Distributed cognitive functions  
- Group's metacognitive functions  
- Elementary cognitive tools  
- Elementary cognitive functions of individuals

Figure 29. The nature of the problem space: with what kinds of practical tools, and with what kinds of cognitive tools?

Now, the final aspect of the collaborative problem-solving process and problem space can be investigated. Within the next chapters, the question of learning through collaborative problem-solving is examined.
5.4 Learning through collaborative problem-solving: producing human, intellectual, and social capital

As argued in the theory section of this research, collaborative problem-solving is seen as a three-veined learning process in which learning occurs through problem-solving, and the cognitive products (i.e. what has been learned) of this process are:

- **Human capital of an individual** (knowledge, skills, and other attributes of a single person).
- **Intellectual capital possessed by a group** (the knowledge and knowing capability of a group).
- **Social capital partly possessed by a group and partly by an individual** (the 'knowing-who' knowledge of a group or an individual).

The aim of this research was not to measure the amount of human, intellectual, or social capital existing in the two R & D teams studied, but specifically, to study what has been learned and how when producing human, intellectual, and social capital during the particular collaborative problem-solving processes.

5.4.1 Producing human capital - learning new knowledge, skills, and attitudes

In a recent OECD report (2001), the author writes: "Human capital formation takes place not only in formal education or training programmes, but also in informal interaction with others as well as through self-reflection and self-directed learning" (20). This phrase indicates the idea presented earlier in this research well: learning through problem-solving is partly seen as formation of human capital. As many researchers have argued, human capital is an individual attribute defined as individually possessed knowledge, skills, and other characteristics. Following this definition, learning through problem-solving should produce and increase the human capital of these people attending a joint and collaborative problem-solving process. In other words, the outcome of learning through collaborative problem-solving should be new knowledge, skills, and other attributes of individuals. To test and verify this argument, every team member was asked to evaluate his/her own learning during
the investigated collaborative problem-solving enterprise. Every team member was interviewed separately, and the following three questions were asked:

a) What did you already know about the area of this particular R & D project?
b) What kind of new knowledge and skills did you acquire during this particular R & D project?
c) Did you learn something during this process?

The purpose of asking two almost similar kinds of questions (questions b and c) was to avoid misunderstandings and to get more reflective answers (just asking "what did you learn?" might have produced more meager answers than a somewhat more leading question about the new knowledge and skills acquired during the project). The purpose of the first question was to lead the interviewee to reflect on his/her knowledge and skills about the subject matter and, moreover, to help the interviewee to separate what he/she already knew before the project started from the knowledge and skills he/she acquired during the particular project.

The transcribed interviews were analyzed using the following matrix:

<table>
<thead>
<tr>
<th>What has the individual learned during the collaborative problem-solving process?</th>
</tr>
</thead>
<tbody>
<tr>
<td>New knowledge</td>
</tr>
<tr>
<td>New skills</td>
</tr>
<tr>
<td>New attitudes</td>
</tr>
</tbody>
</table>

While investigating these categories, it became evident that people created new human capital in the form of new knowledge during the particular R & D projects. They became more knowledgeable about the subject matter (i.e. the 'knowing-what' knowledge) they were working on. The following passages illustrate this well:

"My knowledge about the appliances and materials used in packing has become stronger all the time."
(an interview, Mika, material specialist, not a permanent employee, case B)
"I have learned new things about indicators, and then I have learned when comparing the competitors' products."
(an interview, Hilkka, Quality Manager, case B)

"I have had to find out more about damp-proofing and sound-proofing."
(an interview, Timo, Project-Engineer, case Y)

"I have learned new things about the prices of some products, how to rationalize documents, and then about construction permits."
(an interview, Mikko, Purchase Manager, case Y)

As an interesting nuance, the new knowledge people felt to have acquired during the particular R & D problem-solving processes is related to their positions and duties in the R & D teams (see the examples above).

People also created new skills or enhanced old ones (i.e. 'knowing-how' knowledge). Many learned to use the Internet better or enhanced their project working skills. Most frequently, however, the interviewees thought that they had improved their social skills during the R & D processes under study. Here are a few examples of the statements:

"I have learned social skills."
(an interview, Hilkka, case B)

"I have improved my social skills while interviewing people here."
(an interview, Miisa, case B)

"I have been able to improve my communication, now I can communicate my ideas a bit more clearly than before."
(an interview, Mika, case B)

The third attribute of human capital existing in literature is a rather vague notion of 'other attributes or characteristics'. What could those attributes be? On the basis of this research, the third dimension of human capital is called 'attitudes'. During a collaborative problem-solving process, people create new attitudes of themselves. The individuals interviewed for this research thought that they had learned new things about themselves:

"I have learned to be more independent, to work more independently."
(an interview, Miisa, case B)
"I have learned to be more persistent."
(an interview, Hilkka, case B)

"I have realized that it is me myself that needs to develop all the time. Only then I can develop other things."
(an interview, Jari, case Y)

On the basis of this research, people do create new human capital while engaging in a joint problem-solving process. The forms of human capital can be divided into three categories: new knowledge about the subject matter, new skills, and new attitudes toward self. The next question arising from this result is: How is human capital produced in co-operation with others? As argued in Chapter 3.4.1.4, the development of human capital is facilitated by the development of intellectual and social capital. In other words, "societies founded on networks of trust and co-operation can help to realize human potential" (OECD 2001, 39). The facilitative function of social capital in the development of human and intellectual capital became evident in the course of this research. This phenomenon is investigated next.

5.4.2 Producing social capital - enhancing and realizing human and intellectual capital

The attributes of social capital found in literature twist around the following concepts: networks, trust, obligations, a shared language, and norms (see Chapter 3.4.1.2). Many researchers see these attributes as components that constitute social capital, while some (cf. e.g. Woolcock 2001) view them as an outcome of social capital. For this research, however, the question of different attributes of social capital is rather secondary. More important is the question of how social capital is produced during a collaborative problem-solving process. As argued in Chapter 3.4.1.6, "all these different attributes are conditions under which social capital as well as human and intellectual capital are produced, but the actual mechanism of producing these capitals is learning by sharing distributed cognition, both at the explicit and the tacit levels of knowledge creation." (page 97 in this research). The aim of this chapter is to investigate what the mechanisms of producing social as well as human and intellectual capital by learning are. To be able to do that, the different attributes of social capital mentioned by other researches are used as evidence of the existence of social
capital. The mechanisms of producing social capital by learning are taken under scrutiny from the transcribed interviews and team meetings videotaped for this research.

Maybe the most typical characteristic of the existence of social capital within the context of a social collectivity (an R & D team in this case) is the creation of networks. As the author of the OECD report (2001) writes:

"Central to the definition of social capital is the concept of networks. Firms can benefit from norms of co-operative trust embodied in various types of intra-firm and inter-firm networks because these facilitate co-ordination and lower transaction costs arising from negotiation and enforcement, imperfect information and layers of unnecessary bureaucracy." (57.)

The existence of networks became evident in the course of this research as well. The networks found while analyzing the empirical data were of three kinds: intra-firm, inter-firm, and personal. In the following table, the locus and the nature of these networks are defined. Examples of the team discussions expressing the existence of each type of network are also given.

<table>
<thead>
<tr>
<th>LOCUS</th>
<th>DEFINITION</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-firm</td>
<td>In-company interconnections between the employees created or utilized in favor of the current R &amp; D task.</td>
<td>Case B, part of episode 2.5.</td>
</tr>
<tr>
<td></td>
<td>Miisa: &quot;From where could we get competitors' products?&quot;</td>
<td>Hilkka: &quot;There are some.&quot;</td>
</tr>
<tr>
<td></td>
<td>Hilkka: &quot;There are some.&quot;</td>
<td>Kari: &quot;Timo [another employee of the firm] has lots of them.&quot;</td>
</tr>
<tr>
<td></td>
<td>Kari: &quot;Timo [another employee of the firm] has lots of them.&quot;</td>
<td>Hilkka: &quot;Yes, Timo has those.&quot;</td>
</tr>
<tr>
<td></td>
<td>Case Y, part of episode 1.2.</td>
<td>Case Y, part of episode 1.2.</td>
</tr>
<tr>
<td></td>
<td>Antero: (a phone call to a colleague named Juha)</td>
<td>Antero: (a phone call to a colleague named Juha)</td>
</tr>
<tr>
<td></td>
<td>&quot;Hi, is there a possibility for a misunderstanding with these radiators used in wet areas? If we order service water radiators to be placed in wet areas it is all right. Okay, then there is no possibility of misunderstanding. Bye!&quot;</td>
<td>Antero: (a phone call to a colleague named Juha)</td>
</tr>
</tbody>
</table>
**Inter-firm**  Interconnections between the employees of two or several companies created or utilized in the favor of the current R & D task.

