Department of Education, Center for Activity Theory and Developmental Work Research, University of Helsinki, Finland

CRITICAL TRANSITION FROM DEVELOPERS TO USERS

Activity-Theoretical Studies of Interaction and Learning in the Innovation Process

Mervi Hasu

Academic Dissertation

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To Jari, Joel and Taneli

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Mervi Hasu

Critical Transition from Developers to Users

Activity-Theoretical Studies of Interaction and Learning in the Innovation Process

Abstract

Often, inventions of scientists and engineers that start in backyard garages and research laboratories come into the hands of users unfinished, clumsy and user-unfriendly. It has been shown that putting an innovation into use may be a major challenge for the adopter organization. This study focuses on the question of how people involved in the innovation learn to master the shift from developer to user.

The study focuses on the "gray area" *between* research and development (R&D) and introduction onto the market, an area in which developers and users actually meet and interact. This coming together is significant, although not easy, for the communities responsible for the development of the new product. Early collaboration and application work with users may be crucial to the expansion of user networks and the diffusion of innovation. I refer to this phase of innovation as "critical transition."

The innovation under scrutiny is a science-based technological product originating from research on low-temperature physics at the Helsinki University of Technology. This product, the neuromagnetometer, is a measurement instrument for brain research and diagnostics. The neuromagnetometer and its use in studying the brain are called magnetoencephalography (MEG). I studied the neuromagnetomer innovation and the innovation network in 1996-1997, when the spin-off company responsible for the commercialization of the technology targeted new, clinical markets.

The study is an analysis of producer-user relations, and of the implementation and use of the neuromagnetometer in a Finnish and an American hospital laboratory. It is a qualitative case study and includes four analyses (articles) that open four complementary "windows" onto an innovation trajectory tracing the neuromagnetometer and its early implementation into clinical use in two hospitals (one in Finland and one in the United States) in a short period of time (1996-1997).

Cultural-historical activity theory offers a framework for studying technology development and use in terms of object-oriented and historically-constructed activity. The activity-theoretical framework is applied in this study of producer-user interaction and implementation processes in a given innovation, in a specific historical phase.

The findings and implications of the study are discussed in relation to (1) the problems of producer-user relations and implementation, (2) learning, and (3) the research framework and methodology.

The study contributes to the debate on producer-user relations, implementation and learning in innovation processes by exploring the transition of a neuromagnetometer innovation to practical use. By building on theoretical and empirical literature on innovation and technology management, and by drawing on a theoretical framework sensitive to systemic relationships, I develop the concept of critical transition from developers to users as a potential new, dynamic perspective on integrating the above-mentioned classic themes of innovation.

Keywords: activity theory, implementation, innovation process, learning, producer-user relationship, technological innovation

Contents

1 Introduction

Why would a social scientist be interested in studying technological innovation, the work of high-tech geniuses? What has fascinated me and motivated the study at hand is that inventions of the scientists and engineers that start in backyard garages and research laboratories come to the hands of the users unfinished, clumsy and user-unfriendly. Users start to apply the new "thing", sometimes by struggling to learn to use it and improve it. If they succeed in convincing the developers to provide a better, more viable product, what comes out is a success story. Who, then, was the innovator?

This might sound an oversimplified account of the development of new products and services. I believe, however, that as long as technical professions and entrepreneurial spirit coincide, there will be innovations driven more by technological opportunity than societal need. A large body of literature exists on genius inventors and heroic high-tech entrepreneurs, but little is said about the users who implement and practically re-configure the innovation. They are anonymous and left in the background as if they had nothing to say.

What I am looking at in this study is innovation, not only as the work of high-tech experts, but also as the concrete, mundane work of ordinary users. I will show that putting an innovation into use may be a major challenge for the adopter organization. This is not to under-estimate the efforts of the developers of new technical products. Their work involves painstaking problems. An individual developer's work may also change over time as the innovation he or she is contributing to moves from the research laboratory to a spin-off firm and onto the market. Within an individual scientist's career, what started as experimental work with a piece of specific technology in the laboratory corner may lead to systems-application work driven by customers' needs. This may be a radical shift from one activity to another. How do people learn to master such shifts?

How this kind of transition within an innovation network is accomplished is the subject matter of the present study. My special interest here is the "gray area" *between* research and development (R&D) and introduction onto the market, an area where developers and users – surprisingly often for the first time - actually meet and interact. These interactions bring together different trajectories of the developer community and the user community, as well as different developmental traditions and perspectives. There is little research on this gray area, the transitional phase of innovation. My study shows that the coming together within the gray area is significant, although not easy, for the communities responsible for the development of the new product. Early collaboration and application work with users may be crucial to the expansion of user networks and the diffusion of innovation. I will refer to this phase of innovation as "critical transition."

Studying critical transition from basic research to clinical use: The case of the neuromagnetometer innovation

In the present study, the innovation under scrutiny is a novel, science-based technological innovation originating from research on low-temperature physics at the Helsinki University of Technology. This innovation, the neuromagnetometer, is a measurement instrument for brain research and diagnostics, and it integrates biomagnetism, low-temperature physics and superconductivity. The neuromagnetometer and its use in studying the brain are called magnetoencephalography (MEG).

I studied the neuromagnetomer innovation and the innovation network in 1996-1997, when the spin-off company responsible for the commercialization of the technology targeted new, clinical, markets.

The neuromagnetometer innovation provides an interesting case for studying the challenges and complexities involved in the transition from basic research to introduction onto the market. First, the history of the innovation is rooted in the academic community of physicists, pioneers in building instruments for measuring ultimate low temperatures and in starting to measure the weak magnetic fields of the brain with these instruments in the 1970s. The community of physicists not only accepted a huge technological challenge, but also took a big step into a new discipline, brain research. To bridge the gap between instrumentation expertise and the measurement object, the human brain, a clinical neurophysiologist and medical doctor was hired for the physics laboratory in the early 1980s to develop and apply MEG for basic neurophysiological research. This brain researcher, and other researchers following her, emerged as the first “non-physicist” users of the new measurement device within the laboratory. This could be interpreted as the first critical transition of the innovation from developer to user in the innovation process that took place mainly in the 1980s (Fig. 1).

Second, the innovation was commercialized by its original developers. A small group of physicists, researchers who had built the first experimental instruments, founded the spin-off company to utilize the commercial potential of the innovation and to build the commercial measurement system. This was also a remarkable new step: a group of researchers and instrument builders involved in entrepreneurial activity. The enterprise proved successful as the prototype version of the first whole-head neuromagnetometer was completed in 1992 (Fig. 1). The main market for the device was basic research, namely brain-research groups all over the world. During the first wave of commercial installations in 1994-1996, the company supplied seven MEG systems to Japan, Germany and the United States. The price of the entire system was about 2 million US dollars. The research market was considered too limited for maintaining the production of the MEG devices in the long run. The company faced the necessity of acquiring clinical markets in the near future.

Third, potential clinical applications for MEG emerged during the 1990s, but their evaluation and establishment in medical practice turned out to be a great challenge. Its clinical utility was demonstrated in pre-surgical localization of functionally irretrievable areas, such as the motor cortex, and in the localization of epileptic foci. The first MEG systems supplied by the Finnish spin-off company, Neuromag, were installed in the hospital environment in 1994 in Finland and in the United States. The infrastructure to start the clinical utilization of MEG existed in principal. I consider this phase the second critical transition from developer to user, namely from basic research to clinical use. It was ongoing or emerging at the time of the present study.

The simplified trajectory of the neuromagnetometer innovation is depicted in Figure 1. It describes both the development of technical R&D work (instrumentation) and the development of the user activity in Finland during the innovation process. The innovation trajectory is presented as a linear time line for the sake of simplicity.

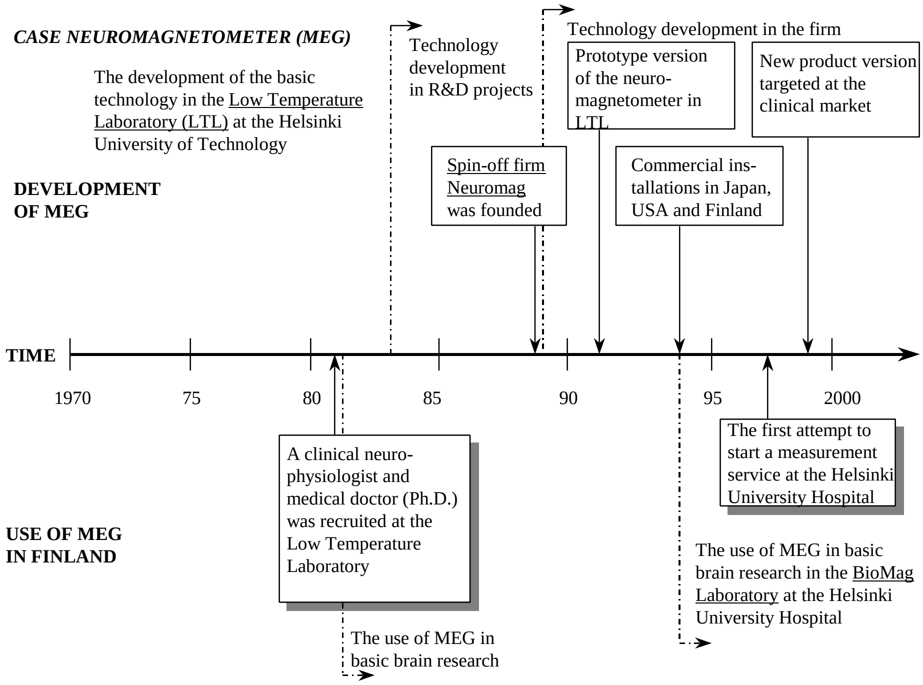

Figure 1. The innovation trajectory of the neuromagnetometer. The data collection for the present study was conducted during 1996-1997. The important developmental points for the use of MEG in Finland are depicted below the time line. The first versions of the neuromagnetometer were originally developed at the Low Temperature Laboratory at the Helsinki University of Technology during the 1970s and 1980s. The spin-off company, Neuromag, was founded in 1989. The MEG system was installed in the BioMag Laboratory at the Helsinki University Central Hospital in 1994.

This study is an analysis of producer-user relations, and of the implementation and use of the neuromagnetometer in a Finnish and an American hospital laboratory in 1996-1997.

The structure of this introductory essay is as follows. First, I will briefly introduce the theoretical scope and focus of my study concerning producer-user relations, implementation and learning. Second, drawing from the literature on innovation and technology management, I will discuss the problem of producer-user relations (section 2), implementation (section 3) and learning (section 4) in the innovation process. I will formulate my own perspective on the problem at the end of each section. Finally, I will summarize and discuss the methodological decisions and empirical findings reported in the four articles of this study (section 5).

The theoretical discussions in this study: the problems of producer-user relations, implementation and learning

Introducing an innovation, a new technological artifact, onto the market has been a classic problem in economics and management studies of technology and innovation (e.g., Kline & Rosenberg, 1986; Burgelman & Maidique, 1988; von Hippel, 1988; Rhodes & Wield, 1985; Preece, 1989; Rothwell, 1994). Within this broad area, two major lines of research are particularly relevant. (1) Is it possible to *develop* innovations that are able to meet future market needs successfully? Alternatively, how can they be re-developed to meet changing market/user needs? Traditionally, this field of research has underlined the pre-development or design phase of an innovation, as well as the role the manufacturer and the user (von Hippel, 1988; also Lundvall, 1992). (2) How is the market *introduction process* managed successfully? This type of research has typically taken a post-development view, focusing on the implementation of the innovation in various organizational settings, and the significance of various groups, including manufacturers and users, to ensure successful implementation (Rhodes & Wield, 1985; Preece, 1989). The debates concerning producer-user relations and implementation have remained separate, addressed by different authors in slightly different disciplines. In practice, however, the two problems are not clear-cut, as will be shown in the present study.

The relevance of the two problems also derives from the key characteristics of the case under study. The *neuromagnetometer* innovation constitutes challenging conditions for product development and introduction. It is a complex technological artifact, a scientific instrument originating from basic research, and it is expected to be used as medical equipment in hospital environments. The emergence and development of clinical applications is critical for market expansion and commercial success. During the data collection for this research in 1996-97, its practical implementation was still ongoing and proved to be a slow and costly process. The complex and hierarchical target environment is currently beset with cost-reduction policies and competition over scarce resources. Relationships with clinical users and mastering the implementation processes in the target organizations were urgent questions for the spin-off company, Neuromag, engaged in the commercialization of the innovation.

I aim to contribute to the debate on producer-user relations and implementation with my own study which explores the transition of a neuromagnetomer innovation to practical use. The study is qualitative and includes four analyses that open four complementary "windows" onto an innovation trajectory. I have chosen to deal with the three issues within the discussions mentioned above. I am placing my study within the following boundaries.

Firstly, I have chosen to focus on and relate my study to literature which shares an interest or intention (1) to explore concrete, identifiable technological innovation and its "inner" dynamics. This decision excludes a large body of studies in the economics of innovation that focus on large-scale quantitative analyses of industries, and also studies of technology transfer and diffusion (e.g., Scherer, 1982; Pavitt, 1984). The main focus is not on retrospective case histories of technological systems (e.g., Hughes, 1983) or innovations (e.g., Blume, 1992), either. My interest lies especially in the interactive processes which take place in the early introduction of innovation, between development and commercialization, among producers and users. Therefore, I have also excluded marketing studies on buying behavior and buyer-seller interaction based on survey analyses (e.g., Webster & Wind, 1972).

Secondly, I chose to refer especially to studies which (2) place innovation in the context of local, ongoing practices taking place in a specific organizational setting or in a network. Maintaining a focus on the firm is essential, however, because the firm is the key institutional form and structure responsible for the commercialization of innovation. This interest excludes most constructivist studies of science and technology (e.g., Bijker, 1999; Latour, 1987; 1988), in which the interest has been in actors of various kinds, and which have not usually considered the firm as a focus of analysis (Coombs & al., 1996).

Lastly, I refer to studies which share an interest in (3) localized collaboration and learning within the innovation process. This position excludes studies focusing on formal, established agreements between firms and their customers (e.g., Chesnais, 1996). The emphasis is rather on relationships as they are actualized in real-life collaborative efforts and actions. Researchers on innovation and technology management have been increasingly interested in questions of learning in producer-user relations and implementation (e.g., Malerba, 1992; Lundvall, 1992; Fleck, 1994; von Hippel & Tyre, 1995). Within this literature, I refer to studies in which learning is present as a "latent" possibility for transition and change.

2 The problem of producer-user relations

> *If there is a single lesson this review of innovation emphasizes, it is the need to view the process of innovation as changes in a complete system of not only hardware, but also market environment, production facilities and knowledge, and the social contexts of the innovating organization. (Stephen J. Kline & Nathan Rosenberg, 1986)*

The emergence of producer-user relations in innovation studies

In a recent introductory article, Martin and Nightingale (2000) trace the emergence of interest in "user feedback" in the 1970s and early 1980s to the work of Nelson and Winter (1977). Nelson and Winter argued that production functions[1] fail to explain what lies behind the uncertainty and diversity of performance that characterize technical change. They suggested that a more 'appreciative' type of theorizing was needed to capture the empirical richness of innovation. According to Martin and Nightingale, their work catalyzed two streams of "interacting research". In the first, analysts began to model innovation, taking account of uncertainty and diversity. This grew into the field of evolutionary economics (Freeman, 1979; Dosi, 1982; Dosi & al. 1988). The second stream of research began to empirically explore the institutional

[1] Early work on the economics of basic research aimed at understanding innovation in terms of profit maximization by industrial firms. Today, economists recognize that the cost of transferring and using external sources of information is often very high because of the cumulative, tacit nature of technical knowledge (Martin & Nightingale, 2000, xiv).

causes of uncertainty and diversity. This work attempted to highlight the very tacit, localized nature of technical knowledge and the difficulties of treating technical change as an information allocation problem. According to Martin and Nightingale, the work on the institutional causes of uncertainty and diversity in economics was part of a wider shift towards understanding the role of non-market institutions in economic growth (xvii-xviii). The work of von Hippel, and of Rothwell et al. (1974), on *user involvement* has its roots in the second stream of research interests.

Freeman (1991) noted in a review article that, until the 1960s, most studies on innovation were anecdotal and biographical, or purely technical. Although economists had always recognized the great importance of innovation for productivity growth and for the competitive performance of firms, industries and nations, they produced very few empirical studies of innovative activities or of the diffusion of innovations. Until the early 1970s, most of the research concentrated on the study of specific, individual innovations. It focused on identifying the characteristics of each one that led to commercial as well as to technical success, whilst recognizing the inherent element of technical and commercial uncertainty (Freeman, 1991, p. 499). Within this period of research, the source or "locus" of innovation was assumed to remain almost exclusively in the firm. Consequently, the models of product innovation were conceptualized from the manufacturer's perspective (Rothwell, 1992; Biemans, 1992; Teece, 1988)[2].