**Case B, an episode where an outside expert advises the team.**
Tapio: "You should co-operate with Nokia [a telecommunication company], it is not your competitor, but they are in the same state than you are. But they lost Esa-Matti to ABB's research center. He was Jussi's right hand..."
Kari: "Yes, I met him in Paris."
Tapio: "He is responsible for developing the mobile sector. This is one way to seek co-operation, he knows a lot. Another information source is professor Osmo, his area of interest is precision mechanics.
Kari: "Yes, I have noticed that information on precision mechanics must be searched from abroad."
Tapio: "Then, the third way is Tekes [The National Technology Agency]. Tekes's technology secretaries can help you find countries like the USA and Japan, and from there, companies like Canon and Sony, you can get to their factories for sure."
Kari: "I know Reijo very well. Do you know him?"
Tapio: "No, but I'll call Esa-Matti, he will co-operate with you for sure, he has the same problems than you."

**Case Y, part of episode 2.1.**
Jari: "Is there a contract of this?"
Mikko: "Yesterday, I discussed with the gardeners about it, and they told that they'd rather define the items by themselves than go according to those plans. It does not cost us anything."

**Personal**  Personal relationships created in non-work-related social settings but utilized in the favor of a current R & D task.

**Case B, part of episode 2.2.**
Miisa: "We will try to get to Kanta-Häme Hospital. They do not use our products, but if we want to gather experiences, it is not worth going and investigating the usage of our own packages."
Hiilka: "Yes."
Miisa: "We can get in there because my father works there."

**Case Y, part of episode 1.5.**
Timo: "Could it be a rational idea that a fence were shared between two row house apartments?"
Jari: "I can ask Riikka, she lives in a row house."

Table 14. The nature of networks found in this research.

All these networks were used to accelerate and promote the actual problem-solving processes at hand. Thus, one way of producing social capital in the collaborative problem-
solving process is to create and utilize intra-firm, inter-firm, and personal networks while solving problems together. However, mere networking is not enough, people need to have certain social and communicational skills in order to network. How are these social skills acquired? Lundvall & Johnson (1994) argue that social skills are acquired in the process of gaining 'knowing-who' knowledge. The 'knowing-who' knowledge, on the other hand, is defined as a social ability to cooperate and communicate with different kinds of people. In addition, the 'knowing-who' knowledge refers to those relationships created in networks which provide people with an access to various resources (Nahapiet & Ghostal 1998). On the basis of this research, people acquire 'knowing-who' knowledge by learning about other team members as well as learning from others during team discussions. The following statements illustrate it well that people improved their social ability (i.e. gained 'knowing-who' knowledge) to co-operate with other people (i.e. they learned something about the other members of the team):

"I have learned how other people do their work, all with their own style, of course."
(an interview, Hilkka, case B)

"When there are many members in this team, you learn how they behave."
(an interview, Antero, case Y)

Based on the interviews carried out for this research, one way of producing social capital and enhancing human capital during a collaborative problem-solving process is to gain ‘knowing-what’ as well as ‘knowing-who’ knowledge (i.e. learning from others) through learning via communicating (i.e. discussing, changing ideas, asking, listening) with people, either within the team, the company, or with people from other companies or other social settings. These examples of the interviews illustrate this process well:

"If I'm a part of a group in which there are bright people, the old stagers in this business, I learn a lot just by listening to them. And, of course, these team meetings are very educational, I learn new terminology."
(an interview, Mika, case B)

"I acquire quite a lot of information by asking people working here, they know quite a lot."
(an interview, Miisa, case B)
"The intercommunication and the feedback I get from my colleagues and customers is very educational."
(an interview, Timo, case Y)

"I try to learn from other peoples' talk."
(an interview, Petri, case Y)

Another key attribute of social capital is a shared language. When Nahapiet and Ghoshal (1998) argued that a shared language and shared narratives are important factors of social capital, they were actually talking about creating shared understanding among people within a same social collectivity. In other words, a shared language and narratives facilitate the creation of shared understanding. Shared understanding, on the other hand, enhances the formation of intellectual capital within a certain social collectivity. The existence and the importance of a shared language have been substantiated earlier in this research when arguing that one of the practical mediational tools used to aid the collaborative problem-solving process is the usage of professional jargon (see Chapter 5.2.2). Professional jargon (or a shared language and narratives) makes the conversation of an R & D team easier, fluent, and more efficient. Then, the team members understand each other perfectly while, for an outside observer, the team's discussion makes little or no sense.

Thus, a shared language is a precondition for the creation of intellectual capital of a certain group of people. Other preconditions for the creation of intellectual capital mentioned by Nahapiet and Ghoshal (1998) are: a) the opportunity to exchange or combine ideas by gaining accessibility to the objectified and collective forms of social knowledge, b) the existence of an anticipated benefit gained in such social interaction and exchange, c) motivation, and d) the capability to combine information or experience gained in social interaction. Arguably, the most important precondition for the creation of new intellectual capital is the combination capability. As Nahapiet and Ghoshal (1998) write:
"Even where the opportunities for knowledge exchange and combination exist, these opportunities are perceived as valuable, and parties are motivated to make such resource deployments or engage in knowing activity, the capability to combine information or experience must exist" (249-250).

However, what actually is combination capability? To be able to combine new information as well as experiences gained from others in social interaction, a person needs to be able to learn in those circumstances. Therefore, the ability to gain new intellectual capital possessed by a group of people and created in social interaction is highly dependent on the capabilities of both the individuals as well as the group to learn by sharing distributed cognitions, both in the explicit and the tacit levels of knowledge creation.

However, it must be noted at this point that, the most apparent feature of the construct of the intellectual capital evidenced in this research is the tacit nature of the joint knowledge and knowing capability of a group. Therefore, the existence of intellectual capital within some social collectivity is rather cumbersome to proof. First of all, the intellectual capital of a group is constituted of knowledge, which is not known in its totality by any single mind (Tsoukas 1996). Secondly, the knowledge or knowing capability of a group is presumably greater than those of a single member of the group. And thirdly, intellectual capital is distributed between individuals in the group so that every individual possesses local knowledge, which cannot be investigated as a whole, and, furthermore, a part of their knowledge originates from outside the group. Therefore, in order to investigate intellectual capital in its totality, we should be able to infiltrate simultaneously into the heads of every team member, and maybe we still would not reach the answers. While those means of information gathering are not available, we need to confine with more qualitative methods.

The mechanisms of producing intellectual capital facilitated by social capital have actually been demonstrated earlier in this research. The constructs of planning, monitoring, and revising a group's cognitive strategies and actions, transactive memory, shared mental
models, and meta-knowledge can be seen as mechanisms whereby the intellectual capital of a group is produced. These constructs are being called group's metacognitive tools in this research. With these tools, the members of a group are able to:

1) plan the group's cognitive strategies or actions,
2) monitor the group's cognitive progress, strategies, and actions,
3) revise the group's cognitive strategies or actions,
4) be aware of the total pool of knowledge within the group,
5) be aware of the information gathering activities of the other group members,
6) be aware of the areas of expertise and formal roles of the other group members.

In Chapter 5.3.2, evidence of the existence of metacognitive tools is given.

All in all, the usage of a group's metacognitive tools is a mechanism by which a group of people gain intellectual capital (i.e. knowledge and knowing capability), not possessed by any individual *per se*, but by the group as a whole.

Other attributes of social capital mentioned by other researches are trust, norms, and obligations. These means of gaining social capital are not explicitly investigated in this research. There are two reasons for not doing so. First of all, the research design developed for this research was not suitable for the investigation of trust, norms, and obligations shared among the members of the R & D teams. Secondly, one of the main purposes of this study was to reveal the learning processes as well as the outcome of those processes embedded in a collaborative problem-solving process. However, trust, norms, and obligations are all multi-faceted phenomena that simply cannot be learned (at least according to the common meaning of the word). For example, trust, as well as norms, are socially defined attributes, which are created and adopted in social interaction, but their existence is not controlled by an individual person, but a social collectivity as a whole.

To conclude, on the basis of this research, the process of producing human, intellectual, and social capital is a collaborative learning process featured and facilitated by intra-firm, inter-
firm, and personal networks, a shared language and understanding (i.e. distributed cognitions), as well as a group's metacognitive functions. Furthermore, the products of the collaborative learning process are new human capital of an individual (i.e. new knowledge, skills, and attitudes), new intellectual capital of a group (i.e. knowledge and knowing capability of the group), and social capital (i.e. ‘knowing-who’ knowledge) partly possessed by the group and partly by the individuals.
DEFENDING THE VALUE AND THE VALIDITY

All research must respond to the criteria against which the trustworthiness of the research can be evaluated by an outside reviewer. However, and unfortunately, qualitative research does not (at least yet) have the general acceptance that the quantitative paradigms enjoy (Marshall & Rossman, 1995). There are not sound criteria for “goodness”, but many perspectives from where researchers view the world and determine the nature of good investigation. Therefore, I dare to admit that some researchers might view the results of this study erroneous, and it is my duty to truthfully consider the value and validity of the present study. This is done by considering the credibility, the generalizability, as well as the dependability issues usually understood as the main criteria in determining the value and the validity of a scientific study.

6.1 The credibility of the research findings

The first criterion of validity is to ask about the basis according which the findings of the study are judged. Within this research, the issue of credibility (internal validity) is viewed from several standpoints. First of all, "...information obtained in qualitative research is directly affected by the way the information is recorded and the choice as to what is recorded" (Boyatzis 1998, 147, emphasis original). The ways of gathering empirical data for this research were of three kinds: interviewing, observing, and verifying some observations with the interviewees. To reduce variation in the observations, all team meetings were videotaped and transcribed by the researcher. Every interview protocol was standardized by means of asking the same questions from all of the interviewees. The interviews were also recorded and transcribed word by word. However, only team meetings were videotaped, eventhough the researcher was very well aware of the fact that collaborative problem-solving as well as learning also occur outside formal team meetings. However, the means of observing and videotaping every moment of collective action among the team members was naturally impossible (and perhaps not even necessary) within this research. Also, the low proportion of non-relevant talk (0.3 % in team B's meetings and 0.7 % in team Y's meetings) reported in this study might be seen as a credibility as well as a dependability
(discussed in Chapter 5.3.4) problem. It is possible that the low proportion of non-relevant talk can be explained by the presence of a researcher. It is possible that the team members felt observed and did not, therefore, act normally, but more task-centered as they would under normal conditions. However, during the coding process, only the so called problem-solving episodes (pieces of a conversation in which a team deals with one problem statement) have been coded, all other talk (non-relevant) has been left outside the coding procedure. The non-relevant talk in coded the problem-solving episodes has been defined as jokes and non-serious comments.

Secondly, the credibility of the interpretations of the empirical data was attained by coding the videotaped and transcribed problem-solving episodes twice. This technique of double-coding (Miles & Huberman 1984) was carried out by the researcher herself. The time difference between the first and the second coding was six months. The percentage agreement (the number of times the coded categories matched divided by the number of the times the coding was possible) method was used in order to determine the congruence between all of the coded problem-solving episodes. It was 95.6 percent for team B and 97.8 percent for team Y. The composition of all of the coded episodes for both of the teams can be seen in appendices 1 and 2. The credibility of the researcher's interpretations concerning the practical tools used during the collaborative problem-solving was obtained by verifying the interpretations during the second interviewing of every member of both teams.

Thirdly, the concern about the internal validity of qualitative research may be extended to a broader problem of drawing inferences. Basically, a qualitative study involves an inference every time a phenomenon cannot be directly observed (Yin 1994). When considering the epistemological orientation of this research (see Chapter 4.2), the problem of the relationship between conscious cognitions and language was discussed. Within this research, the relationship between cognitions and language is particularly important, and the basic ontological assumption in this research is that a language is, at least, the best access to higher cognitive processes. Therefore, the researcher made an inference every time she "inferred" that a particular utterance was a result of an earlier cognitive function. For example, let us consider the following utterance by Hilkka (case B, episode 1.4.): "What are
the requirements of the product itself, why does it need to packed?”. As explained in page 124, this utterance can be coded into three categories. First, the individual elementary (lower) level cognitive function of asking ("What are the requirements...why does it need...?") is easily determined. However, to be able to ask such questions, Hilkka needed to understand that a problem existed. She also identified the problem (the problem dealt with the requirements of the product). This is judged to be evidence of individual higher cognitive function, which is not directly observable, but going on “inside Hilkka's head”. Hilkka also distributes her understanding of the existence of the problem to the other team members (distributed cognitive function). This procedure has been explained more specifically in page 125. Also, the researcher made an inference, for example, when she "inferred" that listening to others (individual elementary cognitive function) serves as an impulse to the individual higher cognitive function of memory retrieval (see e.g. page 170, case Y2).

Fourth, to enhance the transparency of both the quality of the empirical data as well as the actual system of coding the collaborative problem-solving episodes, four examples of the coded episodes are given in appendices 3, 4, 5, and 6.

6.2 The generalizability of the present study

The second major issue to consider while determining the validity of the present research is the generalizability or transferability (external validity) of the study. This issue concerns the question of knowing how applicable the findings of the present study are to another setting or group of people (cf. e.g. Marshall & Rossman 1995; Yin 1994; Merriam 1991). In a qualitative study, the generalizability of the findings to another setting may be problematic and is seen as the most serious weakness of the approach. Lincoln and Guba (1985) shift the problem onto the shoulders of another researcher by stating that the burden of demonstrating the applicability of one set of findings to another context rests more with the investigator who wants to make that transfer than with the original investigator. However, this is too trivial an answer to the problem.
First of all, to ensure the generalizability of the present study, the original research questions (see Chapter 4.1) have already been shown to have emerged either directly from the earlier theories of human problem-solving and learning, or from the recognized limitations of those theories. For example, the first research question about the characteristics of R & D problems and problem-solving situations got its boundary concepts (the problem agent, ill-defined problems, the initial and goal state of problems, problem constraints) from the theoretical frameworks of information processing (Newell & Simon 1972), praxiology (Kotarbinski 1965), and design-making (Goel & Pirolli 1989; Goel 1995). The second research question concerning practical tools used in collaborative problem-solving has risen out from the criticism presented in this research against the limited research carried out earlier in the area of cognitive and collaborative problem-solving. The analysis matrix created to study cognitive tools (both individual and distributed) used in collaborative problem-solving (research question number 3) was partly developed based on the findings of previous research and theories of human problem-solving (mainly the categories of individual cognitive and metacognitive functions), and partly by further elaborating the existing theories (mainly the categories of distributed cognition and group's metacognitive functions). The fourth research question of what kinds of learning takes place in a collaborative problem-solving processes, got its boundary concepts from the frameworks of producing human, intellectual, and social capital.

All of the research findings have also been considered against the earlier theories and research findings of human problem-solving and learning referred to in this study. This process of bouncing back and forth between the theory and empirical findings is a peculiar characteristic of the abductive research logic followed in this research. Furthermore, it ascertains the generalizability of the findings of this particular qualitative study to other theories and other research results. In other words, instead of trying to generalize the findings of the present study to other settings or groups of people, the attempt was to generalize the findings to previous theories and to the results of other researches.

A third way to enhance the external validity of this research was the attempt to bring more than one source of data to support one single point (triangulation). For example, the answer
to the research question of the practical tools used by the problem-solver or solvers while solving R & D problems is reached by combining two different sets of empirical data (the observation interpretations and the interviews) gathered with two different research methods (observation and interviewing) (see Chapter 5.2).

6.3 The dependability of the research findings

The third criterion for the validity of the present study is the issue of reliability. The meaning of ‘reliability’ is to make sure that if another researcher followed exactly the same procedures as described by the particular researcher and conducted the same study all over again, the other researcher should arrive at the same findings and conclusions (cf. e.g. Yin 1994; Merriam 1991). This rather positivist notion of reliability assumes an unchanging universe where an inquiry could be replicated. On the contrary, for example Mäkelä (1990) has stated that a qualitative inquiry's repeatability cannot be treated as a reliability problem, and the concept of replication is problematic in itself. Instead of reliability, Marshall and Rossman (1995) as well as Varto (1992), for example, talk about dependability, addressing the researcher's attempts to account for changing conditions as well as to discharge the study from incidental and irrelevant elements.

In the present study, the issues concerning dependability became important while collecting and analyzing the empirical data. As stated earlier (see Chapter 4.2), in a qualitative study on human cognition and behavior, the researcher must be aware of the fact that the knowledge structures, presupposals, and prejudices of both the researcher and the research subjects affect the progress of the research. And, furthermore, that both the researcher and the research subjects learn during the research process. There are also no clear criteria for the interpretation of the research findings. The impact of these rather disturbing objectivity issues was reduced by the following procedures: 1) All empirical data was gathered at a time and in a place recommended by the interviewees. 2) The basic principle followed by the researcher during the interviews was the belief that the interviewee was the one who knows something about the subject matter, the researcher only listened and made additional questions. 3) During the observed and videotaped team meetings, the researcher did not talk.
at all. 4) The criterion for the representativeness of the empirical data was not whether the problems the teams were concerned with got solved or not (i.e. the end result of the problem-solving process), but the existence of the problem-solving processes themselves. Following this criterion, the "quality" or the field of the investigated R & D teams did not play important roles. The only criterion for choosing the particular investigated teams was that they do innovative R & D work in some technology-related companies. However, there are no clear criteria or regulations for the adequacy of the empirical data of a qualitative inquiry. Very often researchers talk about "reaching the saturation point", meaning that the collection of the empirical data can be finished when the collected data starts to repeat itself. Perhaps the best way to secure the adequacy of the data is to analyze the collected data as it is gathered. In this research a so called raw analysis (organizing the data according to loosely defined themes) was carried out during the actual data gathering. During this process, the researcher noticed that many phenomena occurred in multiple occasions but could not be absolutely sure if the saturation point was reached. Therefore, authentic examples of the interviews or team discussions of both of the cases were written down in the study to allow the reader to assess the truthfulness and the dependability of the study him/herself.