In practice, innovation-related activities are not always performed by the manufacturing firm alone. During the latter part of the 1970s, seminal studies centering around this finding were conducted by von Hippel (1976; 1978). He discovered that in the case of scientific instruments and process machines used by the semi-conductor industry, users play a dominant role in the innovation-development process (v. Hippel, 1976; 1977a). At that time, this finding was like a breath of fresh air, if not radical, and it was picked up by several other researchers and elaborated upon (e.g., Foxall & Tierney, 1984; Shaw, 1985; Voss, 1985; Lundvall, 1988). Von Hippel and his colleagues continued to develop research on the *user role,* as well as on the practical implications and techniques based on it in the development of new-product concepts and the products themselves (e.g., von Hippel, 1986; Urban & von Hippel, 1988; von Hippel, Thomke & Sonnack, 1999). This work has been widely cited in a variety of studies within innovation and technology management, and it is also of special interest for the present study.

From accurate understanding of user needs to users as innovators

The classical SAPPHO study[3] underlined market-related factors that discriminate most strongly between successful and unsuccessful industrial innovation. The most

[2] Interactive process of innovation was introduced originally by Freeman (1979) as a reaction to the dichotomy between "market pull" and "science push" models of innovation, and modeled later on by Kline & Rosenberg (1986) and Rothwell (1992), who replaced the linear model. The question remains whether these interactive models represent radically different conceptualizations of the nature and dynamics of innovative activity, or whether they are extended linear models.

[3] The way to identify the factors which are important for success is by paired comparison between the innovations which succeed and those which fail. In one of the most comprehensive empirical studies on innovations (project SAPPHO), a hundred characteristics of 40 pairs of innovations were measured, but only about a dozen of the hypotheses systematically discriminated between success and failure. The most important of these were: (1) user needs and networks, (2) the coupling of development,

important single factor was found to be a lack of understanding of user needs and circumstances. Failures were characterized by neglect or ignorance of these needs (Freeman, 1991, p. 500). However, it was not within the scope of that research to determine how a manufacturer acquires the necessary understanding of user needs. These findings were a starting point for von Hippel in his first study about the role of users in the scientific-instrument innovation process. He initiated a research program which was directed to both practical implications and scientific debate on the dynamics of the innovation process.

Among the interesting questions left unanswered are: How does an innovating firm go about acquiring an "accurate understanding of user need?" Via an information input from the user? If so, should the manufacturer take the initiative in seeking out such output, or will the user seek him out? And, what does a need input look like? Should one be on the alert for user complaints so vague that only a subtle-minded producer would think of using them as grist for a product specification? Or, perhaps, should one be touring user facilities on the alert for something as concrete as home-made devices which solve user-discerned problems, and which could be profitably copied and sold to other users facing similar problems? Answers to questions such as these would be of clear utility to firms interested in producing innovative industrial goods and (…) of interest to researchers working towards an improved understanding of the industrial good innovation process. (von Hippel, 1976, p. 212)

Von Hippel concluded that the innovation process for scientific instruments is user-dominated: 77 per cent of the innovations studied were developed by users (von Hippel, 1976)[4]. In a large majority of cases, it was the user, not the instrument manufacturer, who perceived that an advance in instrumentation was required (that is recognized the need), invented the instrument, built the prototype, and diffused information on the value of the invention to both user colleagues and instrument manufacturers. After the manufacturer became interested in the developed prototype, his contribution would be to perform product-engineering work on the user's device to improve its reliability, and convenience of operation, and to manufacture, market, and sell the innovation.

A second study by von Hippel arrived at similar findings: 67 per cent of the new process machines used by the semiconductor industry were developed by users (von Hippel, 1977a). Both studies led him to hypothesize that there are in fact two different paradigms describing the idea-generation stage of the product-development process. In the Manufacturer-Active Paradigm (MAP), "it is the role of the manufacturer to select and survey a group of customers to obtain information on needs for new products or modification of existing products; analyze the data; develop a responsive product idea; and test the idea against customer perceptions and purchase decisions" (von Hippel, 1978, p. 40). MAP was assumed to correspond with consumer product markets, where potential users can be identified relatively easily, user requirements change slowly, and the manufacturer has a relatively long time span to develop and market new products.

However, in industrial markets, the number of potential customers is relatively small, user requirements may change quickly, and new products need to be developed in

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production, and marketing activities, (3) linkage with external sources of scientific and technical information and advice, (4) concentration of high-quality R&D resources on the innovative project, and (5) high status, wide experience and seniority of the business innovator (Rothwell & al., 1974).

[4] The first study concerned a sample of 111 successful innovations in scientific instruments, which were divided into three categories: basic innovations, major improvements, and minor improvements (von Hippel, 1976, 217).

response to urgent problems. The user may be forced to develop the innovation in-house. Von Hippel hypothesized that a Customer-Active Paradigm (CAP) provides a better fit with observed reality.

> In the CAP, it is the role of the would-be customer to develop the idea for a new product; select a supplier capable of making the product; and take the initiative to send a request to the selected supplier. The role of the manufacturer (…) is: to wait for a potential customer to submit a request (…); to screen ideas (not needs) for new products; and to select those for development which seem to offer the most promise from the manufacturer's point of view. (von Hippel, 1978, p. 40)

Von Hippel thus originated the idea of the *"user-innovator" as a source of novel product concepts or products*. Users provide more than merely an idea for a new product. They may supply a manufacturer with the identification of a problem or need, product-related specifications, or even a complete product design.

The MAP/CAP dichotomy was elaborated upon by Foxall & Tierney[5] (1984). They criticized von Hippel's (1977b) assumption that user-innovators often have no incentive to take their developed devices beyond their own company, and the related implicit assumption that the major benefits must inevitably accrue to the manufacturer. A case study of a user-initiated innovation describes how a division of British Aerospace played the role of user-initiator but also went further than this by actively seeking out markets and marketing arrangements for its internally-generated innovations. Foxall and Tierney proposed a second paradigm of customer activity, CAP2.

> CAP2 describes a user-innovator, who also takes an active, entrepreneurial role in the successful commercialization of the new item, while CAP1 (Von Hippel's Customer Active Paradigm) actually describes customer-led invention/innovation but tends to ignore the possibility of customer-initiated entrepreneurship involving the alertness to opportunities for product innovation. (Foxall & Tierney, 1984, 13)

Foxall (1986) further suggested that user-manufacturer interactions in new-product development should not be regarded as a simple manufacturer-active/customer-active dichotomy. Instead, there is a continuum of possible interactions.

Important implications were drawn from the MAP/CAP distinction for manufacturers of industrial innovations. For instance, market-research strategies should focus on finding *user solutions* with attractive market potential rather than finding user "needs" (von Hippel, 1977b, p. 20). Von Hippel proposed a new stance toward the industrial product innovation process, and also a different problem from the initial one of "accurate understanding of user need." This involved identifying and finding innovating users with user-developed new solutions.

Von Hippel (1986, 1988) introduced the concept of *lead user* as a solution to this problem. How should market research on innovative products be conducted if traditional methods are inappropriate? According to von Hippel (1986, p. 796), lead users face needs that will be general in a market-place, but do so months or years before the greater part of that market-place encounters them. They are also positioned to benefit significantly by obtaining a solution to those needs. Von Hippel (1986) and

[5] Foxall & Tierney's critique on the MAP/CAP dichotomy referred to here is reviewed in Biemans (1992, pp. 72-75).

Urban & von Hippel (1988) introduced a lead-user method in which lead users may be incorporated into market research. This method consists of four steps: (1) identify an important market or technical trend, (2) identify lead users who lead that trend in terms of experience and intensity of need, (3) analyze lead-user-need data, and (4) project lead-user data onto the general market of interest. This method has been elaborated and further developed by von Hippel and his colleagues in collaboration with established industrial firms (von Hippel, 1998; von Hippel, Thomke and Sonnack, 1999; Sonnack, von Hippel & Churchill, 2000).

By underlying users' product solutions, von Hippel puts much emphasis on their intelligence and agency as developers of their own instruments. On the other hand, he distinguishes strongly between average users' (also termed non-lead users) and innovative (lead) users' abilities.

> [A]verage users have a poor ability to identify novel product attributes accurately because they do not have real-world experience with them. But lead users are well positioned by the very same reasoning: They have real-world experience with the needs that future profitable products must serve and with attributes they must contain. (von Hippel, 1985, p. 317, cited in Biemans, 1992, p. 71)

The lead-user concept and method include the assumption that accurate, explicit information can be obtained about lead-user needs via systematic survey data, interviews and group exercises (von Hippel, 1986; Urban & von Hippel, 1988)[6]. Who (individual, group or firm) is perceived as a lead user varies: experts of an industrial sector (von Hippel, 1986; Urban & von Hippel, 1988), expert machine user/s (von Hippel & Tyre, 1996), and "users as designers" (von Hippel, 1998) are termed lead users. Typically, various kinds of experts are seen as knowledgeable and competent lead users. The interests or motives of the users to partake in the process are not further elaborated on. Hence, the *collaboration* between manufacturers and users is implicitly assumed as unproblematic. Because the focus was initially on innovative design for new markets, the role of lead users is discussed almost exclusively in the idea-generation stage of the innovation process. The question of the emergence of a lead user, or the conditions under which lead users emerge or change, remains marginal.

A growing focus on user-manufacturer interaction and networks

Other researchers who have also reported on user-initiated innovations have emphasized not so much the different roles of manufacturers or users in various stages of new-product innovation, but rather the significance of *interaction* during the innovation process (e.g., Voss, 1985; Shaw 1985; also Lundvall, 1988; 1992). Shaw (1985, p. 283) studied thirty-four medical equipment innovations in eleven companies. Twenty-six (76 per cent) were developed through multiple and continuous interaction between manufacturers and clinical users, twenty-two (65 per cent) of these being successful. He concluded by giving two major reasons for the high level of interaction: any equipment that is to be potentially introduced into clinical use needs clinical assessment and trial, and state-of-the-art clinical and diagnostic

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[6] In more recent studies, however, von Hippel and his colleagues have also discussed problems of acquiring informative lead-user data. They have, for instance, discussed local "sticky" information (von Hippel, 1994, 1998), and the need for "real-world use tests" and learning by doing (von Hippel & Tyre, 1996), and reported on the use of real-life contextual information for a lead-user process in a firm (von Hippel, Thomke & Sonnack, 1999).

knowledge resides in the user. A special relationship is therefore needed between the clinical advisory and trial team and the manufacturer. The key relations are not, however, limited to a single producer-user relationship. *Intermediaries* such as the above-mentioned clinical advisory and trial team and the manufacturer are crucial in the medical-equipment innovation process, resulting in good communication and understanding of user needs (ibid. p. 283).

A few researchers within innovation studies have intended to go beyond simple manufacturer-user relationships and have suggested that other parties may be involved as well (e.g., den Hertog & al., 1996). Håkansson (1982, 1987a) proposed and developed an interaction approach to product development. The initiative for product development is located solely neither in the manufacturer nor in the user, but rather in the interaction between the two (the idea of interaction development). In principle, therefore, even this interactive viewpoint is limited to two or a few actors. Biemans considered this view to be too narrow: product development should be regarded as the interplay between a number of actors, that is, as taking place within networks (Biemans, 1992, p. 82). According to him, the manufacturer operates within a network consisting of a number of organizations linked together by individual interactive relationships. New knowledge in terms of new product or process ideas often emerges at the interface between different knowledge areas (e.g., Conway, 1995; Powell, Koputt & Smith-Doerr, 1996; Miettinen, 1996, 1998). Thus, Biemans (p. 85) defines the network approach in the context of innovation to include manufacturer-user interaction as a “network of its most simple form”.

Håkansson (1987b, pp. 14-17) distinguished three basic elements or variables forming a *network*: actors (which may be individuals, groups or companies), activities performed by actors (transformations and transactions), and resources (physical assets, financial assets and human assets, although it is not clear how human assets differ from actors).[7] Each of the three classes of variables form within them a network structure, and at the same time are interwoven in the “total” network. This approach implies two extensions to the initial interaction view. First, although the manufacturer-user relationship can still be seen as having major importance in developing innovations, other parties need to be emphasized as well. Second, apart from identifying direct relationships, that is, the formal or straightforward relationship between the focal firm and its partner, one should distinguish indirect or informal relationships (Biemans, 1992, p. 85-86).

Despite the obvious relevance of the network concept, its applications to the area of developing innovations have been quite limited (Biemans, 1992, pp. 92-93; Coombs & al., 1996, pp. 1-5). In spite of more recent exceptions (Emirbayer & Goodwin, 1994; Elzen, Enserink & Smit, 1996; Powell, Koput & Smith-Doerr, 1996; Sydow & Windeler, 1998), researchers who have used network approaches seem to have been more interested in the description and understanding of complex processes than in

[7] An interest in networks has developed among researchers who might be described as being at the interface between marketing and innovation. The work of Håkansson (ibid.), and also Biemans (1992), could be considered representative within this framework. The inclusion of both actors and resources in Håkansson’s approach has some resonance with sociological actor-network theory, but it lacks the dynamics of the latter, and the notion of the enrollment of new supporters (Coombs & al., 1996, p. 3). For a review and evaluation of the actor-network perspective for studying technological innovations, see Miettinen (1999).

empirical generalizations or managerial implications.[8] They have been confronted with methodological problems such as setting the limits for collecting data, and with making decisions about sampling elements to estimate existing linkages (Biemans, 1992, p. 89, also Miettinen, 1993). Although networks may be studied by using multiple data, many studies have relied on survey data or interviews only. Network analyses have also typically been retrospective. This is one possible reason for the limited consideration of difficulties, hesitations and constraints in network interactions. Often, mapping the number of linkages or the variety of different information/resource channels between actors has been the main objective in network studies. Consequently, intention or agency of actors participating in the network has remained obscure. The actual content, and the quality of interaction and learning between parties, is seldom considered.

More recently, researchers focusing on networks have started to elaborate upon questions such as learning, agency and the “evolving community” or practice within them. Emirbauer and Goodwin (1994) examined different (implicit) models in the network literature of the interrelations of social structure, culture and human agency. They concluded that only a strategy for historical explanation that synthesizes social structural and cultural analysis can adequately explain the formation, reproduction and transformation of networks themselves. Powell, Koputt and Smith-Doerr (1996) argued that when knowledge is broadly distributed and brings a competitive advantage, the locus of innovation is found in a network of interorganizational relationships that sustain a fluid and evolving community. According to the authors, “learning occurs within the context of membership in a community and may require different kinds of organizations and organizational practices to access that community” (p. 142). They conclude that, rather than using external relations as a temporary mechanism to compensate for capabilities they have not yet mastered, firms use collaborations to expand all their competencies. The authors do not doubt the ability of firms to learn, nor do they question the possibility of “a sense of community-level mutualism.”

Towards a more multi-voiced perspective on producer-user relationships

The harmonious or unproblematic view of producer-user relationships offered in the innovation studies[9] referred to above does not seem to apply to the experience of a

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[8] This is most clearly seen in sociological approaches to innovation networks. The role of the business firm, as the central institution through which innovations are commercialized, does not receive the same emphasis in sociology as in literature on the economics of innovation and management. The actor-network perspective represents one of the most developed theoretical approaches (e.g., Latour, 1987). The concept of ‘actor-network’ draws attention to the fact that actors do not exist without the network of relationships they create in the course of their social existence, and which define who they are and how they function (Coombs & al., 1996, p. 2-5). The fact that links with all kinds of actors – individuals, institutions and non-humans such as samples of biological material – are treated in a similar way tends to ignore the roles (and constraints) of institutional actors as participants in certain work practices with specific divisions of labor and tasks.

[9] I do not include here the research around *uncertainty* in innovation discussed in the seminal article by Kline and Rosenberg (1986). Innovation is indeed known to be complex, uncertain, somewhat disorderly, and subject to changes of many sorts (ibid. p. 275). My view is of the producer-user relationship within (a certain critical phase of) the innovation process. Von Hippel briefly discusses the possible manufacturer-as-innovator bias that exists in the links that a manufacturer establishes with product users (von Hippel, 1988, pp. 118-119). He has not, however, further elaborated on, or studied empirically, the effects of such bias.

layman as a user of new appliances and information systems, or to product developers at user sites. These questions were addressed during the 1980s and 1990s, particularly in the field of systems design, in studies which applied contextual and ethnographic methods (Winograd & Flores, 1986; Blomberg & al., 1993). Research that has explored *difficulties* in the relationship between users and designers can be grouped into three general categories: (1) analyses of power relations and politics, (2) studies of the fit of technology with organizational processes, and (3) analyses of the need for mutual learning and negotiated/shared meaning (Weedman, 1998). Wagner (1997) has also discussed "disagreements" that frequently develop in multidisciplinary projects of systems design.

Power relations have been analyzed in terms of resource dependencies. Actors gain or lose power as a result of the design decisions. Rational explanations could be seen as tools used to legitimize the hidden motives of seeking and maintaining power and pursuing self-interest.

Although politics and conflicts of interest are important, the critical factor is more often inadequate understanding of the organizational realities of the use situation. Failure to anticipate or address *social and organizational settings* within which the system will be used often result in resistance, suspicion or resentment. To prevent such problems, the participatory design approach[10] has emphasized the need to educate users about the design process and to include them more extensively and at earlier stages, in contrast to approaches where the emphasis has been on educating the designers about the users (Weedman, 1998, 317-318).