This takes us to the last and maybe the most important criteria while assessing the value and the validity of the present study. As Usher and Bryant (1989), Walker (1980), as well as Kennedy (1979) have stated, an important criteria for the validity and the reliability of a study are whether the readers of the research or the practitioners in the particular field find the findings of the study authentic, relevant, and useful for their own situations. Like Tuomi (1999) writes:

"...the results cannot be validated only internally within a specific research work; instead, the results are validated in a discourse. In this discourse, hopefully, researchers and practitioners working under different paradigms can develop interpersonal agreement on what in the results counts as knowledge." (73.)
Within the following illustration, the progress of the research and the development of the researcher's understanding during the research process are demonstrated. Also the issues concerning the value and the validity of the present study discussed above can be recognized and placed into the more comprehensive framework.

Figure 30. The progress of the research and the development of the researcher's understanding during the research process.
CONCLUSION

This research started out as a criticism toward the contemporary cognitive psychology's and information processing theory's way to investigate, define, and conclude human problem-solving and learning activities. These theoretical orientations were criticized for simplifying the complex and multi-faceted processes of human problem-solving by founding their explanations and reasoning mostly on investigations carried out in laboratory environments in which single individuals were confronted with well-defined and rather simple problems. While, in real-life, people face problems which only seldom are well-defined by nature. Also, in real-life circumstances people rarely solve complex problems of whatever kind alone. The more complex the problem, the more advice and shared expertise is required to solve it. In technological product development, the vast majority of problems are ill-defined and complex which require different kinds of knowledge, skills, and expertise in order to be solved.

Despite the criticism presented toward the information processing theory and the contemporary cognitive psychology, it has been acknowledged in this research that these approaches have provided researchers with important knowledge about the functionality of the human brain and memory systems. Also, the construct of the problem space developed by information processing scientists was taken under a detailed investigation by amplifying its original formation. Therefore, the information processing theory, and, also the theory of efficient action were used as theoretical stepping stones, and their valuable constructs were combined with the theories of human metacognition, distributed cognitions, as well as theories of producing human, intellectual, and social capital.

The introduced theoretical construct was then applied to develop a new approach to cognitive and collaborative problem-solving and learning processes. The explanatory power of the novel approach was tested through the empirical data gathered by observing and videotaping two research and development (R & D) teams. All team members were also interviewed twice. Also, twelve engineers from the fields of industrial design, planning engineering, and teaching were interviewed. All empirical data was transcribed and
analyzed using qualitative research techniques. The research logic followed in this research was abductive. Following this logic, the empirical data gathered for this research was engaged in a close conversation with the theoretical framework.

The main research goal of this research was to capture the nature of the cognitive and collaborative problem-solving and learning processes embedded in technological product development. To fulfill the goal, the whole problem space in which collaborative problem-solving and learning takes place was investigated. Based on the both, the theoretical framework formulated in the course of this research and the findings from the empirical data gathered for this research, the joint problem space is composed of the following elements: a) a problem, b) problem solver/s, c) cognitive tools, d) practical tools, e) human capital, f) intellectual capital, and g) social capital.

The possibility of the existence of some universal and logical process-model for cognitive and collaborative problem-solving and learning processes was disagreed in the early states of this research. In other words, the phenomena of collaborative problem-solving and learning taking place simultaneously at the individual and the group-level of cognitive processing are too complicated processes to be illustrated with logical process models. Therefore, the following illustration of the cognitive and collaborative problem-solving and learning processes created during this research only sets forward the elements of which the joint problem space is constructed.
First of all, based on the findings of this research, the problems occurring in technological product development are large in size and complex by nature. They are ill-defined problems which are most often caused by the further development of the already existing technology or by the need to increase the security of the already existing technology. The problems in technological product development do not usually have absolutely right or wrong answers and they are "never-ending" by nature. The problem-solving in R & D processes is usually
carried out in situations in which the actual problem is known, but the solution and means to reach the solution are missing, as well as in situations in which the initial as well as the goal state of the problem are known, but phrased according people's previous knowledge and experience on the field. According to this research, people in R & D problem-solving situations do not act randomly, but test, model, and evaluate the solvability of the problem before proceeding in solving it. This is partly because the problem-solving situations in R & D processes are those in which the costs of being wrong can be very high. The evaluation of the problem itself as well as the whole problem-solving situation has a great influence on how people proceed in such situations. The issues of problem constraints found in the course of this research have a great impact on the actual problem-solving situation. The constraints are either related to nature, society/situation, or person/group, and they can either be seen as a negative or a positive factor while proceeding in the problem-solving.

Secondly, the personal attributes of people engaged in a problem-solving situation influence the problem-solving process. An individual brings certain characteristics into the problem-solving situation. The personal characteristics investigated in this research were more cognitive than e.g. emotional by nature. Based on the findings of this research, an individual uses certain elementary (e.g. asking, answering, agreeing etc.) as well as higher cognitive (i.e. identifying the problem, understanding what solutions are likely, understanding limitations, and representing the problem) and metacognitive (i.e. being aware of him/herself as a cognitive agent, being aware of his/her way of approaching a cognitive task, being aware of using a cognitive strategy, planning, monitoring, and revising one's own cognitive strategies) tools during the collaborative problem-solving situation. Also, personal knowledge, skills, and attitudes are brought to bear. These are labeled as human capital in this research. Therefore, and even though, the problem-solving processes studied in this research take place in collaboration with others, individuals are understood as single entities interacting with others at a cognitive level. This is called an interactive view of distributed cognitions.

The existence of cognitive and practical tools in the joint problem space support the view of cognitions interacting in a spiral-like fashion in which the individuals' elementary and
higher cognitive, as well as metacognitive and mental mediational inputs affect the joint distributed cognitive system formed by all members of the team. In fact, the role of the practical tools used in collaborative problem-solving is essential. In collaborative problem-solving (of whatever kind), human collaborative cognitive functioning is enabled by the intervening nature of both practical tools: mental mediational tools as well as instrumental mediational tools. Mental mediational tools (e.g. individual experience, experience of others, knowledge acquisition through written, visual, or audio material) enable the usage of both the individual cognitive and metacognitive tools, as well as distributed cognitive and metacognitive tools during the joint process of problem-solving. Moreover, with instrumental mediational tools (e.g. professional jargon, computer software, timetables etc.), the group's cognitive functioning becomes more efficient and faster.

The three other elements of the joint problem space are human, intellectual, and social capital. Once a team starts its work, all team members bring the human as well as the social capital they possess with them. Moreover, during the collaborative problem-solving process, all three forms of capital are gained: the development of social capital facilitates the development of both the intellectual as well as the human capital. It is argued in this research that the process of gaining so called capital "surplus" is actually a three-veined learning process in which learning occurs through problem-solving and in which the cognitive-level products (i.e. what has been learned) of this process are: human capital of an individual (i.e. new knowledge, skills, and attitudes of a single person), b) intellectual capital created in a team (i.e. the knowledge and knowing capability of a group), and c) social capital created in the team (i.e. knowing-who knowledge partly possessed by individuals and partly by the group). In more detail, during the collaborative problem-solving process, the process of producing human, intellectual, and social capital is actually a collaborative learning process which is featured and facilitated by intra-firm, inter-firm, and personal networks, a shared language, and a shared understanding.

The main results of this research are more theoretical than practical by nature. This research provides us with novel ideas of how people in the individual as well as in the distributed cognitive levels solve highly complex problems in co-operation. It also makes apparent the
quality and the form of the cognitive-level outcomes of joint learning processes, which are embedded in collaborative problem-solving. In earlier research, the constructs of intellectual and social capital have been investigated through organization and management theories, and the construct of human capital has been seen through the economics of education. In this research, the viewpoint was different. The process of producing human, intellectual, and social capital was modeled as a cognitive learning process of an individual as well as a group of people working together.

Eventhough the specific problem-solving situations studied in this research arose from the field of technological product development, the results of this research can also be generalized to other situations where people solve complex problems in collaboration. In every such situation, a group of individuals with certain cognitive and metacognitive functions are engaged in an interactive mental process in which cognitions, both individual as well as distributed, interact in a spiral-like fashion. In that process, the individuals' cognitive inputs, through their collaborative activities, affect the nature of the cognitive joint system. The essential tools people use in such an enterprise are the mental mediational tools of individual experience, the experience of others, and knowledge acquisition through written, visual, or audio material. Also, some instrumental mediational tools, e.g. professional jargon, are used. Through this process, people learn new knowledge, skills, and attitudes. They also gain new intellectual as well as social capital during the collaborative problem-solving process.

Some of the more practical implications of the results of this research could be those of becoming more knowledgeable of the process and the effects of collaborative problem-solving in work-related circumstances. In many organizations, the issues of human resources, the value and the validity of the company's knowledge or intellectual capital, as well as the utilization of the personnel's full competence are being widely discussed but underused and often misunderstood. I argue that the functionality and the success of team-work and collaborative problem-solving processes during team-work, in particular, are more depended on the cognitive-level processes taking place in such situations than some external frameworks (i.e. team-work instructions, team-work techniques etc.). If people engaged in a
collaborative problem-solving enterprise are not able to use their own cognitive as well as metacognitive functions to create distributed cognitive processes and, moreover, if they are not able to exploit the human, intellectual, and social capital they possess on behalf of the knowledge creation process of the whole team, no team-work technique or motivational trick will do any good. For that reason, people working in collaboration with others should understand and be knowledgeable of the influence and the effects of their own cognitive processes on behalf of the distributed cognitive processes as well as the ultimate success of the whole process of collaborative problem-solving and learning.

The theoretical as well as the empirical orientation adopted in this research focused only on the cognitive features of collaborative problem-solving and learning activities. No attention was paid to other important aspects of team-work (e.g. providing socio-emotional support to team members, maintaining the team cohesiveness, the influence of the organization culture and motivation, different phases a team goes through, and interaction patterns or power issues). It is almost certain that these other aspects of human behavior indirectly affect the cognitive features and the effectiveness of collaborative problem-solving and learning. The next era in completing the new approach to cognitive and collaborative problem-solving and learning should take a serious look at these aspects.

All in all, this research can be understood as a serious attempt to integrate the individual as well as the group-level cognitive problem-solving and learning processes and their cognitive-level learning outcomes. I wish to underline the word attempt because "...it is obvious that in science (at least in human science, own addition), there are no absolute truths. All theories are merely assumptions which will be tested in the process of the scientific and practical discourse." (Karjalainen 2001, 284.)
REFERENCES


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Appendix 1. The composition of the coded problem-solving episodes of case B.

| Episode n.n. | Identifying the problem | Representing the problem/ dividing the problem into sub-problems | Understanding what kinds of solutions are likely | Understanding the limitations under which the problem must be solved | Sharing a perception that the problem exists | Creating a shared representation of the problem | Sharing relevant information | Sharing information about the possible solutions | Sharing information about the limitations under which the problem must be solved | Planning individual cognitive strategies and actions | Monitoring individual cognitive progress, strategies, and actions | Revising individual cognitive strategies and actions | Metacognitive knowledge of a person | Planning the group's cognitive strategies and actions | Monitoring the group's cognitive progress, strategies and actions | Revising the group's cognitive strategies and actions | Group's metacognitive knowledge | Non-relevant talk |
|-------------|-------------------------|---------------------------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|
| 1.1         | 1                       | 1                                                             | 1                                             | 1                                                             | 1                                             | 8                                             | 0                                             | 0                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                                             | 0                                                             | 0                                                             | 0                                                             | 0                                                             |
| 1.2         | 1                       | 1                                                             | 1                                             | 0                                                             | 6                                             | 8                                             | 0                                             | 0                                             | 0                                                             | 0                                             | 0                                                             | 1                                             | 1                                                             | 0                                             | 1                                                             | 0                                                             | 0                                                             |
| 1.3         | 1                       | 0                                                             | 12                                            | 6                                                             | 0                                             | 1                                             | 12                                            | 6                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 1                                             | 0                                                             | 2                                             | 0                                                             | 0                                                             |
| 1.4         | 1                       | 10                                                            | 38                                            | 7                                                             | 1                                             | 0                                             | 24                                            | 38                                            | 7                                                             | 0                                             | 1                                                             | 0                                             | 2                                             | 3                                                             | 0                                             | 3                                                             | 1                                                             |
| 1.5         | 1                       | 3                                                             | 10                                            | 0                                                             | 1                                             | 1                                             | 18                                            | 10                                            | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                                             | 0                                                             | 0                                                             |
| 2.1         | 1                       | 0                                                             | 6                                             | 3                                                             | 1                                             | 0                                             | 5                                             | 6                                             | 3                                                             | 0                                             | 0                                                             | 0                                             | 1                                             | 0                                                             | 0                                             | 0                                                             | 0                                                             |
| 2.2         | 1                       | 2                                                             | 1                                             | 0                                                             | 1                                             | 0                                             | 4                                             | 1                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 0                                                             | 3                                             | 0                                                             | 1                                             |
| 2.3         | 1                       | 1                                                             | 16                                            | 4                                                             | 1                                             | 1                                             | 28                                            | 16                                            | 4                                                             | 1                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                                             | 0                                                             | 2                                             |
| 2.4         | 5                       | 3                                                             | 11                                            | 0                                                             | 5                                             | 2                                             | 5                                             | 11                                            | 0                                                             | 0                                             | 0                                                             | 0                                             | 1                                             | 0                                                             | 0                                                             | 0                                                             | 1                                             |
| 2.5         | 1                       | 2                                                             | 18                                            | 3                                                             | 1                                             | 4                                             | 23                                            | 18                                            | 3                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 0                                             | 1                                             | 0                                                             | 3                                             |
| 2.6         | 1                       | 3                                                             | 23                                            | 12                                                            | 1                                             | 1                                             | 17                                            | 23                                            | 12                                                            | 2                                             | 0                                                             | 0                                             | 0                                             | 3                                             | 2                                                             | 0                                             | 3                                             |
| 2.7         | 1                       | 2                                                             | 11                                            | 3                                                             | 1                                             | 0                                             | 3                                             | 11                                            | 3                                                             | 2                                             | 0                                                             | 0                                             | 0                                             | 0                                             | 0                                                             | 0                                             | 2                                             |
| 3.1         | 1                       | 1                                                             | 11                                            | 1                                                             | 1                                             | 0                                             | 10                                            | 11                                            | 1                                                             | 1                                             | 0                                                             | 0                                             | 0                                             | 2                                             | 0                                                             | 0                                             | 0                                             |
| 4.1         | 1                       | 3                                                             | 29                                            | 3                                                             | 1                                             | 3                                             | 12                                            | 29                                            | 3                                                             | 2                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                                             | 0                                             | 0                                             |
| 4.2         | 1                       | 1                                                             | 4                                             | 0                                                             | 1                                             | 0                                             | 2                                             | 4                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                                             | 0                                             | 0                                             |
| 4.3         | 1                       | 5                                                             | 20                                            | 0                                                             | 1                                             | 2                                             | 20                                            | 20                                            | 0                                                             | 1                                             | 0                                                             | 0                                             | 0                                             | 2                                             | 1                                                             | 0                                             | 1                                             |
| 4.4         | 2                       | 2                                                             | 6                                             | 0                                                             | 2                                             | 4                                             | 0                                             | 6                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 0                                             | 0                                                             | 0                                             | 1                                             |
| 4.5         | 1                       | 1                                                             | 7                                             | 0                                                             | 1                                             | 1                                             | 3                                             | 7                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                                             | 0                                             | 0                                             |
| 4.6         | 1                       | 1                                                             | 5                                             | 0                                                             | 1                                             | 0                                             | 0                                             | 5                                             | 0                                                             | 1                                             | 0                                                             | 0                                             | 0                                             | 0                                             | 0                                                             | 0                                             | 2                                             |
| 4.7         | 1                       | 1                                                             | 23                                            | 0                                                             | 1                                             | 0                                             | 18                                            | 23                                            | 0                                                             | 0                                             | 0                                                             | 0                                             | 1                                             | 2                                             | 0                                                             | 0                                             | 1                                             |
| 4.8         | 1                       | 1                                                             | 5                                             | 0                                                             | 1                                             | 2                                             | 3                                             | 5                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 0                                             | 1                                             | 2                                             | 0                                             |
| 4.9         | 1                       | 1                                                             | 4                                             | 0                                                             | 1                                             | 0                                             | 3                                             | 4                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                             | 0                                             | 0                                             |
| 4.10        | 1                       | 1                                                             | 8                                             | 0                                                             | 1                                             | 0                                             | 7                                             | 8                                             | 0                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 1                                             | 0                                             | 0                                             | 0                                             |
| 4.11        | 1                       | 5                                                             | 19                                            | 9                                                             | 1                                             | 2                                             | 16                                            | 19                                            | 9                                                             | 0                                             | 0                                                             | 0                                             | 0                                             | 4                                             | 1                                                             | 0                                             | 0                                             |
| 4.12        | 3                       | 0                                                             | 5                                             | 0                                                             | 3                                             | 0                                             | 10                                            | 5                                             | 0                                                             | 0                                             | 2                                                             | 0                                             | 0                                             | 3                                             | 0                                                             | 1                                             | 1                                             |
| 25          | 32                      | 51                                                            | 308                                           | 58                                                            | 32                                            | 34                                            | 239                                           | 308                                           | 58                                                            | 10                                            | 3                                                             | 0                                             | 4                                             | 30                                            | 10                                            | 1                                             | 24                                            | 4                                             | 1185                                           |
| %           | 2.7                      | 4.3                                                            | 26.0                                          | 4.9                                                            | 2.7                                            | 2.9                                            | 20.1                                          | 26.0                                          | 4.9                                                            | .8                                                            | .2                                                             | 0                                             | .3                                                            | 2.5                                            | .8                                                            | .08                                           | 2.0                                            | .3                                             | 100                                             |
Appendix 2. The composition of the coded problem-solving episodes of case Y.

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<td>2.9</td>
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<td>2.8</td>
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</table>
### Appendix 3. An example of a coded problem-solving episode, case B, episode 1.4.