Of special interest for the present study was the category of difficulties in user-designer cooperation which focuses on *learning and the negotiation of meaning*, identifying ways in which problems arise out of an incomplete understanding of the perspectives of the various parties. For instance, Wagner (1997) suggests analyzing the "norms" of the participating disciplines - the role of theory building, empirical grounding, heuristics and aesthetics – for understanding the conditions for creating a shared working culture in multidisciplinary design. Grudin (1991) pointed out that computer scientists' understanding of what makes a program valid very much depends on their conceptions of what the program is, and there is a variety of legitimate standpoints. Suchman (1994, p. 27) referred to "fake collectivity", a problematic assumption of a shared reality and logic in design. "De-realization", typical in design, is the maintenance of an environment (a lab, a computer screen) that provides distance from practicalities that must eventually be faced as the products are exported beyond their local sites (p. 28).

A prominent example is the analysis of the different perspectives of designers and users in the case of the implementation of "Postal Buddy", a stand-alone kiosk for postal services (Engeström & Escalante, 1996). The obvious difficulties and resistance of users in using the device were not recognized and taken seriously by the designers and management during the development and implementation process. The

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[10] Scandinavian approaches to participatory design arose out of labor dissatisfaction with the automation efforts of the 1970s, as unions demanded workers' involvement in the technology planning process in the belief that workers have the right to influence their own workplace (Ehn, 1993). Concerns with the fit between technology and its organizational context have been emphasized in participatory design literature (e.g., Schuler & Namioka, 1993).

researchers concluded that the designers did not perceive Postal Buddy as a mundane tool to be integrated in the context of local postal services of various kinds, but, rather, as an object of affection. Recent evaluative study of user involvement in R&D also suggest that developers often do not see user problems and needs even if the information is ready and available (den Hertog & al., 1996).

Errors, and misunderstanding in user-designer collaboration, when recognized, could also be seen as positive potential, forcing the participants to reflect on their roles and perspectives and to further develop their mutual understanding about the project (e.g., Seifert & Hutchins, 1992; Mogensen & Shapiro, 1998; Engeström, 1999; Hartswood & Procter, 2000). Engeström (1999) has suggested that troubles and breakdowns in everyday work activities can be seen as signaling more underlying, systemic tensions in work activity, and that they can be deliberately used in interventions targeted to develop work practices.

Different technological frames have been described as collective cognitions, held by individuals occupying different organizational positions, that explain and guide decision making and lead to incompatible actions around the technology (Orlikowski and Gash, 1994). Weedman (1998, p. 316, 337)[11] goes further and suggests that there is an inherent misalignment of incentive in the user-designer relationship. Research on user-designer collaboration has generally not questioned the incentives for participation in design. Recommendations for a collaborative approach assume symmetry of initiative: the user's need for a new or improved tool complements the designer's need for a tool to create. The incentive structure that underlies the relationship is, in fact, inherently asymmetric and unstable. At its simplest, the designers' incentive to build the best technical system possible is not well aligned with the incentive for users to move their work directly forward. Participation in the design process is not the same kind of work for the two parties, neither are the kinds of work inherently complementary.

Weedman (1998, p. 338, 340) suggests that certain dimensions of user-designer communication need to be addressed more explicitly. Requirements analysis has received attention in social studies of design because it is both critical and difficult. At this stage, participants who have agreed in principle to collaborate must first negotiate concrete, instantiated meanings for their joint work. However, structural integrity in the incentive systems of application-oriented research collaboration among designers and users does not arise out of the pre-existing motivations of the participants; it must be created. Suchman (1994, p 25) makes the same argument by pointing out that the development of useful systems must be boundary-crossing activity between different partial knowledges. According to Bodker and Gronbaek (1998, 156), cooperation between users and designers is an "interaction between two groups of subjects who from the outset possess different kinds of instruments and work toward different kinds of objectives aimed at different purposes." They argue, however, that in designing

[11] Weedman (1998) studied the incentives, and specifically, the costs in the user-designer relationship, drawing on a case study by Sequoia 2000, a multimillion-dollar collaboration between computer scientists and global-change researchers. Although she does not use the concept of perspective in her analysis, the result and interpretation seem to be targeted more broadly than the term incentive presupposes. The data consisted of questionnaires to project participants, participant observation in project seminars and retreats, and interviews and site visits. The analysis of incentives to participate was based on questionnaires. The study does not analyze actual interaction between designers and users.

computer support, new objects, tailored to the user's needs, have to be temporarily shared between the groups. They call for a more comprehensive understanding and development of the means to enable designers to deal with the object of design as an object for a shared purpose. In this study, I hope to contribute to this goal.

The producer-user relationship in transition: understanding the possibilities and problems of producer-user interaction

Studies on the significant role of users, and on producer-user interaction and networks, offer interesting insights and point out relevant problems for innovation research and management, but they do not seem to provide analytical means that are sensitive and contextual enough for exploring the *evolving, interactive processes within innovation and actual use*. From this specific perspective, the view of current literature on innovation and technology management is partially limited and also somewhat problematic. It could be problematic to consider producers' and users' roles and their mutual relationship as taken-for-granted transaction independent of time and place, in which information (e.g., about user needs or solutions) and resources of various kinds are transferred between parties for a (equally taken-for-granted) shared *object* and *motive*. Hence, it could be equally problematic to assume that mutual learning automatically takes place in the relationship, and that it is a frequent and evident characteristic of every producer-user interaction.

Implicit assumptions of learning as an evident by-product of various activities are still present in most studies on innovation and technology management. These studies have not focused specifically on learning, although it is present as a latent opportunity. Studies in other related areas such as systems design have explicitly addressed learning and the inherent constraints of collaborative relations in design. A few studies also focus on real-use settings and contexts of the work in which interactions take place (e.g. Bødker & Gronbæk, 1998; Suchman, 1998; Robertson, 1998; Viller & Somerville, 2000; also Akrich, 1992). However, there seems to be lack of studies addressing the transition and transformation of the developers' and users' roles, and their mutual relationship during a longitudinal development process.

Recent studies applying the activity-theoretical framework have developed the means to analyze transformations and complex interaction in concrete work practices (Y. Engeström, 1998, 1999, 2000; R. Engeström, 1999a, 1999b; Y. Engeström & Escalante, 1996). These studies have also focused on everyday interaction and learning between providers of the service or product and their clients, such as, judges and clients in courts of law, and doctors and patients in health care. The researchers describe transformations of work practice and interaction as an "invisible battleground", a terrain of constant ambivalence, struggle and surprise which sometimes leads to expansive reorganization and qualitative change (Engeström, 1999, p. 90). They have analyzed disturbances, ruptures, and often unremarkable small initiatives and solutions in practitioners' everyday work actions, and reported on misscommunication patterns in interaction between providers and users of services. They have found that interaction and collaborative relations are both historically embedded and situationally emergent. Yet, the transitional relationships are not determined by conflict only. Rather, they should be considered an opportunity for mutual reconstruction. For Engeström, "negations are essential ingredients and energy sources in an expansive process, not mistakes or anomalies to be eliminated" (Engeström, 1999, p. 91).

The activity-theoretical ideas and analytical means used in these analyses also inspired the four analyses (articles) that constitute the present study. The dimensions of time and development applied in activity-theoretical studies offer analytical resources which could also be applied to the study of innovation trajectory and to a specific developmental phase within it. These theoretical and methodological solutions, based on activity theory, are discussed, together with the empirical findings of the four analyses, in section 5.

At this point, based on the theoretical discussion referred to above, I will formulate my suggestion for understanding the complexity of producer-user relationships as follows.

I will argue that the lack of interaction, and also misscommunication, in collaborative relations is a regular and common feature in producer-user relationships, hindering collaboration and mutual learning. However, hindrances and problems in interaction should not be seen as something inevitable and taken for granted, or as something to be escaped from and denied immediately. Rather, they can be seen and diagnosed as signalling potentially broader, more underlying problems in the relationship and in the innovation process, calling for new *collaboration*, *learning and change*. This is not, however, a matter that only concerns the developer and manufacturer organization and its management. I will argue that agency/incentive for learning and change should not be seen solely as a characteristic of top executives and high-ranking expert users (identified as lead users). All users in the user chain and at various organizational levels are potential learners and change agents.

I propose the following framework to promote understanding – and eventually the better management – of the complex dynamics of collaborative relations within the innovation process;

1. The roles of producers and users (and other parties) should be understood as historically emergent and both historically and situationally constructed heterogeneous standpoints, which provide/involve *different and specific perspectives on, as well as material and cultural resources for, the artifact (innovation) under construction*.

2. This, in turn, entails that the relationship between the developers and users of the innovation process is complementary, but also inherently constrained. One obvious constraint comes from the innovation (artifact) itself, which often has a different meaning and place in the developer's and the user's activity. From the activity-theoretical perspective, the developer/manufacturer typically perceives the artifact as an object of activity, whereas for the user, it is (at first a potential) tool. During the innovation process, the *meaning and place of the artifact changes – or need to be changed - from being the object of the developers towards being a tool for the users* (a critical transition). The ability of developers and users to discriminate between the tool and the object, and to play with their relationship, is a vital feature of an innovation network capable of re-mediation, learning and

change. I will suggest that reflective meta-cognition and communication are required among developers and users to achieve this.

3. Achieving/mastering this critical transition (which is assumed to be constitutive to the broadening of user networks and market creation) requires a *collaborative relationship*, primarily the *emergence of a shared object*, among the parties. This, in turn, presupposes that the developers may need - to some extent - to take the perspective of the users and engage themselves in the construction of their object, and not only "become informed" about it. The users may, to some extent, need to become involved in the construction of the developers' object, in other words, to participate in and take responsibility for the development of her or his own tool (the idea of co-construction). This also entails change in the other elements (rules, division of labor, other tools) of activity systems.

3 The problem of implementation

> *Until fairly recently it was fashionable to measure technology lag in terms of the time taken for an innovation to spread from its origin, implying that an innovation can be regarded simply as a technological module requiring only to be plugged in to other organizations, other economies and other cultures. (Stuart Mcdonald, 1983, p. 29)*

A growing focus on the introduction and implementation of new technologies as a matter of technology management and organization research evolved during the 1980s and 1990s (e.g., Rhodes & Wield, 1985: Burgelman & Maidique, 1988; Preece, 1989; Loveridge & Pitt, 1990; Dodgson & Rothwell, 1994). This was due to the growing impact of technology on business, and the growing prominence of technology as a strategic asset (e.g., Hamilton, 1997). In the present study, however, the emphasis on implementation is not on corporate strategic or economic issues (e.g., Hayes & Garvin, 1982; Pimrose, 1991), labour and workforce issues (e.g., Braverman, 1974; Rosenbrock, 1983; Adler, 1993), or on project management issues (e.g., Brooks, 1982; Holt, 1987; Schroeder, 1993). Of special interest here is (1) research on organizational arrangements and the deployment of expertise for implementation, and (2) how implementation processes have been understood and interpreted in the literature on innovation and technology management. The emphasis on these questions derives from the fact that the implementation of new technology typically involves at least the innovator/supplier organization and the adopter/user organization, and the living, evolving *relationship* between the two. My interest lies especially in how the adopter organization - and the participant roles in the organizations involved in the implementation - is understood and conceptualized.

How the implementation process is understood and interpreted is necessarily connected to the more challenging theoretical problem of the relationship between technology and the organization (Burns & Stalker, 1961; Woodward, 1965; Scarbrough & Corbet, 1992; also Barley, 1986). Much research on implementation has approached the *technology-structure relation* in terms of technology determining organization or vice versa. Traditionally, engineering perspectives have implied that organizations have little choice but to adapt their skills and work to the requirements of technology. The linear model of technological innovation also reflects the determinists' sense of technological "necessity" by welding science, technology, markets and organizations together into an objective and interlocking causal chain (Scarbrough & Corbet, 1992, p. 4-7)[12]. Advocates of organizational choice, often associated with the mainstream management perspective, hold that, in any given context, the relationship between technology and organization is largely determined by the managerial intentions and values and organizational politics which characterize the organization (ibid.). However, it seems that the emergence of *implementation as a focal problem* in technology management and organization research is associated with the questioning of the dualistic views of technology and organization.

The emergence of implementation as a focal problem for industrial organization

Everett Rogers' classic studies on the diffusion of innovations placed implementation within the adoption process. This is the process that a potential customer goes through to reach the *decision* to adopt a new product. Rogers presented the adoption process as a series of stages including (1) knowledge, (2) persuasion, (3) decision, (4) implementation and (5) confirmation (Rogers, 1983, p. 164). Within these stages, he defines the agent of the adoption process as "an individual (or other decision-making unit)." Accordingly, "implementation occurs when an individual (or other decision-making unit) puts an innovation into use" (ibid. p. 164). Rogers' famous ideal-type classification into innovators, early adopters, early majority, late majority and laggards makes the point that not all individuals in a social system adopt an innovation at the same time (p. 241-250). Rather, they adopt in a time sequence, and they may be classified in adopter categories on the basis of when they first begin using a new idea.

This view assumes a linear sequence of stages and a primarily individual actor. Implementation is seen as one stage and "act" of a broader "innovation-decision" process, not as an independent process as such. The problem of the adopter organization is not emphasized. A linear and rather unproblematic view on innovation and implementation was typical of the multi-stage models of innovation and product development reviewed by Biemans (1992, p. 27-41). They typically fail to consider the actual stages and processes in the implementation of the new technologies *after* they are introduced (Slaughter, 1993, p. 82). Interestingly enough, studies on innovation and technology management have paid relatively little attention to implementation and related dramatic changes[13] in organizational and occupational roles. Pacey (1983, p. 6) pointed to this dilemma by suggesting that the definition of technology needs to be enlarged to include "'lifeware' as well as hardware; technology-practice is thus the application of scientific and other knowledge to

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[12] Scarbrough & Corbet (1992, p. 7) suggest that it is possible to accept the importance of these underlying activities of "innovation", "diffusion" and "implementation" without accepting the iron logic of linearity and determinism. The processes of invention, use and exchange can better be viewed not as abstract scientific and economic forces, but in terms of subjective actions and loosely-coupled forms of social organization. This is not to reduce technology to social relations *per se*, since this would neglect the transformational dimension which is one of the most important features of the innovation model. The technology process clearly transforms social relations and actions, not directly through physical constraints, but by the creation of perceived utilities which induce its adoption and use.

[13] Dramatic cultural and social consequences of the introduction of new technology in a native culture were described by Sharp as early as in the 1950s. The introduction of steel axes for stone-age Australians led to a revolutionary confusion of gender, age and kinship roles, with a major gain in independence and loss of subordination on the part of those (young men, women, even children) able to acquire steel axes when they had been unable to possess stone axes before (Sharp, 1952).

practical tasks by ordered systems that involve people and organizations, living things and machines."

A shift of focus from the innovating organization to the adopting organization

Empirical findings concerning problems and failures in the introduction of new technologies such as information systems and advanced manufacturing have directed attention to organizational *factors* and the complexities of implementation (Lucas, 1975; Keen, 1985; Bessant, 1985; Swanson, 1988; Fleck & White, 1987; Voss, 1988). Reviewing the evaluative results of the introduction and diffusion of computer-aided design, industrial robots, computer-based production management aids and flexible manufacturing systems all of which reported serious problems such as learning difficulties, reduced efficiency or delayed benefits of flexibility, Bessant (1985, p. 97-98) addressed the rapidly-escalating problems of adaptation. He noted that the reported problem issues emerged *after* the technology had been adopted by the organization. He advocated a shift of attention towards issues of implementation and adaptation rather than simple adoption, since the latter is just the start of a complex process. Achieving adoption to full-scale use, for instance full computer-integrated manufacturing, will depend on resolving a number of problem issues which include technical, economic and organizational factors, the "integration barrier" between present systems and the fully-integrated models of the future (ibid. p. 100).

Swanson (1988) defined implementation problems as problems in bridging the gap between the design of a system and its utilization. A puzzle metaphor was used to address the necessary relationships that must exist among the implementation factors. Among these were user involvement, management commitment, value basis, mutual understanding, design quality, performance level, project management, resource adequacy and situational stability. Success in information-system implementation was seen as a matter of establishing a fit among the factors. Responsibility for implementation was seen as falling upon a particular person or group within an organization, called an implementor. While none of the factors were entirely under the implementor's control, all were subject to that individual's influence (ibid. p. 11).

Identifying and classifying important organizational factors has been one direction in understanding the complexity of implementation. Voss (1988) elaborated on the need for a distinctive area of study, the management and adoption of inventions. He observed that the research on technological innovation has generally split into two separate areas, that of the study of the process of innovation, and that of the study of the diffusion and adoption of innovations. The latter starts with the first adoption of an innovation, and examines the subsequent spread (e.g., Rogers, 1983). The former assumes that the innovation process is completed when the innovation has been successfully developed (e.g. Utterback, 1971). Voss (1988) criticized the assumption that, once successfully developed, a new innovation will work in all subsequent uses. He also questioned the assumption in literature on diffusion that innovations always work as anticipated, and hence that implementation is always successful (ibid. p. 56). Evidence was presented that a process innovation could succeed in one attempt at adoption and fail in another. He underlined the fact that, unlike in innovation success, many of the activities and conditions that influence implementation success take place in the *adopting* organizations rather than in the innovating organization (original emphasis). He suggested that the study of implementation might more precisely be called the study of the process of the adoption of innovations. Implementation was defined as “the user process that leads to the successful adoption of an innovation of new technology” (ibid. p. 56,59).

The user’s significant role and various user processes in the development of medical-equipment innovations have been pointed out by Shaw (1985; 1994) and Biemans (1992). The introduction of new medical devices necessarily needs clinical assessment and trial, and state-of-the-art clinical and diagnostic knowledge resides in the user (Shaw, 1985, p. 283). Collaborative relationships between developers and users in these settings become important, but may also be complex. The testing of prototypes, clinical evaluation, and the development of crucial application knowledge driven by clinical users, are often closely connected to or embedded in the actual implementation and launching of the medical-equipment innovation (Biemans, 1992, p. 182-189). Biemans found that the manufacturer-user relationships in the context of testing newly-developed prototypes frequently displayed symptoms of ossification. Once relationships are established and strengthened by good personal contacts, they tend to function during a number of successive development projects. He observed that long-term relationships were established with a limited number of physicians in which the very existence of the relationship, rather than the characteristics of the project, determined the co-operation. He concluded that a well-functioning personal relationship is, as such, no guarantee of good results (ibid. p. 189; also Dodgson, 1993).

Product champions characterizing successful implementation

From hero to a champion in a variety of roles

Although the significance of the entrepreneur has been recognized for at least two centuries (see e.g., Shumpeter, 1975), the critical role that “champions” of technological change play within industrial organizations has been recognized only during the last four decades. In a seminal study of radical military innovations, Schon (1963) observed that certain committed individuals, champions, played the key role in successful innovation. To Schon, “product champions” are critical, for

> “no ordinary involvement with a new idea provides the energy required to cope with the indifference and resistance that major technical change provokes…champions of new inventions…display persistence and courage of heroic quality.” (Schon, 1963, p. 84)

To overcome the inner resistance to innovation, someone within the organization has to feel strongly committed to the new product. According to Schon, one person typically emerges as a champion of the new idea (ibid.).

In the decade following Schon’s work, several new entrepreneurial and related roles, and new names for old roles, appeared in the innovation literature, such as “business innovators”, “internal entrepreneurs”, “sponsors”, “change agents”, “technical and manager champions” and “administrative entrepreneurs” (see Maidique, 1980). In more recent literature, the product-champion role is also associated with heroic or extreme qualities. Product champions are characterized by energy, passion, idealism, pragmatism, cunning, towering impatience, an unrealistic unwillingness to allow any barrier to set them back, and love-hate relationships among their subordinates (Peters, 1987, p. 248). To accentuate their strong commitment to the innovation, they have also been called “crusaders” (Davidow, 1986, p. 150).

Chakrabarti (1974, p. 59) compared forty-five cases of new industrial products and found a strong correlation between the presence of a product champion and the eventual success of the new product. The importance of product champions has also been demonstrated by Rubenstein & al. (1976, p. 18), who reported that in the majority of the projects studied, certain individuals had often played informal roles in their initiation, progress and outcome. Ettlie (1986) showed that the most important factor in the successful implementation of advanced industrial products was the supplier-user relationship, while the existence of a product champion in the user organization was mentioned as a separate factor in explaining its success. Voss (1985) also found that the development and commercialization stages actually often had separate champions.

One of the first studies that attempted both to quantify the product champion function and to break it down into *sub-roles* was the SAPPHO study (Rothwell & al., 1974). Four categories of key individuals were defined: (1) *technical innovator*, the individual who made the major contribution on the technical side, (2) *business innovator*, the individual within the managerial structure who was responsible for the overall progress of the project, (3) *chief executive*, the head of the executive structure of the innovating organization, and (4) *product champion*, any individual who made a decisive contribution to the innovation by actively and enthusiastically promoting its progress through the critical stages (p. 291). In this study, the individual who emerged as the principal factor for success was not the product champion, but the business innovator. In particular, the business innovator’s power, respectability, status and experience were important. The study indicated that, besides commitment and enthusiasm, the power and status of the sponsoring executive also play an important role in determining the success of an innovation.

Leonard-Barton & Kraus (1985, 107) included in the “implementation team” (1) a *sponsor*, a high-level person who makes sure that the project receives resources and who is wise about the politics of the organization, (2) a *champion*, who is salesperson, diplomat, and problem solver, (3) a *project manager* for administrative details, and (4) an *integrator*, who manages conflicting priorities and molds the group with his or her communication skills. According to the authors, more than one person may fulfill a given function, and one individual may take on more than a single role. However, one of these individuals, usually the sponsor or the champion, must have enough organizational power to mobilize resources, and that power base must encompass both technology developers and users (ibid. p. 197). More recently, drawing on the history of Silicon Valley, Kaplan (1999) has described the significance of two partners with complementary expertise and enthusiasm forming an entrepreneurial endeavor for developing new technology and business.

Maidique (1980) reviewed the literature on champions and observed that what was written on entrepreneurs and champions was primarily concerned with static behavior, while substantial literature existed on corporate development. He hypothesized that some major transformations in managerial relationships, that is, in entrepreneurial and champion roles, might be expected as corporate evolution progressed from the small, entrepreneurial firm toward integrated and diversified companies. According to him, studies of corporate development did not cover transformations in managerial relationships, although they did suggest that management had a critical role in causing the [corporate-development] process to evolve, and in readying it for technological innovation. Using secondary-interview and case-description data from a few spin-off firms and large industrial corporations, Maidique described change in entrepreneurial roles. For instance, the phase of the integrated firm was marked by the entrepreneur's decreasing product-definition role. He also discussed the risks of the pioneer technological entrepreneur's dual role of sponsoring executive and product-definition agent as the firm progresses from the small firm towards a more integrated firm. He concluded that radical innovation requires a *combination* of entrepreneurial, managerial, and technological roles within a firm. As the firm grows and changes, these roles also *change* (ibid. p. 59).

Limits of product-champion roles in implementation

Maidique (1980) discussed champion roles within the firm and considered them mainly individual and powerful managerial positions. Kivisaari (1992, p. 22) noted that Maidique perceived change in entrepreneurial roles through general, broad organizational life cycles. Time in the sense of specific historical periods was absent. Implementation, however, involves specific inter-organizational relationships in which the installation and application of the new product often require interaction between manufacturers and users, and between various sub-units of the adopting organization (Shaw, 1985; Preece, 1989; Biemans, 1992; Fincham & al., 1995). Implementation does not end with the technical installation, as Voss (1988) pointed out, but continues as a user and adoption process in which various organizational groups become involved.

The discussion on champion roles does not emphasize the obvious *communication and interface functions* in adoption processes. "Technological gatekeepers" refer to individuals whose role is to search for and disseminate useful information (Allen, 1977). "Boundary spanning," derived from the social psychology of learning (Michael, 1973), refers more directly to communication and collaboration functions in organizations. Boundary spanners generate, carry and feed back information, and are argued to be essential elements in effective organizations. Their functions include "scanning, stimulating data-generating activity, monitoring, evaluating data relevance, transmitting information, and facilitating interpersonal intercourse" (Michael, 1973, p. 240; also Leonard, 1998). The individual's communication paths across organizational boundaries may constitute opportunities for learning and the creation of trust (Dodgson, 1993).

It is possible that the "broker function" of product-champion roles and the interface function of boundary-spanner roles are not distinguished when it is the role of the key individuals in the innovation processes that is under scrutiny. Interesting problems for empirical research may also include questions on how champion and boundary-spanner roles emerge, evolve and transform within and between organizations over time, and also what constitutes the constraints of these roles. How many functions can an individual champion actually integrate? How far can an individual champion or boundary spanner take an innovation?

Interestingly enough, limitations and constraints of *individual* roles in product-champion and interface functions have not been given much attention in management and organization literature. Management executives' stories of successful projects have been well represented in mainstream management textbooks. A few recent exceptions have underlined management-systems dynamics between core capabilities and core rigidities (Leonard-Barton, 1992), "distributed" rather than "distinctive core" competencies (Granstrand, Patel & Pavitt, 1997), and the ill-defined boundaries of designing contexts (Bucciarelli, 1994), but they have not traced the inner dynamics of specific development processes and evolving participant roles on the micro level.

Cohen and Levinthal (1990, p. 132) argued that the firm's absorptive capacity, that is, its ability to recognize the value of new, external information, assimilate it and apply it to commercial ends, depends on the individuals who stand at the interface of either the firm and the external environment or between the sub-units within the firm. They found, however, that a "centralized gatekeeper" may not always provide an effective link to the anticipated environment. They argue that organizational absorptive capacity is a question not only of the gatekeeper's capabilities but also of the expertise of the individuals to whom the gatekeeper is transmitting the information. To Cohen and Levinthal, the "background knowledge" required by the group as a whole for communication with the gatekeeper highlights the point that "shared knowledge and expertise is essential for communication (ibid. p. 132-133)."

A growing focus on the adaptive processes of implementation

Ideas of "invisible hand-off" and mutual adaptation

As a key phenomenon in the overall development of technology, implementation has been distinguished from technical development and installation per se (Leonard-Barton & Kraus, 1985; Voss, 1988; Fincham & al., 1985; also Hyötyläinen, 1998). Implementation "involves the organization, its goals and strategies, and is the process through which technology is concretely deployed." It is "the process through which technical, organizational, and financial resources are configured to provide an efficiently operating system" (Fincham & al., 1995, 190).

How, then, have the key processes underlying successful implementation been described and interpreted? In their seminal paper about implementing new technology, Leonard-Barton and Kraus (1985) described the *process* of implementation as a hand-off from the developer or implementor to users in the subsequent organization. The process of adoption should have been designed as "almost invisible."

"The person responsible for implementation – whether located in the developing organization, the user organization, or in some intermediary position – has to design the hand-off so that it is almost invisible. That is, before the baton changes hands, the runners should have been running in parallel for a long time." (Leonard-Barton and Kraus (1985, 103)

This relatively simple and concrete idea of the "hand-off" was introduced because the authors had observed that the managers responsible for shepherding a technical innovation into routine use were frequently much better equipped through education and experience to guide that innovation's development than to manage its implementation (p. 102).

In a study of ten product-development projects, Leonard-Barton (1988) first observed that the project participants altered the technology and also adjusted the user environment in a process of mutual adaptation (also Leonard-Barton & Sinha, 1993). Based on these findings, she argued trenchantly that "implementation is innovation" (Leonard-Barton, 1988, p. 265). According to Leonard (1998, p. 104), *mutual adaptation* is the "reinvention of the technology to conform to the work environment and the simultaneous adaptation of the organization to use the new technical system" that occurs in small and large recursive spirals of change. The adaptive spirals involve both technological and organizational redesign, and vary in magnitude, depending on how fundamental is the change to be made in the implementation (ibid. p. 105).

Focusing on learning in implementation

Leonard-Barton (1988) referred to learning with reference to an example of a large cycle of adaptation. She observed that "although the developers did go 'back to the drawing boards' to select a new technology, the problem they sought to solve was much better understood and structured because of the failed first attempt" (p. 261).

More recently, Slaughter (1993) and Fleck (1994) discussed learning processes within implementation. By drawing on the "learning-by-doing" and "learning-by-using" approach[14], Slaughter (1993) studied the implementation of new technology (stressed-skin panelling) in the construction industry and found that users (builders) who had "relevant experience build upon their acquired learning to create innovations which differ significantly from those produced by manufacturers." She suggested that learning-by-doing and user innovation during implementation could be viewed "as an iterative process that can push forward the development of a technology" (p. 83). She observed how manufacturers perceived user innovations as "specialized applications, or custom orders rather than as significant new product developments" (p. 91). Manufacturers also seemed to rely upon the builders to solve the problems in the implementation process, depending on their learning and problem-solving abilities to develop the technology further. Slaughter, however, pointed to the disadvantages for the development of the technology and its market, since "the learning and problem-

[14] Economists have made reference to learning in firms. Arrow (1962) referred to "learning –by-doing" as the way unit costs reduce over time or with experience (the industrial learning-curve phenomenon). Rosenberg (1982) referred to "learning-by-using" as the way firms improve performance by eliciting feedback on product and process performance (incremental improvements in the course of using technology). The relation between innovation and learning has emerged as a key issue in the context of evolutionary theories of technological change. Nelson and Winter (1977) referred to learning largely as being about incremental improvements in technological regimes. Concepts such as the "learning curve" are also common in the management studies. For instance, Maidique and Zirger (1985) discussed the product-development learning cycle, and Adler (1990) analyzed how learning in production transfers from one plant to another. For Slaughther (1993) and Fleck (1994), learning in the context of implementation was viewed not as a factor in improving productivity, but as "activities in achieving the user's final objectives" (Slaughter, 1993, p. 83).

solving are scattered, and the technical development between the manufacturers and each user may be distinct and unconnected" (p. 92) (also Green, 1992).

Fleck (1994) studied the implementation of the computer-aided production management system (CAPM), which he defined as "configurational technology", built up to meet specific organizational requirements. He suggested that a "distinctive form of learning by 'struggling to get it to work', or 'learning by trying'" constitutes a basic mechanism through which implementation is achieved and the potential for innovation opened up (p. 637). Implementation was seen as "the key process through which CAPM was evolving." It is not the case of the technology being unproblematically available, but rather that new developments are being forged during implementation within user organizations. Fleck emphasized the crucial role of people inside the user firm, and of the organizational structures within which they operate (p. 640).

Types of knowledge in implementation

Research on innovation has shown that external inputs are critical for success (e.g., Rothwell & al., 1974). Industrial companies are believed increasingly to be developing external linkages and networks with other organizations to reduce technological and market uncertainty (e.g., Freeman, 1990).

The ability to exploit *external knowledge* (Cohen & Levinthal, 1990), and to import and absorb technological knowledge from outside of the firm (Leonard, 1998)[15] are thus seen as critical components of innovative capabilities on the organizational level. Cohen & Levinthal (1990, p. 128) argued that the firm's absorptive capacity, its ability to evaluate and utilize outside knowledge, is largely a function of the level of prior related knowledge. For the authors, *prior knowledge* includes basic skills or shared language, and knowledge of the scientific and technological developments. This "prior related knowledge" confers an ability to recognize the value of new information, assimilate it, and apply it for commercial ends (ibid. p. 128).

Cohen and Levinthal (1990) reason that, although an organization's absorptive capacity will depend on the absorptive capacities of its individual members, it is not simply the sum of the absorptive capacities of its employees. For the organization, such capacity refers not only to the acquisition or assimilation of information, but also to its ability to exploit it. It therefore depends on "transfers of knowledge across and within sub-units that may be quite removed from the original point of entry" (Cohen

[15] "Knowledge management" literature has arisen at the interface of innovation research and management research (e.g., Nonaka, 1994; Nonaka & Takeuchi, 1995). Nonaka developed a model of the various ways in which organizations create knowledge. The focus is on managing the firm's interactions between the different "modes of knowledge conversion". Leonard's interest is in the "key knowledge-building" activities – shared problem solving, implementing and integrating new technical processes and tools, experimenting and prototyping, and importing and absorbing technological and market knowledge. Coombs and Hull (1998) compared the evolutionary-economics perspective and what they call the "knowledge-centered-model of the enterprise." They observed that the Nonaka/Leonard perspective emphasizes the potential openness of the firm to the acquisition of external knowledge and the possibility for it to increase its potential to create radically new knowledge. In contrast, the evolutionary-economics perspective emphasizes the way in which the knowledge base of a firm and its routines reinforce path-dependency and limit the rate of integration of external knowledge and the production of new knowledge.

& Levinthal, 1990, p. 131-132). Although Slaughter (1993) did not explicitly discuss *knowledge transfers* in the context of implementation, her idea about learning with a view to "achieving the user's final objectives" would require knowledge about those objectives, and the transfer and exploitation of that knowledge across manufacturer and user organizations.

While both *internal communication* and the ability of the sub-unit to assimilate and exploit information from other sub-units are necessary for effective organizational learning, excessive dominance by one or the other will be dysfunctional (Cohen & Levinthal, 1990, p. 133). An internal language, coding scheme, or any particular body of expertise could become sufficiently overlapping and specialized in that it impedes the incorporation of outside knowledge. Morgan (1986) described how departmental structures focus the attention of their members on parochial rather than organization-wide problems, and how there is a gap between actors' rationalized statements of what they do and what actually occurs. Dodgson (1993, p. 91) noted that organizations' strategic decision making tends to reflect past histories, and to be based upon existing technologies and capabilities. Both Slaughter (1993) and Fleck (1994), in the context of implementation, mentioned dysfunctional communication or information asymmetry, but they did not elaborate on the origin and emergence of this asymmetry.

Fleck (1994) found that the configurational-development-process implies a great amount of implementation effort within the user organization. He (p. 641) suggested that generic technology knowledge and *local practical knowledge* are essential inputs of expertise in successful implementation. The local practical-knowledge component covers day-to-day activities, and it is tacitly embodied in skills and practices which have been gradually performed over a period, not (yet) available in a centralized or formalized form. In such cases, "users constitute the only available repository of the local knowledge component which might be essential for achieving successful implementation" (ibid. p. 642). Hence, the local knowledge element becomes a crucial source of innovation. Fleck describes the two-way process of knowledge transfer.