<table>
<thead>
<tr>
<th>Analytic Unit</th>
<th>Individual Cognitive Functions</th>
<th>Distributed Cognitive Functions</th>
<th>Individual Metacognitive Functions</th>
<th>Group’s Metacognitive Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>“What are the requirements of the product itself, why do they need to be packed?” Proposing a problem, asking.</td>
<td>Sharing perception that the problem exists</td>
<td>Planning individual cognitive strategies and actions</td>
<td>Planning group’s strategies and actions</td>
</tr>
<tr>
<td>C2</td>
<td>B2 “Well, the requirements are...” C interrupts</td>
<td>Sharing problem relevant information</td>
<td>Monitoring individual cognitive strategies and actions</td>
<td>Monitoring group’s strategies and actions</td>
</tr>
<tr>
<td>C3</td>
<td>C3 “Of course part of the reason is that in a moist body the product will dissolve, but the product will remain its solubility in a dry, dark, and cool atmosphere.” Proposing a solution</td>
<td>Sharing information about possible solutions</td>
<td>Revising individual cognitive strategies and actions</td>
<td>Revising group’s strategies and actions</td>
</tr>
<tr>
<td>C4</td>
<td>C4 “Package won’t itself the temperature...” Proposing a limitation</td>
<td>Sharing information about impositions on the problem must be asked</td>
<td>Metacognitive knowledge of a person</td>
<td>Transactive memory / Meta knowledge</td>
</tr>
<tr>
<td>C5</td>
<td>C5 “No, that’s right.” Agreeing</td>
<td>Creating shared solutions of the problem</td>
<td>Planning group’s and actions</td>
<td>Non-relevant talk</td>
</tr>
<tr>
<td>C6</td>
<td>C6 “But the package will provide the moist block, light block.” Defining solution more closely</td>
<td>Agreeing</td>
<td></td>
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</tr>
<tr>
<td>B7</td>
<td>B7 “Here we come to the point which we have discussed earlier, the storing temperature, how can we store the product?” Asking</td>
<td></td>
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<tr>
<td>A8</td>
<td>A8 “Didn’t we have a brochure, which tell about these...” C interrupts</td>
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<tr>
<td>A9</td>
<td>A9 “...indicators.” Assisting A to remember</td>
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<tr>
<td>A10</td>
<td>A10 “The label had been made out of a special paper that changes its color according the temperature, you have read it, haven’t you?” Explaining more closely/ asking</td>
<td></td>
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<tr>
<td>D11</td>
<td>D11 “Yes I have.” agreeing</td>
<td></td>
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<tr>
<td>A12</td>
<td>A12 “Those were mainly for frozen products, wasn’t it?” asking</td>
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<tr>
<td>D13</td>
<td>D13 “Yes, the difference between temperatures must be significant.” asking</td>
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</tr>
</tbody>
</table>

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C15

A14 "So I don't know if it would be suitable for our product."
C15 "But there are indicators, little ones
that watch over."
Proposing a solution

A16 "Yes, those which will react on a certain temperature."
Defining solution more closely

B17 "Yes."
Agreeing

C18 "But the problem is how do we get the indicator in the side of the package?"
Proposing a subproblem, asking

B19 "And in which products will we use it, or do we use it in all products?"
Defining subproblem more closely, asking

C20 "It should be used in all products."
Proposing a solution

B20 "So we have a reason to do so."
Defining solution more closely

C21 "But can it be glued on before sterilization or after sterilization?"
Proposing a subproblem / asking

C22 "Yes because these...
Proposing a solution

C23 "So that they won't brake during transportation."

A24 "The mechanical protection is apparently less important, mainly...
Proposing a subproblem, asking

C25 "To the product."
Defining solution more closely

C26 "Yes, to the product."
Agreeing

C27 "No matter how the product is packed, the package will give necessary mechanical protection."
Proposing a solution

C28 "It just has to prove somehow."
Proposing a limitation

B30 "So we have to consider the design of the package."
Defining the subproblem more closely

C31 "On the other hand, if the product is in a box, it has to stay still somehow, so that it won't move and brake it."
Proposing a subproblem

C32 "Yes."
Agreeing

C33 "Yes."

D34 "It is very interesting question that how much the product can move inside the package?"
Proposing a subproblem more closely / asking

C35 "Yes, so can it get up, and stay in a bouncing position?"
Defining the subproblem more closely / asking

D36 "We won't shape them that big."

C37 “Yes.”
Agreeing

D38 “The question I have always try to ask people, is that what is the demand, that does the product have to stay absolutely still inside the package or can it make some natural movement?”
Proposing a subproblem, asking

C40 “For example, nine hour flight to US and a little tinkle in a plane’s cargo space and every product was like this…”
Answering

C41 “And how about the chance in air pressures?”
Proposing a subproblem, asking

D42 “There is always it’s own atmosphere.”
Proposing a solution, answering

C43 “Yes, that’s right.”
Agreeing

D44 “So, when the outside pressure changes, it goes flat…”
Defining solution more closely

C45 “How does it strain the joints of the package?”
Proposing a subproblem, asking

C47 “At the moment we have flat bags, there is no air.”
Answering

C49 “Then they fly to US in airplane’s cargo space.”
Commenting
B50 “We have already used airfreight.”
Commenting
A51 “Is it now a vacuum?”
Asking
B52 “No.”
Answering
A53 “So no vacuum?”
Asking
D54 “If it would be in vacuum it would be packed very tight to the product.”
Commenting
C55 “Yes.”
Agreeing
A56 “Yes.”
Agreeing

D57 “Then we can use some other kind of atmosphere, for example nitrogen, if the pressure proves to be…”

A39 “Yes.”
Agreeing that the subproblem exists

D46 “Yes.”
Agreeing that the subproblem exists

B48 “We do have a lot to do.”
Evaluating the progress
Proposing a solution
A58 "The kind of pressure that packages explode by themselves."

Defining solution more closely
A59 "If there are enough reasons to do so."

Defining solution more closely
B60 "The bag will be tight."

Defining solution more closely
C61 "And if it helps us to standardize something, so the package won't become dented."

Defining solution more closely
B62 "Or by doing so the product will keep it's quality better while stored."

Defining solution more closely
C63 "That's right."

Agreeing
B64 "Yes it is."

Agreeing

A68 "But if we think about the options of the packaging machine, it is worth while to..."

Proposing a subproblem / Defining solution more closely

A69 "Yes, it is worth while."

Agreeing

A70 "It doesn't cost much at this point if we choose to take some options..."

Expressing a opinion

B71 "It is worth while to check with the manufacturer how much the options cost now and later, this applies to automation, machine eye..."

Proposing a solution

C72 "So that we won't be releasing empty packages, maybe it cannot be used."

Defining solution more closely

A73 "How much those weight?"

Asking

C74 "We make 35 000 out of one kilo."

Answering

A75 "Weigh them on the scales then."

Commenting

B76 "Machine eye is an option."

Repeating the solution

B77 "About the gas again, it is worth while to keep it as an option, because sometimes we put a little bit of overpressure to the cup so it remains it shape...so when it is taken to place where the temperature is lower it will become dented."

Defining solution more closely

C79 "That's right, will it?"
<table>
<thead>
<tr>
<th>B83</th>
<th>Agreeing</th>
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<tbody>
<tr>
<td>D84</td>
<td>Agreeing</td>
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<tr>
<td>C85</td>
<td>Agreeing</td>
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<tr>
<td>A86</td>
<td>Agreeing</td>
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<tr>
<td>D87</td>
<td>Agreeing</td>
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<tr>
<td>D88</td>
<td>Agreeing</td>
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<td>C89</td>
<td>Agreeing</td>
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<tr>
<td>A90</td>
<td>Agreeing</td>
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<tr>
<td>C91</td>
<td>Agreeing</td>
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<tr>
<td>A92</td>
<td>Agreeing</td>
</tr>
<tr>
<td>D93</td>
<td>Agreeing</td>
</tr>
<tr>
<td>A94</td>
<td>Agreeing</td>
</tr>
</tbody>
</table>

**D80** "There are couple of meters and the temperature is 100-150 then."

**Answering**

**B81** "How do they pack the sausages, it doesn't get spoiled?"

**asking**

**C82** "Yes, but sausage is boiled, it is not raw..."

**Disagreeing**

**B83** "Should there be an option for a cooling?"

**Proposing a solution**

**D84** "And then there is the joining when the product is already in the bubble, and folding machine has it's temperature too."