"Over a number of successful instances of implementation, local knowledge becomes gradually absorbed into generic knowledge; i.e. firm specific knowledge becomes appropriated by suppliers. At the same time, existing generic technology knowledge becomes implemented in a form suitable for exploitation by the user." (Fleck, 1994, p. 642)

Fleck concluded that the value of the local knowledge held by users should be recognized as crucial for successful implementation, not least by the users themselves (ibid. p. 650). He attempted to distinguish his findings about learning-by-trying from the notion of "incremental improvements." In the case study, the organizations struggled to get to the state of actual use which, however, was never achieved. Fleck referred to a "more fundamental process of learning, much more like the trial and error nature of genuine experimentation" (p. 648).

Eisenhardt and Tabrizi (1995) discussed the firm's growing need to accelerate product innovation through fast adaptation. They take a more dynamic view on innovation and knowledge. Drawing on the classic distinction of organizational thinking (e.g., Burns & Stalker, 1961) between *situations* that can be described as certain, predictable, well-understood or routine, and those that are characterized as unpredictable, intractable or uncertain, the authors distinguished two ways of theorizing on fast product development. The compression strategy assumes that product development is a predictable series of steps that can be compressed, and acceleration involves planning these steps. An alternative view, the "experiential strategy", assumes that acceleration involves rapidly building intuition and flexible options so as to cope with an unclear and changing environment (ibid. p. 87-88). The experiential view simultaneously involves providing enough structure so that people will concentrate on sensemaking, avoid procrastination, and be confident enough to act in these highly uncertain situations, which easily lead to paralyzing anxiety and conflict (p. 88). According to the authors, both compression and experiential strategies accelerate product development. To the extent that product development is a predictable path through well-known markets and technologies, then the compression strategy is relevant. If the path is more uncertain, then an experiential strategy is preferable.

Strategies for managing implementation have also focused of the careful planning of pre-implementation activities, and on mastering the stages of implementation through planning (Voss, 1994). Although Fleck (1994) does not further elaborate on the situational and organizational characteristics of implementation, his description of about the type of learning required as "experimentation" has some resonance with Eisenhardt and Tabrizi's view of an experiential strategy for fast adaptation in product innovation.

Towards more contextual and complex interpretations of implementation

Literature on implementation and related innovative activities has mainly focused on the exploitation of external knowledge, and has addressed knowledge resources or "location" of information (who knows what, for example). Powerful entrepreneurial or managerial roles such as product champions and gatekeepers are seen as crucial for innovation and implementation. Although there were some mentions about differences in perceptions between manufacturers and users, possible asymmetry of relations in terms of differences in motives, perspectives or power were not further elaborated upon. The mutuality of the "implementation endeavor" among participant groups was not gone into either. Implementation is rather assumed to be invisible and to involve *unproblematic* learning processes. Learning is seen as adaptation (gradual or rapid) to the environment, or as an evident by-product of activities (learning-by-doing/using). Seldom is it specified who learns, what is being learnt, or what is *not* learnt.

Recently, however, more complex interpretations of the development and introduction processes involved in an innovation have been introduced by a number of researchers on innovation and technology management (Rip, 1995; Fleck, 1997; Millar, Demaid & Quintas, 1997; Pitt & Clarke, 1999; also Blackler, 1995; Williams, Faulkner & Fleck, 1998). Although these studies do not apply the frameworks to empirical cases, they do provide some interesting insights for the present study. Fleck (1997) addressed the significance of knowledge embodied in the *working contexts* of implementation, that is, local, application-specific "contingent knowledge." The emergence of a *collective structure or agency* in terms of a "macro-actor" (Rip, 1995), and "collaborative knowledge interchange and learning" (Millar, Demaid & Quintas, 1997) have been emphasized. Pitt and Clarke (1999) discussed the "attention problem” in collective learning, and introduced the “*direction-of-innovation domain*” in addition to traditional substantial knowledge domains.

According to Fleck (1997, p. 390), contingent knowledge is “distributed, apparently trivial, highly specific to the particular application domain, and, consequently, accidental to the general process of technology development,” and “often overlooked or under-valued.” He argues that the process of successful technology development often depends critically upon the incorporation of contingent knowledge. Such knowledge, however, is not within the immediate power of the developer, but within the *context of implementation* typically “owned by the user” (p. 394). Fleck concludes that there is a need to appreciate the apparently trivial and distributed nature of contingent knowledge which “may be found in the hands or minds of anyone in the organization, not just the technical specialists” (also Blackler, 1995). Although Fleck observes that “not everyone’s contingent knowledge is equally recognized… or acted upon”, he does not elaborate upon the crucial question of *how* critical contingent knowledge/expertise can be perceived as relevant, or how it is transferred from its very local origins to the broader contexts and communities.

Building on insights from sociology and the economics of technology, Rip (1995, p. 423) argues that technologies are always composite: beside artefacts exist maintenance and user services, for example. The whole package should be in order, that is, internally and externally aligned (mutually adjusted). The notion of *alignment* - as an activity and as a goal to be reached – should replace the ideology of letting the market decide about the fate of the new technology (see also Bijker, 1999). Alignment activities need not be limited to the introducer, however, as the simple distinction between producers, markets and regulating agencies is increasingly becoming mixed in relation to new technology (ibid.). Rip (p. 426) argues that “there must be a macro-actor to realize the necessary alignment, and if there is no existing body (organization, agency) to fulfil such a role, a macro actor should be constructed.” There is a need for local and regional actors as well as for actors involved in technology-oriented alignment. He observes, however, that the “actual processes of constructing such macro-actors, in such a way that alignment is furthered, has not come in for much analysis.”

According to Millar, Demaid and Quintas (1997), *negotiation*, the communicative basis of the product-design process, is responsible for transforming the evolving designed form and function of a product through to the market and beyond. Knowledge, however, “is differently implicit to its audiences, depending on their own particular heritage” (p. 407). Despite this observation, the authors do not analyze or concretize an actual negotiation process or the different participant roles within the innovation development. Therefore, the actual collaborative negotiation, and the opportunities or difficulties of “transformation”, remain obscure and a subject for empirical research.

Drawing on the resource-based strategy paradigm, Pitt and Clarke (1999) discuss the strategic management of innovative activity as purposive attempts to orchestrate knowledge development and its application in the firm. Orchestration implies “assembling and co-ordinating the performance of human and instrumental resources.” In addition to the entrepreneurial decision domain and the engineering domain, they define a “direction of innovation domain” (p. 306-307). This is hypothesized to generate responsibility over long-term development, and to guide activities such as issue framing and agenda forming. They question the model of the orchestral conductor, a leadership role implying a manager's instincts for control and intentional direction setting. They recognized the emergent, ecologically-driven nature of organizational learning in which leadership is distributed (p. 312). In this particular kind of learning cycle, it is more difficult, if not impossible, for any one person to control collective learning.

Blackler (1995) suggests an activity-system perspective to explore the development, application and extension of knowledge in *specified contexts*. Pitt and Clarke (1999) also refer to this perspective as they argue that there is a significant distinction between *awareness* of particular knowledge content and its transformation into *active knowing*, manifest in directed, collective endeavor (the authors' emphasis). They refer to it as an attention problem and question how learning cycles can be proactively orchestrated for strategic benefit. I hope to further elaborate upon this problem in this study.

Implementation as a collective endeavor involving developmental transitions

Although organizational change has been a major object of research in studies of organization and management, situational variety and organizational transition within the adoption of new technology has been elaborated upon amazingly little. Put simply, the current view of implementation based on the notions of *invisibility, individuality and adaptivity* also seems to include (implicit) situational and organizational stability. Technological complexity is assumed as a major source, although not the only constraining implementation. I will argue that this is a rather limited view, and I suggest that a more complex interpretation of adoption processes needs to be developed.

The implementation of a new artifact could be seen as a form of change within the adopter organization, altering its occupational structure and local work practices. Barley (1986) showed how the introduction of CT scanners challenged traditional role relations among radiologists and radiological technologists. By studying two different hospital settings using the same technology, he showed that technical uncertainty and complexity are social constructions that vary from setting to setting even when identical technologies are deployed (p. 106).

Implementation and adoption processes typically are accompanied by simultaneous organizational changes, transitions, or crises. It is not only that the technology is under development and uncertain, but the adopter organizations are also living through developmental phases which often involve uncertainty and chaos. This aspect of adoption processes is seldom addressed or analyzed in detail in empirical studies.

Recently, in the context of firms reaching out to new markets, Eisenhardt and Brown (1998, 61) found to their surprise that "managing transitions, or the shifts from one activity to the next," were often neglected by managers. For most, *event pacing* constituted the familiar and natural order of things. By way of contrast to the reactive and often erratic strategy of event pacing, Eisenhardt and Brown defined *time pacing* as a regular, rhythmic and proactive strategy. Time pacing refers to creating new products or services, launching new businesses, or entering new markets. According to the authors, it includes two critical, but often neglected, processes that are essential in changing markets. The first is managing *transitions*, and the second is managing *rhythm*, or the pace at which companies change. They describe “common transitions” as a shift from one product-development project to the next, and entering and leaving markets, for example. They characterize transitions as “critical”, since “major transitions” are periods when companies are likely to stumble. Transitions involve a “large number of people, many of whom are not used to working with one another.” Because they “occur less frequently than other activities, managers have fewer opportunities to learn from experience.”

I will suggest that in the implementation and adoption of new technology, both the producer and user organizations and their key processes may be characterized in terms of *transition*. Besides re-developing current or designing new products, the producer firm may face the simultaneous challenge of moving from the prevailing market to new markets. The adopter organization, while moving from the testing or pilot phase toward more institutionalized adoption, may live in the middle of major organizational changes. Changes in organizations involve different schedules and priorities, in Eisenhardt and Brown’s terms, different rhythms. It could be argued that different organizational and context-related transitions and rhythms constitute a constraint environment for anticipated adoption into use, that is, the transfer of the innovation from developers to users. Transitions also constitute qualitatively new possibilities for organizations – if only recognized and properly managed - the point which Eisenhardt and Brown attempt to make. The “inter-organizational” process, a shift of the innovation from developers to users, could be seen as one locus of critical transition in the innovation process, taking place within and through implementation.

As sketched by Eisenhardt and Brown (1998), the characteristics of transition involving “shifts from one activity to the next,” and a proactive rather than a reactive strategy, could also be connected to adoption processes involving radically new products. The adoption of a new artifact may not be possible without major, intended changes in the work practices of the adopter community. Neither the challenges to organizations involved in the adoption nor the critical character of the transition, however, coincide with the current view of implementation characterized above in terms of invisibility, individuality and adaptivity. Rather, the characteristics of critical transition seem to suggest that adoption processes involve many people rather than individual champions, require “experimental learning” and improvisation rather than learning from past experience, and need to be addressed as critical rather than ignored by managers (see also Eisenhardt & Tabrizi, 1995).

Although the advocates of “transition management” (Eisenhardt & Brown, 1998) and crisis management (e.g., Pitt, 1990) emphasize organizational turbulence, they have not questioned the management’s central role and control. Hence, empirical studies have not been sensitive to specific situations and critical organizational transitions, or to how these emerge and evolve, and how they involve different sub-groups within organizations. A characteristic not fully recognized in these studies is that transition is always specific and unique to the particular organization and context, and cannot be mastered easily using standard managerial means. It could also be assumed that adoption processes in the middle of organizational transitions cannot always be “invisible”, smooth and solely adaptative.

Researchers applying cultural-historical activity theory have recently focused on specific organizational changes involving the design of new products or introducing of new concepts and models to particular work practices (Blackler, Crump & McDonald, 1999; Engeström, 1995; 1999; 2000a; Engeström & Escalante, 1996). These studies have demonstrated the significance of the historical perspective for understanding a specific organizational change or situation. Transitions involve not only shifts from one project to the next, but also *developmental transformations* from one historically-constructed phase of the activity to another. The studies emphasize the collective and systemic character of transformations, and the importance of contradictions and collective learning for achieving them. Developmental transformations are seen as attempts to reorganize, or re-mediate, the activity system in order to resolve its pressing contradictions (Engeström, 1999, p. 67). Activity-theoretical studies of work have focused on qualitative transformations, and have also made deliberate attempts to develop collective work practices, such as through the concrete visualization of “hidden” or emerging work activities (ibid.).

An activity-theoretical perspective on adoption processes

Activity-theoretical studies have reported on developmentally significant contradictions – and solutions by employees - of work activity in periods of intense change. People are not only affected by or required to adapt to changes. They initiate and seek new solutions, and actively make sense of the world they live in (Engeström, Y., Engeström, R. & Vähäaho, 1999). These actions may lead to a developmental process conceptualized as *expansion* or expansive development/learning (Engeström, 1987; 1999; 2000a).

According to Engeström (1999, p. 90), work activities undergo transformations which sometimes lead to expansive reorganization. Organizational transitions could be seen as invisible battlegrounds, a terrain of constant ambivalence, struggle and surprise. Engeström reported on a redesign process for medical work in which parts of the invisible battleground were deliberately made visible. During this process, the construction of the patient as an object of clinical work began to expand in significant ways. The author describes how “the formation of a new, expanded object is the basis for the formation of a new motive, which in turn is the foundation for opening up the developmental dimensions of work and eventually for achieving sustainable transformations” (Engeström, 1999, p. 91; Leont’ev, 1978). He also emphasizes that “negations” of the redesign process are essential ingredients and energy sources in an expansive process, and are not mistakes or anomalies to be eliminated. Hence, in situations that require innovative solutions, negotiation takes the form of improvisation and bricolage, namely, constructing solutions by means of ad hoc combinative tinkering with available imperfect resources and tools (Engeström, 2000a).

In the present study, findings concerning organizational transitions and developmental transformations have inspired further understanding of adoption processes. I suggest that, in many cases, implementation involves major developmental transitions within the producer organization and the adopter organization, *and* the transformation of the artifact or system being adopted by users. On the other hand, adoption processes are constrained by historically constructed and situationally complex challenges constantly going on within organizations, such as the struggle for economic growth, organizational survival and scientific credibility. Adoption processes are unique and specific – “contingent” - to every organization, and therefore highly complex and uncertain. They may be difficult to master using past experience, and may rather require improvisation and rapidly-building intuition. This does not imply that mastery and control should be ignored, but rather suggests that presumptions about managing adoption processes may need to be reconsidered.

Adoption processes are continuous and sequential, and involve various groups and individuals. Often, the artifact is first transferred from the developers to pioneer users, then from the pioneer users to user collectives, and finally diffused and internalized. In this process, knowledge and expertise have to be transferred from one organizational context to another, and also shared and collectively understood and interpreted within a given community or the “inter-organizational structure” involved in the adoption. Relevant knowledge may include recognizing the “direction” domain, the historically emergent path or phase of an activity along the innovation trajectory, and potential alternative directions. In this respect, the transitions that take place within the adopter organization during implementation and adoption are crucial and also of central importance for this research.

In the context of decision making, Engeström (2000a) attempted to demonstrate its *multi-dimensionality* within an activity involving several organizations. Potentially, shared activity is not automatically perceived in the same way by the participants. The emerging new activity, and the way it differs from the way the work is being done, or was in the past, may need to be concretized and deliberately constructed together with the parties involved. In order to help this joint visualization of work, and to monitor its change and possible new directions, Engeström introduced four dimensions of potential expansion of activity. Potential reformulation and reconsideration of changing work activity include, at least, contexts and locations, schedules and temporal structures, rules and hierarchical relations, and future development among related work communities.

On the basis of the theoretical ideas referred to above, I will now formulate my suggestion for interpreting adoption processes, and the new opportunities for collective learning that arise, as follows.

I propose that the transformation of the artifact from an introductory-type instrument to a viable, collectively-used tool cannot be understood solely in terms of mutual adaptation. It also needs to be analyzed as a qualitatively broader integration process in which *expansion* takes – or needs to take - place. This involves the emergence of a shared object of activity among those involved in the adoption. Accordingly, organizational transformation can hardly be the sole responsibility of an individual champion or sub-group. Rather, the transition of an innovation into collective use requires the emergence of collective responsibility and expertise through the visualization of work and reflective dialogue.

This notion of visualization and dimensions of expansion calls for a potentially new interpretation of adoption processes. The dimensions, as they were originally formulated, are meant to capture change in the entire activity system, and do not specifically cover the development or implementation of artifacts in the subsequent system. In order to further the discussion, I have therefore extended the concept by focusing specifically on the artifact.

I will suggest that adoption into use involves expansion of the user activity along the four *dimensions of potential expansion* in implementation. I also propose that this view constitutes an alternative to the more traditional view of adoption characterized above in terms of invisibility, individuality and adaptivity. It may be characterized in terms of deliberate visibility/transparency, collectivity and expansion. I therefore suggest that adoption into use involves the following considerations.

1. Instead of being regarded as an independent, isolated piece of technology (or operation), the artifact may need to be constructed as a tool *in its use contexts*. This includes other artifacts, as well as various organizational relations. (Social-spatial dimension)

2. Instead of being seen as a discrete, one-time project or endeavor, the implementation needs to be constructed as a *continuous, iterative process* involving various phases and levels of activity. (Anticipatory-temporal dimension)

3. Instead of each individual user being responsible just for a specific work task within the implementation, *all practitioners involved may need to take responsibility* for the entire implementation and adoption trajectory. This also implies the reconsideration of power relations: it is no longer automatically given that the highest-ranking specialist or the most experienced, advanced champion alone has absolute power and responsibility to determine the course of the implementation and adoption. (Moral-ideological dimension)

4. Actions are seen not only as influencing the given local context of implementation, but also as *shaping the broader development* of the technology and its adopter practices. (Systemic-developmental dimension).

4 The problem and significance of learning in the innovation process

> *Only the strongest incentives can lead an organization to effect deliberate change. For an organization to increase significantly its capacity for innovation, it is not enough that a man or a few men – even at the top – understand that it would be advantageous for the organization to change. Something like a state of crisis must arise. The organization must come to feel that its survival, or at any rate, its survival as it has been, is threatened. (Schon, 1967, p. 127)*

Learning has recently aroused new, growing interest in mainstream economics (e.g., Malerba, 1992; also Teece & Pisano, 1994), and in a variety of studies on innovation and technology management (e.g., von Hippel & Tyre, 1995; 1996; Pisano, 1996; Leonard-Barton, 1992; Dodgson, 1991b; 1996; also Cohen & Levinthal, 1990). It has emerged as a key issue in the systems-of-innovation approach (SI)[16] that has evolved

[16] The systems-of-innovation approach assumes that innovation processes involve evolutionary economic change over time, and that these processes are interactive and uncertain. A broad definition of SI is all the important factors that influence the development, diffusion and use of innovations,

during the last decade for the study of innovations as an endogenous part of the economy (e.g., Edquist & McKelvey, 2000; Lundvall, 1992).

Malerba (1992) developed a broader conceptualization of learning in firms than is common in standard economic models in which external macroeconomic factors are used to explain differences in company performance. He argued that firms learn in various ways, sometimes incrementally "by doing", but at other times (purposefully) by costly processes of search. These processes not only reduce average costs – as standard economics typically views the significance of learning[17] – but also generate potential new sources of technological advance by developing firm-specific knowledge bases. In the field of studies on management and organization, similar ideas but also a more complex view about organization-specific learning was developed by Leonard-Barton (1992), who showed how innovation within firms is related to routines that form part of the organizational culture. Changes in technology brought about by innovation will require changes in organizational routines which, in turn, may require changes in organizational culture. "Core competencies" can therefore become "core rigidities" if they prevent the firm from adapting to – learning – new markets.

Insights into learning as firm-specific, dynamic and interactive *processes* that can also go wrong are echoed in various ways in a few recent studies on innovation and technology management. These studies view learning as a key process within innovation processes (Lundvall, 1988; 1992), aim at conceptualizations of learning concerning technological and innovative activity (Dodgson, 1991b; 1996), or focus specifically on related activities such as problem identification and problem solving (von Hippel & Tyre, 1995; 1996; von Hippel, 1994; 1998). For this reason they are also of special interest for the present study. To the extent that they approach the actual institutional/organizational *processes and contexts* of learning, whether implicitly or explicitly, and open up questions such as *agency and outcomes*, they come close to the on-going transition within the theories of learning in which there has emerged a need to conceptualize the phenomenon from a social rather than only an individual psychological perspective[18].

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including the relations between them (Enquist & McKelvey, 2000, xi). This field of studies is broad and heterogeneous, however, and includes research on systems of innovation on the levels of nations, regions and sectors. The assumption is that when the parties involved in an innovation originate in the same national or regional environment, sharing its norms and culturally-based system of interpretation, interactive learning and innovation will be easier to develop.

[17] Dodgson (1991b, p. 110) refers to Bell and Scott-Kemmis's (1990) criticism that the "learning-by-doing" approach is fundamentally flawed as it assumes that learning is automatic and costless and that it ignores the continuance of technical change. For a review of learning discussed within studies on technical change and innovation, see Dodgson (1996).

[18] The theoretical perspective on the social nature of learning aroused growing interest within learning theories during the 1990s. One prominent research field within this new theorizing has centered around the notion of learning as situated participation in "communities of practice" (Lave & Wenger, 1991; Wenger, 1998). Research on distributed cognition is another prominent field which challenges individual cognition as the main locus of learning (e.g., Salomon, 1993; Hutchins, 1995). These ideas have recently been echoed in studies of organizational learning (e.g., Gherardi, Nicolini & Odella, 1998; Easterby-Smith, Snell & Gherardi, 1998). Learning that emerges in everyday life activities has also become of central interest (e.g., Lave, 1996). Learning associated with social practices has been central in cultural historical activity theory (e.g., Cole & Engeström, 1993; Engeström, Miettinen & Punamäki, 1999; Chaiklin, Hedegaard & Jensen, 1999). Practice-based approaches to innovation, knowledge and expertise inspired by activity theory have recently emerged (Blackler; 1995; Blackler, Crump & McDonald, 1999).

Describing the theoretical starting points of a developing framework for studying innovations, Lundvall (1992) placed *knowledge* and *interactive learning* at the center of the systems-of-innovation approach. Several innovation theorists had already argued that the model of the isolated, homogeneous, profit-maximizing firm was an inappropriate tool for interpreting certain important aspects of innovation processes (e.g., Nelson & Winter, 1977). The idea of interactive learning at the heart of the systems-of-innovation approach stresses interactions between users and producers in the production system, and this notion of interaction paved the way for a systemic approach. Lundvall's (1988; 1992) main point of departure was a critique of orthodox economic views that saw innovation as a process that takes place within firms in perfectly competitive markets, and where firms make decisions only on the basis of price signals. The argument against this view is that, in the learning economy, firms and other agents are involved more or less permanently in processes of interactive learning. This might involve exchange of knowledge between them, and even creating new knowledge in collaboration. Such interactive learning is seen as an important source of innovation (also Edquist & McKelsey, 2000). Various network approaches have a close affinity to these ideas of interactive learning in that they stress the importance of relationships for creating and transferring knowledge about technical and economic opportunities (e.g., Håkansson, 1987a; Biemans, 1992; Powell, Koput & Smith-Doerr, 1996).

For Lundvall (1992), learning is also a *socially embedded* process which cannot be understood without taking into account its institutional and cultural contexts. Interactive learning involves "collective entrepreneurship" (p. 9). Through introducing systems of innovation as analytical means, the approach aims at pursuing a trajectory from individual towards collective entrepreneurship. Lundvall further assumes that learning takes place in connection with routine activities in production, distribution and consumption, and gives important input to the process of innovation. He also stresses "the everyday experience of workers, production engineers, and sales representatives" influencing the agenda which directs innovative efforts, and producing knowledge and insights as "crucial inputs" (e.g., bottleneck problems). According to him, *institutions* provide agents and collectives with guide-posts for action. They may be "routines, guiding everyday actions in production..., but they may also be guide-posts for change" (p. 10).

The concepts of the social embeddedness of learning, collective entrepreneurship (collective agency of learning) and learning associated with everyday experiences and routines coincide with recent developments in conceptualizing learning from a social perspective. However, the discussion on mechanisms or underlying processes of learning does not further elaborate upon or bring new insights to the understanding of learning processes as presented by innovation theorists since the 1960s. Referring to the work of Arrow (1962) and Rosenberg (1982), Lundvall suggests that the everyday routine activities of innovation involve learning-by-doing, thus increasing the efficiency of production operations, and learning-by-using, thus increasing the efficiency of use of complex systems. He extends these different types of learning by adding *learning-by-interacting*, involving users and producers in such an interaction that results in product innovations (p. 9). Because these types or mechanisms of learning have not been discussed in the context of empirical data, characteristics such as agency, and possible constraints or actual outcomes of interactive learning, remain obscure. Although learning within the innovation process is strongly addressed, learning as a purposeful activity as such which can be enhanced to achieve institutional change is not emphasized. It seems that learning is still assumed as automatic, and it therefore remains like a "black box".[19]

Dodgson (1991b; 1993; 1996) studied technological collaboration, and especially learning, trust and inter-firm technological linkages, and extended the technological perspective towards an organizational and managerial view. Dodgson (1991b) argued that learning occurs through purposive activity, and does not occur automatically. Senge (1990) and Malerba (1992), among others, suggest that firms learn through purposefully adopting strategies and structures that encourage learning. Of importance in this process is the way they develop shared cultures that facilitate learning (e.g., Schein, 1985). According to Dodgson, learning can be seen to have occurred when organizations perform in changed and better ways, and when competences are better defined, more appropriate, and effectively implemented.

Dodgson (1991b) elaborated upon learning by differentiating its different aims and focuses. According to him, aims may be strategic or tactical. *Tactical learning* has an immediate problem-solving nature, the aim is identifiable, and the time-scale is short and prescribed. Improvement in innovative capability is project-specific. *Strategic learning* extends beyond the immediate issues and involves the development of skills and competences which provide the basis for future, often unforeseen, projects. Strategic learning attempts to maximize the returns from the opportunities that the innovation process provides. Dodgson noted that the strategic and tactical division is not synonymous with the idea of research as opposed to development, as both of these activities may be strategic or tactical in focus.[20]

Dodgson (1996) extends the notion of learning to include broader aspects of the firm's competitiveness, survival and (strategic) development in a changing environment. According to him, learning has to be seen in the context of the uncertainties facing firms, and the competitive imperatives and power relationships under which they operate. In a sense, learning is associated with future challenges, unforeseen problems and endeavors. Although Dodgson does not discuss this

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[19] Dodgson (1996, p. 55) also observed that economics literature is still chary of looking in the "black box" of the innovation process, and is primarily concerned with analysis of the external sources and outcomes of learning. It seems to me that the institutional perspective of the systems-of-innovation approach has not included analysis of organizational contexts or organizational praxis. This might be a problem considering Lundvall's interest in everyday activities. Within the approach, empirical studies have typically been based on quantitative methods and data, and macro-level or "meso"-level analyses (Edquist & McKelvey, 2000). For instance, Fagerberg's (1995) study on the positive impact of advanced domestic users on competitiveness, based on trade statistics of 16 countries, is discussed in the context of interaction and learning. In this study, learning is assumed to exist in the relation between users and producers, and described as a "high degree of integration" between them. Increasing learning is associated with increasing the stability of relationships and increasing the volume of transactions. Such an analysis does not describe the quality or development of relationships and learning.

[20] Dodgson (1991b, p. 111) relates tactical and strategic learning to Argyris and Schon's (1978) distinction between single-loop and double-loop learning and deutero-learning. Single-loop learning involves feedback into current decision-making practices so as to improve future decisions. Double-loop learning involves organizations questioning the whole basis of their decision-making practices and involves wholesale modification within the company. Deutero-learning examines the whole process of learning within the company, and can be viewed as "learning about learning". Tactical learning is equivalent to single-loop learning. Strategic learning includes both double-loop and deutero-learning.

developmental aspect explicitly, this view also requires collective agency in learning. He does not further elaborate upon its developmental and collective characteristics, however.

From strategies and institutions to local interaction at the production site

Learning-by-doing has also inspired researchers at the interface of the economics of innovation and management studies (Von Hippel & Tyre, 1995; 1996; also Pisano, 1996). The idea was the starting point for von Hippel and Tyre in their study of problem identification and problem solving during process machine use. The authors attempt to elaborate upon and further develop the concept in the context of micro-level empirical research. Rather than studying learning-by-doing as transferring knowledge from master to apprentice and from colleague to colleague, they aim at "closely examining a number of small instances of … capability improvement – specifically, the discovery and collection of flaws in novel production equipment – in order to gain a better understanding of the mechanisms of learning by doing in micro level" (von Hippel & Tyre, 1996, p. 314). The authors focused on the problems encountered in the early factory use of process machines. Data on machine failures in the factory and on the process by which these were identified were collected through on-site interviews with both users and developers (p. 316). The authors proposed that micro-level understanding of learning by doing can contribute to a better understanding of learning curves for entire production processes.

These studies arose from the commonplace observation and practical concern of R&D practitioners that when new products, processes and services are introduced to their intended use environments, things often go wrong. Von Hippel and Tyre (1996, p. 316) discovered that the majority of the identified problems were true surprises to both users and developers, that is, they had been identified only during the early field use of the machines. They saw this recognition of an unanticipated problem as a consequence of "doing" – operating the machine in its actual use environment – as a new and theoretically inspiring finding.

Von Hippel and Tyre (1996, p. 326) identified *interference finding* as a learning mechanism associated with the discovery of unanticipated problems in process machines, a mechanism implemented by "doing" in the factory environment. They defined it as "a form of pattern matching that is sensitive to the interferences between juxtaposed objects (such as a process machine and a plant environment)." It occurs when two very different and highly-complex patterns, the new machine and the plant context, are brought into close juxtaposition during field use. The authors reasoned that previously unsuspected and often subtle interferences between the two were discovered because they were then, for the first time, associated with an obvious symptom – poor machine performance (p. 318). They concluded that the unique contribution of "doing" to problem discovery in the field environment appears to be precisely this precipitation of symptoms.

In other studies, von Hippel has used the notion of "sticky information" to refer to R&D practitioners' difficulties in technical problem solving (von Hippel, 1994; 1998). The information used in technical problem solving is often costly to acquire, transfer, and use in a new location, that is, "sticky" (von Hippel, 1994). Information might be sticky because it is local, specific and tacit, and there is too much of it to be transferred, or because the attributes of the information transmitter and receiver do not mach (pp. 430-431). Von Hippel and Tyre (1996) proposed that the concept of sticky information could help to place the physical location of the learning-by-doing activities they observed into a more general context. They argued that it is often cost-effective to transfer problem-solving activities to the site of the sticky information (e.g., plant) rather than to attempt to transfer the information to a problem-solving site (e.g., the R&D lab.).

Von Hippel and Tyre's work clearly develops and opens the "black box" of learning-by-doing. Their focus on actual, real-world contexts and failures as important instances for learning represents a new perspective within studies on innovation and technology management. To some extent, the focus also echoes recent transitions in conceptualizing learning that emphasize everyday practices and communities. It seems, however, that the analysis of problem discovery in machine use is restricted to technical problems. "Sticky" information is associated with technical complexity and the transfer of technical information. Hence, the authors do not discuss the significance of work organization or the division of labor between users and developers. In other words, problems with machine use are not discussed in relation to the complexity of the work organization, power relations, or the entire implementation endeavor. Learning is associated with improving the performance of the machinery, not with the collaboration between developers and users.

In von Hippel and Tyre's analysis, learning is neither an automatic by-product of "doing", nor is it explicitly addressed as proactive. The significance of failures (and interference finding) as symptoms of potential organizational misalignment and as a springboard for purposeful learning to achieve organizational change, is not discussed or elaborated upon. The nature of learning remains tacit.

Critical transition as a challenge for learning: an activity-theoretical perspective

The above views on innovation and learning advocate the importance of learning, but do not address the concrete learning challenges of organizations and groups. In some cases, there may be no interest in going into a micro-level contextual analysis. In the event that such a level of analysis is reached for, there seems to be a lack of concepts and units of analysis sensitive enough to capture the very contents of learning *within a given technology and its organizational context*. This problem was touched upon in the section concerning implementation and learning. It was suggested that implementation needs to be seen as a collective endeavor involving developmental transitions. From this perspective, transitional processes within innovation may constitute important challenges for learning.

Transferring the right or "sticky" pieces of information from one context to another may not be the only critical issue in ensuring the continuity of the innovation process. Recent discussions about managing organizational transitions (Eisenhardt & Brown, 1998) and strategic transformations (Pitt, 1990; Pitt & Clarke, 1999) seem to suggest that mastering the direction, or transitions, of innovative processes deserves more attention among managers and practitioners.

When transitions are poor, businesses lose position, stumble and fall behind (Eisenhardt & Brown, 1998). Because major transitions are periods when companies are likely to stumble, Eisenhardt and Brown expected to find that managers would devote extra attention to them. To their surprise, that was not the case. The authors describe how the managers managed the product development but not the switch from one project to the next. They spent months analyzing an acquisition but far less time planning the integration. They observed that "some managers simply ignore transitions, hoping that somehow they will get from one activity to the next" (p. 61).

The situation that Eisenhardt and Brown describe can be seen as the type of occasion for strategic learning described by Dodgson (1991b). The problem they point out is that the need for transition – and the need to learn to master that transition – is not recognized within the organization. This recognition problem, the need to understand and conceptualize critical transitions as a *learning challenge*, have not attracted attention in studies concerning innovation and learning.

I will suggest an additional or complementary view on learning in innovation, according to which it is seen as a purposive activity carried out in order to recognize and proactively direct and develop the organization's capabilities for mastering transitions, or the *emerging* trajectories and challenges of innovative activity. If transitions are essential, how can organizations better achieve a sense of recognition for them? How is the need for learning during a transitional stage recognized and mutually understood? I will suggest that research on learning and organizational change within activity theory and developmental work research (e.g., Engeström, 1987; Cole & Engeström; 1993) provides concepts and methodological ideas for the necessary new view of learning in innovation.

Activity-theoretical studies have analyzed transformations in work practices and organizational relations, in which there is a challenge to collectively learn "activity that is not yet there" (Engeström, 1999; 2000a; Engeström, Y., Engeström, R. & Vähäaho, 1999). From this perspective, Eisenhardt and Brown's (1998) "shift from one activity to the next" in essence includes learning a new and emergent activity while still being engaged in the previous one. Activity theory distinguishes the notion of "activity" from the narrower concept of action, unlike in Eisenhardt & Brown's discussion which refers to activity as a common-sense concept and discusses transition at the level of actions (the shift to a different project or market).