**Proposing a limitation**

**C85** "Yes but it is only a narrow wheel on the side..."

**Proposing a solution / A interrupts**

**A86** "Or is it like this..."

**D interrupts**

**D87** "It is only a mould, so we can do only for those places we..."

**Proposing a solution**

**D88** "But still there will be some amount of radiation."

**Repeating the limitation**

**C89** "Yes."

**Agreeing**

**A90** "Yes, there will be."

**Agreeing**

**C91** "But it is pretty fast anyway, split seconds and it moves on."

**Proposing a solution**

**A92** "If in one minute it wrap 30."

**Defining solution more closely**

**D93** "Yes it is pretty fast."

**Agreeing**

**A94** "Yes it is couple of seconds."

**Agreeing**

C95 One hour and year's product is packed..." laughing

<table>
<thead>
<tr>
<th>Analysis Matrix</th>
<th>Individual Cognitive Functions</th>
<th>Distributed Cognitive Functions</th>
<th>Individual Metacognitive Functions</th>
<th>Group's Metacognitive Functions</th>
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<tbody>
<tr>
<td>Case B</td>
<td>Episode 4.12.</td>
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**TIME**

<p>| | | | | | |</p>
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</table>
| A1 | Proposing a problem | D2 | "Yes, I think so, because these requests we have been sent were sent a long time ago."
|   | Understanding the problem | Agreeing | defining the problem more closely | A3 | "Yes, and the employees might have changed at the other end, too."
|   | Understanding the solutions available to be solved | Agreeing | Defining the problem more closely | D4 | "Yes."
|   | Representing the problem into sub-problems | Agreeing | Defining the problem more closely | A5 | "Have you contacted Multiplan again?"
|   | Sharing perception of the problem | Agreeing | Defining the problem more closely | A6 | "I see."
|   | Sharing relevant information | Agreeing | Defining the problem more closely | B6 | "We have been there once. Have you contacted them since?"
|   | Sharing information under which a solution might be found | Agreeing | Defining the problem more closely | D7 | "No, I haven't."
|   | Creating a shared representation of the problem | Agreeing | Defining the problem more closely | D8 | "Multiplan and Kiromat are clear, they have the machines, but the best way to reach the smaller companies is to call and ask them."
|   | Planning individual strategies and actions | Agreeing | Defining the problem more closely | A9 | "I guess I don't have to send the requests in writing, but if I call them and tell them that I want this kind of information, so will they send it to me?"
|   | Monitoring individual cognitive processes and actions | Agreeing | Defining the problem more closely | B10 | "Well, it might be so."
|   | Reviving individual strategies and actions | Agreeing | Defining the problem more closely | B12 | "When we ask for information, we could mention to them that we don't have any previous experience of this kind of technology, and we would need information on how to pack these kinds of small products."
|   | Monitoring knowledge of a person | Agreeing | Defining the problem more closely | B12 | Planning a strategy

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</table>
| A1 | "Should we now start from the scratch again, so that we would send requests..." | Agreeing | Planning a strategy | A5 | Planning a strategy
|   |   |   |   |   |   |
| A10 |   |   |   |   |   |

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<table>
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<tr>
<th>Time Slot</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>A15</td>
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<tr>
<td>B16</td>
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<tr>
<td>D17</td>
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</tbody>
</table>

A15: "Well, and then..." Commenting

B16: "Multivak and Kromat, and maybe a third one, too." Defining the solution more closely

D17: "Yes, there might be others, too..." Agreeing

B18: "Multivak is from Switzerland, and Kromat is from Germany." Explaining

D19: "Yes." Agreeing

B20: "I think it is impossible to find any other company than those two." Expressing an opinion

A15: "We could ask them to provide us with certain kind of information, and once we get that, we can ask for more information from those that seem to be the most appropriate." Planning a strategy
### Appendix 5. An example of a coded problem-solving episode, case Y, episode 2.1.

<table>
<thead>
<tr>
<th>Analysis Matrix</th>
<th>Individual Cognitive Functions</th>
<th>Distributed Cognitive Functions</th>
<th>Individual Metacognitive Functions</th>
<th>Group's Metacognitive Functions</th>
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<tbody>
<tr>
<td><strong>Case Y</strong></td>
<td><strong>Episode 2.1.</strong></td>
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<tr>
<td><strong>TIME</strong></td>
<td><strong>Proposing a problem</strong></td>
<td></td>
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</tr>
<tr>
<td>A1 “Here we have about 20 items that need to be solved.”</td>
<td>A1</td>
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<tr>
<td>A2</td>
<td></td>
<td>A2 “Mikko has come up with an idea that an architect puts them into his plan and then our gardener would choose plants.”</td>
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<tr>
<td>F3 “Is there an agreement of this?” Asking</td>
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<tr>
<td>C4 “There has been a discussion about this with gardeners yesterday.” Explaining</td>
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<tr>
<td>A5 “Right now we do training for spring, that gives us initial level.” Explaining</td>
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<tr>
<td>A8</td>
<td></td>
<td>A8 “All though I do not know if one gardener can do all the work in spring.” Proposing a limitation</td>
<td></td>
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<tr>
<td>B9</td>
<td></td>
<td>B9 “Doesn’t this clearly belong to this material – point?” Proposing a solution / asking</td>
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<tr>
<td>C10 “Yes.” agreeing</td>
<td></td>
<td>C10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A11 &quot;So here are more items like this, almost twenty of them.” Connecting</td>
<td></td>
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<tr>
<td>B12 “Does anybody remember or know about those houses that get their gardens this spring, that are those products closely defined in those safety documents?” Proposing a subproblem / asking</td>
<td></td>
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<tr>
<td>F13 “If there is an apple tree, pomegranate, height 1.5 meters.” Defining more closely</td>
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<tr>
<td>C14 “There is what ever...” Commenting</td>
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<tr>
<td><strong>Non-relevant talk</strong></td>
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</tbody>
</table>
F38 "What else is in here, I only see these trees?"
  Asking
C39 "And three birches."
  assisting
A40 "And lawn."
  assisting
F41 "Will there be anything else?"
  Asking
C42 "Yes, there will be something else."
  Answering
F43 "Has the architect followed new instructions in this case already?"
  Asking / no one answers
A44 "Lawn and plants see report 203. I cannot find it as a appendix?"
  Reading the sketch aloud

A45 "So the sketch number 203 can be as we want, we just have to make sure it will be like we want."
  Proposing a solution
B46 "That's right."
  Agreeing
C47 "And another thing is that it would be important that the contractor knew year earlier what kinds of plants he will need. The price would go down that way."
  Defining solution more closely
B48 "Is there a catalog of sketches?"
  Asking
C49 "203 is there as a directive sketch."
  Answering
C50 "In my opinion the architect could decide where to put grass and bushes, but the contractor would decide what kind they are."
  Defining solution more closely
F51 "Is it like that?"
  Asking
C52 "Yes it is, there has been discussions with the architect."
  Answering
F53 "But I was thinking that we could say that it is not a good idea to have hedge in here, as well."
  Commenting
C54 "If the hedge is in a plan then there will be a hedge."
  Explaining / F interrupts
F55 "But they cannot go on with only this plan."
  Commenting
C56 "Why not?"
  Asking
F57 "Well there will be something else than grass too."
F78: “I think we should soon start to work on that too, it connects with the quality planning too.”
Agreeing with solution / planning for future actions

<table>
<thead>
<tr>
<th>Analysis Matrix</th>
<th>Individual Cognitive Functions</th>
<th>Distributed Cognitive Functions</th>
<th>Individual Metacognitive Functions</th>
<th>Group’s Metacognitive Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case Y</td>
<td></td>
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<tr>
<td>Episode 3.6</td>
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</tbody>
</table>

**TIME**

<table>
<thead>
<tr>
<th>Time</th>
<th>Coder</th>
<th>Code</th>
<th>Transcript</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>E1 &quot;There is the permanent fixture and the tile samples... at the last page you can see the unit prices.&quot;</td>
</tr>
<tr>
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<td>E2 &quot;We can state that a couple of thousand marks, and seven thousand marks... for alternatives one and two.&quot;</td>
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<td>E3 &quot;The biggest investment is the toilet because it is paved with tiles...&quot;</td>
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<td>E4 &quot;I do not know how widely the Helsinki-model [a house-building model] got distributed, but they have sort of standards, like Peri, Kia, and Asu, they have classified three different standards of equipment, do you have it Peri?&quot;</td>
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<td>E5 &quot;No, I don't. I only have these ones and two...&quot;</td>
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<td>A6 &quot;Mika might have them.&quot;</td>
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<td>A7 &quot;How about Jari, have you seen them?&quot;</td>
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<td></td>
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<td>F8 &quot;In what sense? Now, I cannot remember.&quot;</td>
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<td></td>
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<td>A9 &quot;Now we are talking about quality standards, they have three levels, there is an original Mendoa, then there is Kia, and then...&quot;</td>
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<td></td>
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<td>A10 &quot;There is so much re-selling information, and when my working style is so that it is often impossible to apply...&quot;</td>
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<td></td>
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<td>B11 &quot;Well, this was just an example, we can continue in our own way. Mikko, you know, when we get this advice is it orders or examples or what?&quot;</td>
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<td></td>
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<td>C12 &quot;Examples.&quot;</td>
</tr>
</tbody>
</table>

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A17 “Do you know if we have a very tight price...?”
Proposing a problem / asking

Answering
F13 “If you get it by mail, it can only be examples.”
Defining more closely
B14 “Yes, just like this.”
Agreeing

B16 “They have to go through these three levels in terms of permanent fixtures and tiles.”
Explaining
B18 “Ok, let’s get back to this.”
Commenting
E19 “The tiles are actually the only thing. Fornico tiles from Lantagiste...”
Answering / explaining

C15 “I have those papers on my desk. I can go through them and look if I can find them.”
Planning a strategy

A20 “Then Timo as a Project Manager decides which pattern we use...”
Proposing a solution

D21 “Yes, but which delegation decided?”
Proposing a limitation

A22 “According to the letters, the Project Manager is...”