The relation between the concepts of action and activity are of central importance in differentiating between levels or qualities of transition within the innovation process. Activity theory makes a theoretical distinction between individual goal-oriented action and collective object-oriented activity (Leont'ev, 1978; Engeström, 1987; 2000a). Activity is seen as a historically-constructed and object-oriented activity system involving constant development (Engeström, 1987). The temporal duration of actions is relatively short. Activity, or the activity system, is relatively durable, historically evolving as a collective formation that produces individual actions and consists of members who share the same general object. It is assumed that the developmental aspects of an activity can only be grasped when the unit of analysis is expanded to the collective activity system.

Hence, the activity-theoretical notion of *object* is not the same as the concept of goal or object*ive*. The object is understood as a project under construction, moving from potential "raw material" to a meaningful shape or outcome. The motive is thus embedded in the object of activity. It is formed when a collective need meets an object that has the potential to fulfill that need. In this respect, motive should not be confused with the concept of interest.

From the activity-theoretical perspective, therefore, transitions involve not only shifts from one project to the next, but also a broader developmental transformation from one certain historically-constructed activity to another which involves change in the object of activity. In the innovation process, for instance, this would mean major shifts from the research phase to product development, or from product development to implementation into practical use. Such shifts from one phase - or activity - to another may include actions, or clusters of actions, in a local organizational setting or a network, leading to the transformation of the product under construction. From the point of view of the commercializing company, the "target" activity of the innovation would be its institutionalized use through diffusion and internalization. Such a challenge may involve major organizational changes – and learning - within the company.

Organizations and institutions also go through historical changes largely independent of the specific technology or product they produce or implement. These kinds of historical change may include broad transitions from craftwork and one-off production to automated work and mass production. Organizations go through historical changes in ways of doing things: they shift from one pattern of work or performance – activity - to another. Typically, such major transitions involve changes in the object of activity and the emergence of a new or transformed activity. Within the innovation process, the development and implementation of the new product is often interrelated with the organizational transitions that take place in the key organizations involved. For instance, the transformation of the specific technology into a clinical instrument may be altered by simultaneous organizational transitions in the adopter institutions. A mismatch may exist between these various transitions. There may be a lack of organizational change supportive to the introduction of the innovation, or turbulent changes may constrain the introduction. Such situations constitute a major challenge for learning among the organizations and groups involved.

Potential types of transition in the innovation process that are significant for learning are outlined in Table 1.

Type of transition	What is being transitioned?
(1) From one project to the next	Work input/sub-element of the product
(2) From R&D to implementation into practical use (e.g., clinical use)	Technology/product
(3) Changes involving patterns of work or performance in the developer and the user organizations (e.g., from craft work, i.e. start-up production, to mass production)	Organization/pattern of work or performance

Table 1. Three types of transition in the innovation process.

Eisenhardt and Brown (1998) use the metaphor of running the 4 x 100 relay when they describe the transition from one project or market to the next in a rapidly-changing environment. The laps are so short that the baton passes often determine the outcome of the race. Interesting though this metaphor is, it seems to suggest that the transitions are similar and that the direction or motive of the activity does not change. The short-term transitions described by the authors are driven by company or business-unit goals. The first type of transition depicted in Table 1 involves the shifts described by Eisenhardt and Brown.

As discussed above, in addition to the short-term changes that take place from one project to the next, there are also broader transitions and transformations in organizations and their work practices going on “behind” the short-term shifts. If shifts from one project to the next are driven by business-unit goals, what, then, drives the transition from one historically-constructed activity to the next? Management literature would suggest that it is the company’s strategy. In the second type of transition depicted in Table 1, management’s strategic decisions and goals are typically involved in the transitions, at the very least. In the third case, the question is more complicated. What drives major, long-term organizational change from one pattern of work or performance to another?

Activity theory suggests that change in the activity is driven by *contradictions* (Engeström, 1987). As complexity increases, it seems that the inherent cognitive, communicative and motivational contradictions in activity systems press for new directions and solutions (Engeström, 1990). According to activity theory, developmentally significant contradictions are sources of dynamics and change in the innovation process. It is suggested that the third type of transition depicted in Table 1 are driven by developmentally significant contradictions within and between the activity systems involved in the innovation.

Transitions from one activity to the next are *inherently contradictory*. This arises from the nature of transition that involves participating in a new activity while still being engaged in the previous one. To the extent that the historical organizational changes are closely interrelated with the more short-term processes such as the implementation of new technology into a given organization, contradictions are also present in the second (and first) type of transition depicted above.

Contradictions manifest themselves in everyday *breakdowns and disturbances,* and in participants’ improvised solutions appearing in the concrete-use situations involving the technology. These concepts may be used sensitively for analyzing learning and the developmental challenges related to critical transition.

In activity theory, disturbances and breakdowns are explicitly considered important *opportunities for learning and development*, which was not yet the case in von Hippel and Tyre’s (1996) related notion of interference finding. Studies involve the deliberate tracing and visualizing of disturbances and breakdowns in everyday work practices in order to create a sense of pressing developmental contradiction within the activity and to enlarge or reformulate – *expand* - work practices.

Disturbances and breakdowns[21] (Engeström, 1987; Toikka & Kuivanen, 1993) are seen as manifestations of systemic contradictions in the activity system, signalling potential new directions or emerging transformations. On the other hand, contradictions may manifest themselves in workers' innovative attempts to solve problems of work "from below". In the innovation process, a typical situation generating disturbances would be the challenge of transitioning from the research phase to the commercializing of the innovation. Perspectives and patterns from the previous activity may hinder the practitioners in their efforts to learn the required new perspectives and work patterns involved in the emerging activity. These "mismatches" manifest themselves as disturbances and breakdowns in the course of everyday work. The analysis of disturbances and breakdowns, as well as the practitioner perspective may be used to represent learning challenges and to concretize dimensions and tasks of learning (Engeström, 1999; 2000a). Critical transitions in organizations and inter-organizational relations may be seen not only as moments when a company or the innovation is likely to stumble, but also as possibilities for expansion, that is, new learning, development and change.

As contradictions of an activity system are aggravated, some individual participants begin to question and deviate from its established norms. In some cases, this escalates into collaborative envisioning and a deliberate collective change effort from below (Engeström, 2000b). Engeström (1987) proposed this as a historically new form of learning: *expansive learning* of cultural patterns of activity that are not yet there. An expansive transformation is accomplished when the object and motive of the activity are re-conceptualized to embrace a radically wider horizon of possibilities than in the previous mode.

Engeström (2000b) suggests that expansion involves *horizontal or sideways* learning and development. I further suggest that the notion of expansive learning is also relevant for understanding - and possibly in better mastering – the challenges of critical transitions within the innovation process.

5 A summary of the methodological decisions and empirical findings reported in the articles

Introduction to the articles

The empirical findings of this study are presented in the following four articles:

> [1] Miettinen, R. & Hasu, M. Articulating user needs in collaborative design – Towards an activity-theoretical approach. Accepted for publication in *Computer Supported Cooperative Work.* (To be published in 2001.)

[21] The notion of breakdown has been used to refer to a disruption in the normal functioning of things, forcing the individual or collective to adopt a more reflective or deliberative stance toward ongoing activity (e.g., Koschmann, Kuutti & Hickman, 1998). In analyses of disturbances in work practices (e.g., Norros, 1998), standard work actions are defined as procedural steps that follow the flow (or script) of a disturbance-free "normal" process. Disturbances are analyzed as deviations from this "normal" (scripted) procedure.

[2] Hasu, M. & Engeström, Y. (2000). Measurement in action: An activity-theoretical perspective on producer-user interaction. *International Journal of Human-Computer Studies*, 53, 61-89.

[3] Hasu, M. (2000). Constructing clinical use: An activity-theoretical perspective on implementing new technology. *Technology Analysis & Strategic Management*, 12, 369-382.

[4] Hasu, M. (2000). Blind men and the elephant: Implementation of a new artifact as an expansive possibility. *Outlines*, 2, 5-41.

The data in all four articles included in this study is based on the same case study, the case of the *neuromagnetometer* (MEG) innovation, although the research sites and the units of analysis differ. All the data was gathered during the innovation phase in 1996-1997, when Neuromag Ltd., the spin-off company responsible for the development and commercialization of the innovation, targeted its strategic goal on clinical markets. The articles represent four different windows on the then emerging transition phase of the innovation, from basic research, or experimental use, toward clinical use. I assumed that this phase was transformational for the innovation and for producer-user relations. I also assumed that the transition would show in various ways in the interactive processes between developers and users. The articles report on what the “data windows” that I looked at signalled about the critical transition.

The articles are presented and discussed in the order that they were written. This is not exactly the chronological order of the events. The events analyzed in the second [2] article took place a few months before the occasion (user seminar) analyzed in the first [1] article. I chose presenting this article first because it introduces the broader innovation network involved in the implementation process. It also opens up, in more general terms, the different steps and challenges required for clinical use. The other three articles highlight the concrete actions related to these challenges.

The first article [1] introduces the local Finnish innovation network that was critical in the transition to clinical use. The network consisted of (1) the spin-off company, (2) the physics laboratory from where the innovation and the company first originated, (3) the hospital user laboratory with its commercial MEG system, and (4) the clinical communities at two hospitals as potential clinical users. The article focuses on the points of view of the potential users - concerning clinical use and user needs - which were presented to and discussed with the producers and developers in the user seminar. These discussions highlighted the variety and complexity of motives for clinical use. The analysis of user needs illustrates the qualitatively new tasks and preconditions needed for clinical use compared to experimental use. The article suggests that the emerging user needs of collective actors need to be analyzed on three levels. The first level covers the use value of the product, and its capacity for solving the vital problems and challenges of developing user activities. The second-level analysis concerns the creation and development of the necessary complementary tools and services that make the use of the product possible. The third level refers to the practical use of the product. The tasks and preconditions that the users articulated presuppose collaboration between several communities in the innovation network. The resourses and motives of the key communities are described from a historical perspective, and their capabilities for collaborative effort are discussed.

The problem discussed in the second article [2] focuses on the transfer of new technology from developers to users. The article presents a detailed analysis of disturbances, leading to a breakdown, in a patient-measurement event at the Finnish hospital laboratory. The analysis covers how the disturbances emerged and accumulated in the failed measurement, and how and why the miscommunication between developers and users emerged in the ensuing problem-solving situation. Close analysis of the breakdown revealed inadequacy in the organizing of the measurements and in the system-software features that were incomprehensible to the users in a problem situation. It is suggested that the disturbances in patient measurement and the misscommunication between the developers and the users signalled underlying, systemic contradictions within and between the key communities which needed to be resolved. They indicated problems in the transformation of producer-user relations and in the anticipated transformation of the technology into a clinical tool. The historically-accumulated and situationally-constructed contradictions within and between the producer and the user communities are examined, and the possibilities and problems for their resolution discussed.

The third article [3] focuses on the problem of transition from experimental or pre-clinical use toward clinical use in an analysis of the first attempt to start a clinical measurement service using the MEG at the Finnish hospital laboratory. To capture the dynamics of the implementation process, the analysis was focused on one key actor, a physician, as a user and implementor in the process. The start-up process was in trouble from the very beginning, and the attempt temporarily failed. The questions addressed concern how and why the attempt was interrupted, and why the initiatives of the practitioners, especially of the users, to resolve the problems were not enough. The discussion covers what can be learnt from these difficulties in implementation. The analysis indicates that the disturbances in providing a clinical service signalled contradictions within and between the communities involved in the implementation endeavor. As a single actor, the physician hired to start the clinical service was unable to solve the historically-accumulated contradictions within and between the key communities. These recurring contradictions are examined, and the emerging signals of expansive learning discussed.

The fourth article [4] focuses on the problem of transition from the pioneer phase of implementation to established adoption into medical practice. This problem is connected to a common situation in the development and use of originally new products: an enthusiastic pioneer user is needed for the initial adoption. A pioneer user had taken the first troublesome steps with the new device in the user laboratory in question. The discussion concerns how an artifact, namely the neuromagnetometer, is transferred from its individual pioneer user to a user collective. The article focuses on an American hospital laboratory during a period in which it was facing the challenge of moving from the introductory phase of implementation toward more established adoption into clinical use. This challenge, together with simultaneous changes in the work organization such as the departure of key persons and a decrease in financial resources, is described. It is shown that the implementation constituted a major challenge and constraint for the organization and its practitioners. The urgent need to transfer and expand the individual expertise of a pioneer user to a user collective is identified and discussed.

Methodological decisions and analytical resources

Ethnographic case-study design and the innovation trajectory

I have used an ethnographic case-study strategy in my study over a certain time period, in a specific historical phase, of the neuromagnetometer innovation. My intention was to capture the ongoing, concrete "micro" processes and interactions in the innovation network, and to look at them in the context of the entire innovation trajectory with a particular history and evolving future directions. The neuromagnetometer innovation and the innovation trajectory are described in the introduction of this report.

Studying the evolving processes of an innovation involves openness and sensitivity to the new data and the unexpected elements that come to light as the study progresses. The principle of openness applied here originates from the ethnographic research tradition in which there is an underlying need to remain open to elements that cannot be codified at the time of the study (Baszanger & Dodier, 1997). I conducted the preliminary ethnographic observation at the research sites to find the then unrecognized foci for the study, and to evaluate the relevance of my preliminary research problems. On the basis of this preliminary observation and of the interviews with the key persons in the innovation network, I chose the focus of the fieldwork and decided the units of observation. During the fieldwork, I followed the processes and problems at the research sites that were essential not only to my own research interests, but also to the organizations that I studied.

Analyzing actual empirical data in the light of the innovation trajectory requires a historical perspective. The historical perspective on innovation applied in this study was based on cultural-historical activity theory (e.g., Engeström, Miettinen & Punamäki, 1998) which offers a framework for studying technology development and use in terms of object-oriented and historically-constructed activity. It is assumed that the current phase of the innovation process and its developmental challenges are historically constructed. Therefore, ethnographic observation should be supported by historical data and analysis. In order to understand and interpret the actual, ongoing processes that I observed, I also analyzed the history and developmental phases of the neuromagnetometer innovation (Hasu, 1999).

This research strategy, which includes concrete organizational contexts and a developmental time dimension, offers possibilities for context-specific findings and explanations, and the analysis of complex relationships. The findings may be directly relevant to the organizations studied, and they may be used as a means for reflective dialogue between them and the researchers. The strategy therefore permits a "built-in" assessment of the validity of the research.

The selection of the neuromagnetometer innovation for the object of research was based on two main criteria. First of all, I sought a radical innovation, a genuinely new product, because such products are known to constitute a major challenge of development and learning for the commercializing firms and their partners. Second, my aim was to select a company with a radical innovation in an early phase of commercialization in 1996, when I planned to begin my study. My interest was in capturing a "living and breathing" innovation endeavor, not a mature innovation with already established uses. Considering the criteria and my research interests, Finnish science-based innovations in the field of new medical and health-care technologies provided a few potential research cases. The case of the neuromagnetometer was selected because it fulfilled the criteria and because the commercializing company was interested in and willing to take part in the research.

Multiple qualitative data sources and research sites

The producer-user interactions and processes of implementation that I followed took place in the innovation network. The study includes four research sites within the network. In addition to the spin-off company Neuromag[22], they were the Low Temperature Laboratory at the Helsinki University of Technology, and the two user laboratories with the Neuromag MEG system in the hospital environment: the BioMag Laboratory at the Helsinki University Central Hospital, and the New Mexico Institute of Neuroimaging at the New Mexico Federal Medical Center in the United States. The main research sites were the two hospital user laboratories in which I carried out intensive fieldwork in 1996-1997 (see Table 2).

The selection of these four sites was based on the focus of research which aimed at studying the emerging clinical use of the neuromagnetometer device. The problem-solving situations and processes of implementation that I followed took place in the above-mentioned hospital laboratories. Because the situations and processes involved or concretely incorporated practitioners from the other two organizations mentioned above, these sites were also included. The BioMag Laboratory at the Helsinki University Central Hospital was selected because it was the only hospital laboratory in Finland in which the MEG system was installed. The selection of the American hospital laboratory was also obvious. In addition to the Finnish hospital laboratory which was only starting clinical utilization of MEG, I sought another clinical site with the Neuromag system which was more advanced in its clinical use. In 1997, the New Mexico Institute of Neuroimaging was the only hospital laboratory among the Neuromag's customers which fulfilled this criteria.

Case studies may involve either single or multiple cases, and numerous levels of analysis (e.g., Leonard-Barton, 1995). They may employ an embedded design, that is, multiple levels of analysis within a single study (Yin, 1984). They typically combine data-collection methods such as archives, interviews, questionnaires and observation (Eisenhardt, 1989; Silverman, 1997). The present study incorporates several sources of qualitative data, as well as several units of observation (Table 2).