F23 “…in charge.”
F completes A’s utterance

B24 “I tried to think how this process goes, so I think that, as early as possible, I should make the decision about different levels with Lydia.”
Monitoring a strategy

A25 “In the original calculations, we still need to have information about the costs.”
Proposing a limitation

B26 “Yes, so I will get the costs from the references...”
Planning own action

A27 “It must be shown in original numbers. Alison will...”

B28 “Yes.”
Agreeing

B29 “If I still go back... there are no more tiles than we usually have...”
Explaining more closely

B30 “I think that we can continue with three levels...”
Proposing a solution

C31 “We can get even more variations out of this.”
Proposing a solution

B32 “But here we have these three which we should keep.”
E33
Proposing the previous solution again
E33 "We should let Ketola and Aass see these over again."
Defining the solution more closely
B34 "We have a price range... these are costs, not the selling price, right?"
Reading the paper / asking
E35 "Yes, that is what we pay."
Answering
B36 "But now, in costs, there are a 100 per square."
Commenting

A38
Proposing a solution

E39 "I mean, if you compare this to a two-bedroom apartment, there are too few cabinets in this apartment..."
Explaining more closely
A38 "Here, we should check the units... Peka could sell..."
Revising a strategy

A40

E41 "Yes..."
Agreeing
B42 "And then there is that dining room where there is nothing..."
Proposing a sub-problem; E interrupts

E43 "We could draw another cabinet for the dining room..."
Proposing the previous solution again
E43 "We could draw another cabinet for the dining room..."
Proposing a solution
B44 "So, you can see this through, I think it is good..."
Proposing a solution

A45 "So we have Lada, Opel and Mercedes."
Agreeing
Appendix 7. The practical mediational tools used in collaborative problem solving processes.

**MENTAL MEDIATIONAL TOOLS**

**EXAMPLES**

**Individual experience**

- Using experience acquired through formal education
  
  “I guess I learnt something in school too, now I can apply that knowledge.” (An interview, Miisa, case B)

- Using experience acquired through working-life
  
  “Work is the best teacher.” (An interview, Antero, case Y)

- Using experience acquired through life
  
  “I was thinking about the material of those bubbles, for example in children’s toy-packages, Lego-packages, legos are inside the bubble and then there is a lower section where the instructions are.” (Videotaped team meeting, Mika, case B)

**Experience of others**

- Asking from more experienced colleague/s (within the own company)
  
  A phone call to a colleague: “A.K. hello, could you go and see what kind of appliance there is for cars, what is the type of it?” (Videotaped team meeting, Antero, case Y)

- Asking from less experienced colleague/s (within the own company)
  
  “So obviously it (the situation report) has reached people. I have got only one feedback so far… I think we need to give them (other colleagues) little more time and if we get more feedback we can go through those in next team meeting.” (Videotaped team meeting, Timo, case Y)

- Asking from expert/s (outside the own company)
  
  Phone call to a plumber: “Y-company and A.K. hello, what kind of radiators do you use in bathrooms and in saunas? (Videotaped team meeting, Antero, case Y)

- Asking from non-expert/s (outside the own company)
  
  “I sometimes ask for example my wife what she thinks about some problem I have here at work.” (An interview, Mika, case B)

- Asking user feedback
  
  “When I talked with Lea (area distributor) she told me that that people in the hospitals think that the package is very bad.” (Videotaped team meeting, Miisa, case B)
Experience of others (continues)

- Observing users
  “Tomorrow we are going to hospital, so we can solve this problem (how the hospital gets rid of used packages).” (Videotaped team meeting, case B 2)

- Following competitors’ development
  “This Memo is from Kiromat, it says that there is one medical packing machine used somewhere in Finland, I could go and see it?” “Of course, those are often very educational experiences.” (Videotaped team meeting, Miisa & Kari, case B)

  - Benchmarking
    - Inside the own company
      “Y is a big company, we operate in many cities in Finland and all regions do thinks a little bit differently, so we can benchmark each other.” (An interview, Timo, case Y)

    - Between the own company and other companies
      “How about benchmarking, I could go and see how they (a competitor) pack their products.” (Videotaped team meeting, Miisa, case B)
      “And then we could study competitors packages, where can we get those?” (Videotaped team meeting, Kari, case B)

Knowledge acquisition through literature, TV, Internet, exhibitions, standards, laws

- Reading scientific literature of the own field
  “I have done a little summary how to buy a packing line by using information I got from The Medical Advice.” (Videotaped team meeting, Miisa, case B)

- Reading non-scientific literature of the own field
  “Didn’t we have a brochure which tells about these [indicators]?” (Videotaped team meeting, Miisa, case B)

- Reading scientific literature of another field
  “Sure I read for example research reports from other fields, one can learn a great deal from those.” (An interview, Mika case B)

- Reading material books
  Showing material book to others: “With this basin you can use this cabinet, it is number 11139, it is a little cheaper than this smaller one 11140.” (Videotaped team meeting, Mikko, case Y)

- Doing information retrievals through Internet
  “I have read some literature written of this field, they are mostly from Internet, medical-articles…Internet is very good source of information.” (Videotaped team meeting, Miisa, case B)
Knowledge acquisition through literature,
TV, Internet, exhibitions, standards, laws
(continues)

- Watching TV
  “For example, it was in yesterday’s news that biowasteobligation drops
  from 10 apartment building to 5 apartment.”
  (Videotaped team meeting, Timo, case Y)

- Reading newspapers, magazines
  “I read, was it yesterday’s morning paper or Kauppalehti, that within three
  years there is a mega-connection in every apartment, so these cables we use
  now will soon be history.” (Videotaped team meeting, Timo, case Y)

- Studying standards, official reports, documents, laws
  “I’m about to receive the ISO-11607 standard (packing standard for
  medical devises).” (Videotaped team meeting, Miisa, case B)

- Gaining information from exhibitions
  “At the packing –exhibition there were couple of other manufactures,
  We just took their brochures.” (Videotaped team meeting, Kari, case B)

Knowledge acquisition through testing and
Building a model or a prototype

- Testing the product or part/s of it
  “For example storage tests.” “…transportation tests.”
  (Videotaped team meeting, Hilkka, case B)

- Building a model
  “Of course we need to build a model to see how it (package) works.”
  (An interview, Mika, case b))

- Building a prototype
  “After we talked about prototypes, I negotiated with Vipak and they will
  make 5000 packages for stents…and then we can run some tests for them.
  (Videotaped team meeting, Mika, case B)
### Instrumental Mediation Tools

<table>
<thead>
<tr>
<th>Tool</th>
<th>Example</th>
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<tr>
<td>Using professional language or jargon</td>
<td>“Materials must be medical agreed, but if they [materials] are European do they meet FDA-demands?” (Videotaped team meeting, Miisa, case B) “We should stick with K-value, it is the clearest.” (Videotaped team meeting, Antero, case Y)</td>
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<tr>
<td>Distributing tasks between team members</td>
<td>“I can do that (figure out the problem with the paving of sidewalks and yards) because I have to deal with it anyway.” (Videotaped team meeting, Antero, case Y)</td>
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<tr>
<td>Distributing tasks to others outside the team</td>
<td>“I could give this job to Matti, he could figure out stone types, so we know how much every type will cost.” (Videotaped team meeting, Mikko, case Y)</td>
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<td>Making timetables</td>
<td>“Now we have gone through this part, and then we write it out, and the next step is to go through those building regulations.” (Videotaped team meeting, Timo, case Y)</td>
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<td>Preparing situation reports for others outside the team</td>
<td>“With this [situation report] we represented what this team has done so far…and it was distributed to everyone by email and I think Tarja sent it by mail too.” (Videotaped team meeting, Timo, case Y)</td>
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<td>Dividing problems into subproblems</td>
<td>&quot;The goal is to pack these wildly increasing amounts [of company's products] with the packing machine, we need to make sure that it is applicable for packing this kind of product, find out materials we can use, and consider the design of the package too. So with what and how we pack.” (Videotaped team meeting, Kari, case B)</td>
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<tr>
<td>Using computer software</td>
<td>&quot;I thought that if I would first draw some kind of molds with Pro [a computer software] it is very handy, and then we can try to fit the product into it.” (Videotaped team meeting, Miisa, case B)</td>
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<tr>
<td>Drawing sketches</td>
<td>drawing a sketch: &quot;But in my opinion it is clear that if we have a front door here and we have a garage right here, at least this area should be covered with rock material or blacktop.” (Videotaped team meeting, Jari, case Y)</td>
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