I collected documents, interviewed the participants, and conducted observation related to the interactive situations and processes that I followed. I also audio-recorded and/or video-recorded series of specific use situations and meetings in the research sites. When conducting the observation, I wrote detailed field notes of what I saw and heard. The typical, basic categories of field observation of the "normal" flow of everyday work include detailed time duration, participants, work actions, interactions and key discourse. Specific use situations and formal meetings that were scheduled and known beforehand were video-recorded and/or audio-recorded. As an ethnographer, I did not take part in the work of the organizations that I observed. I

[22] In the articles, the company is also referred to as using the pseudonym "Brainview".

stayed outside of the work actions, but I interacted actively (also informally) with the people at the sites, informing them about my research work.

I conducted four types of interviews. (1) I carried out preliminary interviews at the beginning of the fieldwork with the key persons in the innovation network. They were typically managers or senior practitioners in their organizations. In these interviews I acquired general, background information about the network, and information about the ongoing strategies and processes in the organizations in question. (2) I also conducted a few historical interviews, targeted at acquiring information, documents and views about the development of the innovation and the innovation network. (3) The majority of the interviews were focused on the accounts and interpretations that the interviewees gave to the ongoing situations and processes in which they were involved. (4) Finally, I conducted interviews in which I asked the respondents to comment on and give feedback about my preliminary findings or written analysis. Involvement in or close affinity to the situations and processes under study determined the selection of the interviewees.

The interviewing strategy that I applied somewhat resembles the approach known as active interviewing (Holstein & Gubrium, 1997). The active interviewer sets the general parameters for the responses, constraining as well as provoking answers that are close to the researcher's interests (ibid. p. 125). In the active interview, "rather than searching for the best or most authentic answer, the aim is to systematically activate applicable ways of knowing – the possible answers – that respondents can reveal, as diverse and contradictory as they might be." Both the role of the interviewer and the role of the respondent are active. While the active respondent may selectively exploit a vast range of narrative resources, it is the active interviewer's job to direct and harness the respondent's constructive storytelling to the research task at hand (ibid. p. 125).

In the interviews that I conducted, the respondents spontaneously took an active role. Typically, they were participants or deeply involved in the situations and processes that constituted the subject matter of the interviews. These situations and processes were meaningful and highly topical to them. To provoke context-specific and situation-specific accounts, I often presented to the respondent a piece of my own field observation or a preliminary interpretation of the process I had followed at the site. Presenting the preliminary findings or written analyses actively provoked respondent accounts and interpretations.

All the four articles include several types of data (Table 2). Multiple data sources provide complementary views on the object of research under scrutiny, and also possibilities for evaluating the validity of each data set. Ethnographic observation, interviews and documents were used for all four articles. Video-recorded data was the main data source for the first [1] (user seminar) and in second article [2] (measurement situation and ensuing problem-solving situations). Field observation and interviews were the main data sources for the third article [3] (implementation process). For the fourth one [4], interviews concerning the ongoing organizational transition formed the main data source.

Issues of validity and reliability

This study draws on Kvale's (1989; 1995) conceptions on validity in qualitative research. Kvale (1995) integrates validation in the "craftmanship" of research, and extends the concept from observation to include communication about, and the pragmatic effects of, knowledge claims[23].

The quality of craftmanship in an investigation includes continually checking, questioning, and theoretically interpreting the findings. In this approach to validation, the emphasis moves from inspection at the end to quality control throughout the stages of knowledge production (Kvale, 1995). In the present study, multiple data sources and data-gathering methods provided a basis for continuous triangulating and weighting the evidence of each set of data. The relevance of the research problems and the units of observation were evaluated during the fieldwork according to what seemed to be sensible at the time. This involved close affinity with the research sites and timely interaction with the informants. If possible, the data was transcribed and monitored during the fieldwork in order to achieve valid reporting and to be open to possible surprises. I also wrote a field report of each visit (typically one day in the field). One practitioner at the site described the researcher's role by saying: "You really seem to go for news like a reporter!"

Communicative validity involves testing the validity of knowledge claims in a dialogue[24]. Valid knowledge is not obtained merely by approximation to a given social reality. It also involves conversation about the social reality through the argumentation of the participants (Kvale, 1995). In the present study, conversations and also meetings concerning preliminary findings and analyses were held during the research process. Dialogue between the researcher and practitioners at the sites was built-in in the process. The forms of dialogue included: (1) interviews, (2) discussions of preliminary analyses, (3) the researcher's presentations concerning research observations and findings, (4) meetings aimed at enabling the communities to reflect upon their own activity and mutual relationships, and (5) informal discussions during the fieldwork. In these situations, the researcher's interpretations were discussed, which provided opportunities for validation. Dialogue with practitioners from different organizational positions and locations was also a validation source. It was not only the managers', but also ordinary practitioners' voices that were listened to.

According to Kvale (1995), the pragmatic concept of validity represents a stronger knowledge claim than mere agreement through dialogue. Pragmatic validation rests upon observations and interpretations, with a commitment to act upon the

[23] For many ethnographers, this vision of "realism" is no longer compelling (Altheide & Johnson, 1998). Rather, all knowledge and claims to knowledge are reflexive of the process, assumptions, location, history, and context of knowing and the knower. From this point of view, validity depends on the "interpretive communities," or the audiences who may be other than academics and the goals of the research. Validity will be quite different for different audiences (p. 288).

[24] Sampson (1993) commented on what he called the monologist tradition in social sciences. He states that the central device of researchers to gain objectivity has been the distancing of themselves from the object of study. He considers this distancing unfortunate for two reasons. First, the basis of knowledge is by its nature dialogic, that is, co-constructed, thus its transmutation into a monologue is epistemologically unsound. Second, giving the voice of the researcher a privileged standpoint results in denial of the need for participation, responsibility and obligation to the vital interests and points of view of the object of study.

interpretations. For instance, the ultimate test of the credibility of a research report is the response of the information users to it. In the present study, one of the starting points of the research was that the researcher's questions coincided with the practical problems faced by the Neuromag company and the innovation network at the time. I also believe that the good opportunities for dialogue arose from the practical relevance of the issues under scrutiny to the participating communities. The practical relevance of the research process was articulated in the advisory group's meeting, when the managing director of Neuromag was asked about the company's expectations concerning the developmental aspects of the research process.

> Managing director: "It seems clear to me that this kind of a process, that is, making an analysis, does influence the object under study. Things such as impediments to development become uncovered and it is, in my mind, an entirely positive thing. The process has influenced this network in a certain way – I would say in an insight-producing way. And then, these further steps [of the measures taken to advance clinical work with MEG] are partly a result of this process. In that sense, this has been a very nice business (…) which was soon evident." (Excerpt from the discussion in the advisory group meeting, February 6, 1998.)

Openness and trust based on dialogue can also be seen in the empirical analyses in which the actual contexts and communities under scrutiny are presented without a need to extensively prevent identification of the settings.

Kirk and Miller (1986, p. 20) define reliability as the degree to which the finding is independent of accidental circumstances of the research. In ethnographic research, the reliability of the results revolves around whether or not (or under what conditions) the ethnographer expects to obtain the same findings if he or she tried again in the same way (ibid. p. 69).

For instance, checking reliability is closely related to assuring the quality of field notes (Hammersley & Atkinson, 1983). Accuracy and explicitness may be difficult to achieve during fieldwork if there are many participants and simultaneous tasks to observe. Recalling field situations based only on field notes may be unsound after a time. I tried to improve the reliability by audio-recording and video-recording situations in which many people were involved and complex work tasks with technical equipment were being accomplished. To avoid the bias of accidental circumstances in the field data, I conducted sustained longitudinal observation in the settings (Barley, 1995). Sustained observation is suitable for revealing patterned complexities and it increases the odds that researchers will uncover meaningful indicators of those patterns (p. 16).

The activity-theoretical framework and concepts as analytical resources

This study applies the activity-theoretical framework for studying producer-user interaction and implementation processes in a given innovation. Activity theory offers a framework for studying technology development and use in terms of object-oriented and historically-constructed activity. The theoretical and methodological ideas of activity theory coincided with my interest in studying a concrete innovation in the context of its historically-constructed developmental phase.

Cultural-historical activity theory (Leont'ev, 1978; Engeström, 1987; Cole & Engeström, 1993; Engeström, Miettinen & Punamäki, 1998) takes a collective object-oriented activity system as its prime unit of analysis. The contexts are activity systems, which integrate the subject, the object and the instruments (material tools as well as signs and symbols) into a dynamic whole. Activity is driven by a collective object and motive, but it is realized in goal-oriented individual and group actions.

The concept of activity, or activity system, is used as an analytical resource in all four articles. The model in question (Engeström, 1987) provides an analytical tool with which to differentiate between structural elements of activity and yet to analyze their systemic relationships. The *subject* refers to the individual or sub-group whose agency is chosen as the point of view in the analysis. The *object* refers to the "raw material" or "problem space" at which the activity is directed and which is molded or transformed into outcomes with the help of physical and symbolic, external and internal *tools* (mediating instruments and signs). The *community* comprises multiple individuals and groups who share the same general object. The *division of labour* refers to both the horizontal division of tasks between the members of the community and the vertical division of power and status. Finally, the *rules* refer to the explicit and implicit regulations, norms and conventions that constrain actions and interactions within the activity system.

Several activity systems were analyzed in the present study. In each article, the activity system as an analytical resource was also applied slightly differently for empirical analysis. A network of activity systems is depicted in the analysis of the user seminar [1]. In this network-level observation, an organization or a unit of an organization was seen as one activity system. Typically, a pair of activity systems – that of the developers and that of the users interacting in a situation - was chosen for more detailed analysis [2,3]. Different practitioner groups as different activity systems were also analyzed [4]. The theoretical units of analysis used in the articles are depicted in Table 2.

Another central activity-theoretical concept integrating the articles is that of contradiction. Transitions are seen as inherently contradictory. From an activity-theoretical perspective, transition from one activity to the next involves participation in a new or emerging activity along with engagement in the previous one. It is assumed, therefore, that the transitional phase of the innovation examined in the present study does not take place without problems. It is also assumed that the transition constitutes a major challenge for the innovation network which was formerly oriented to the development of specific technology and basic research.

The basically same transition from research to clinical use described in the articles represents the second type of transition depicted in the previous section on page 39 (Table 1). The first three articles describe Finnish transition from experimental research toward pre-clinical and preliminary clinical use. The fourth article describes transition in the American hospital laboratory from introductory-type clinical use toward more established use. Both transitions involve long-term or medium-term development and are, at least partially, driven by the organization's strategic decisions. Broader transitions, involving changes in organizational patterns of work and performance (the third type) are also connected to these local, more specific transitions analyzed in the articles. How this broader development in organizations and their relationships alters the processes of implementation is also examined.

Activity theory regards contradictions as moving forces of change and development in the innovation process. Contradictions manifest themselves in disturbances and breakdowns in work processes – as well as in workers' innovative attempts to solve them. In order to understand the contradictions at play in the transitional phase of the innovation, I traced and analyzed recurring everyday troubles and disturbances that appeared in concrete use situations involving the technology [2,3].

From an activity-theoretical perspective, the early implementation of new technology offers a concise opportunity, in a "laboratory setting", to examine the multitude of historical layers, perspectives and viewpoints in and around the developing activity and the artifact. In such a phase, separate historical layers and perspectives meet and interact. Therefore, I analyzed different viewpoints and perspectives that the parties constructed in their discourse [1,2,3], and perceptions concerning local transition [4].

The main activity-theoretical concept used In the first article [1] was the *network of activity systems*, applied to the analysis of the innovation network involved in the transition from basic research toward clinical use. The concepts of *disturbances and breakdown* are applied in the second article [2] for analyzing the *contradictions* within and between the activity systems. Other key concepts used include *object* and *tool*. The article examines object-tool shifts in the users' activity during the breakdown situation. In the third article [3], I applied the concepts of *perspective* and *disturbances* as an analytical resource for investigating *contradictions* in the construction of a new *object* of activity. Finally, for the fourth article [4], I used the activity-theoretical concept of *expansion*, or expansive development, and the concept of *contradiction* to illustrate the possibilities and problems of the transition.

The research problem, the data, the theoretical units of analysis and the key activity-theoretical concepts described in each article are presented in Table 2. The first column on the left gives the title of the article. The second column shows the broad research problem that guided the empirical analysis. They refer to the debate on, and my formulations to the problems of producer-user relations and implementation discussed above. The third column depicts the specific question addressed in the empirical analysis reported in the article. The fourth column describes the sets and types of qualitative data used, and the fifth column presents the theoretical units of analysis in terms of activity theory. Finally, the sixth column presents the key activity-theoretical concepts used in the empirical analysis. These theoretically-informed analytical concepts were applied as "eyeglasses" to pick up and examine in detail parts of the "raw data" relevant to the problem under scrutiny. The specific way of using the concepts is described in the articles.

1. Article	**2. Problem(s)**	**3. Specific question addressed in the article**	**4. Data**	**5. Theoretical unit(s) of analysis**	**6. Key concept(s) of analysis in terms of AT**
[1] Articulating user needs in collaborative design – Towards an activity-theoretical approach	How could the collective and emerging nature of user needs be analyzed?	What kinds of points of view did the clinical users and the developers formulate on the clinical use of MEG in the user seminar?	Audio-recorded interviews of potential Finnish clinical users in 1996. Video-recorded presentations by and conversations with the clinical users in the user seminar lasting for 3 hours.	Local activity systems of users and developers (as a network) involved in the development and use of the MEG device.	Collective user needs (use value), local network of activity systems.
[2] Measurement in action: An activity-theoretical perspective on producer-user interaction	How does misscommunication in producer-user interaction emerge?	Why/how did the patient measurement and the ensuing problem solving between developers and users fail?	Ethnographic observation and video-recorded problem-solving situations following a measurement breakdown at the Finnish hospital laboratory in May, 1996. Audio-recorded interviews with the users and developers.	Interacting activity systems of the developer company and the hospital user laboratory in a breakdown situation, and the ensuing problem solving.	*Disturbances* (breakdown) in the situated use of the device, *contradictions* within and between activity systems. *Object-tool shifts.*
[3] Constructing clinical use: An activity-theoretical perspective on implementing new technology	What can be learnt from the difficulties of implementation? How do individual users survive the introduction of an innovation into a complex organizational environment?	Why did the first attempt to implement MEG in clinical use at the Finnish hospital user laboratory fail to take off?	Ethnographic observation and video-recorded situations of everyday work practices and interactions at the Finnish hospital laboratory during the implementation endeavor in 1997. Audio-recorded interviews with the key practitioners involved in the implementation.	Interacting activity systems of the developer company and the hospital user laboratory during the implementation attempt	*Contradictions* in the construction of new (emerging, shared) *object of activity*. *Disturbances* (and *perspectives*) in the situated use of the device.
[4] Blind men and the elephant: Implementation of a new artifact as an expansive possibility	How does the user organization adopt a complex technical artifact into collective medical practice? How is an artifact transferred from its individual pioneer user to a user collective?	How did the practitioners at the American hospital user laboratory perceive the local transition in the implementation and use of MEG?	Audio-recorded interviews with the practitioners involved in the use of MEG at the American hospital laboratory and hospital departments during a 6-week visit in 1997. Ethnographic observation of work practices and video-recorded use situations in the lab and operation room.	Different practitioner groups as activity systems interacting in a process of adopting the MEG device.	*Dimensions of expansion.* *Contradictions* in activity systems in the construction of a new (emerging, shared) *object of activity*.

Table 2. Research problems, specific questions, data, theoretical units of analysis, and key activity-theoretical concepts in the articles.

Empirical findings and implications

The specific situations and processes analyzed in the articles illustrate local transition within the critical phase of the innovation process. At the time of the study in 1996-1997, the neuromagnetometer innovation was reaching for a new, clinical, market. Experimental clinical use had emerged, but a breakthrough in clinical applications was yet to come. Within this inherently uncertain process, in the long run, the user network needed to be broadened, and the innovation needed to become institutionalized through diffusion and internalization. The innovation as a product also needed to develop as a clinical tool.

The transition analyzed in the four articles mainly illustrates the second type of transition depicted in the previous section on page 39 (Table 1). It is shown, however, that the local processes were altered by broader organizational changes and relations in the key communities and in the network (the third type of transition in Table 1).

In the following, I will discuss the findings and implications in the four articles in three respects: in relation to (1) the problems of producer-user relations and implementation, (2) learning, and (3) the research framework and methodology.

Findings and implications in relation to the problem of producer-user relations and the problem of implementation

The findings of this study illustrate that changes in strategy and in the acquisition of new markets for an innovation are embedded in concrete, mundane actions and activity taking place in local, interactive processes of implementation and adoption. In cases such as the neuromagnetometer innovation, the anticipated clinical use may not materialize spontaneously by selling and installing measurement systems in hospitals. Much application work is needed in the R&D laboratories and in the various user sites simultaneously. The findings of the study highlight the users' concrete work and efforts in putting the innovation into clinical use. Transformation of the technology into a clinical tool constitutes a major challenge not only for the developer firm but also for the user organizations and their practitioners.

<u>Transformation of the product and producer-user relations does not take place smoothly and spontaneously</u>

The findings of this study suggest that producer-user relations during implementation are often complex, involving misscommunication and discoordination. In this respect, the findings do not support the view of implementation as a smooth hand-off from developers to users, as suggested by Leonard-Barton and Kraus (1985). Fleck's (1994) argument about configurational technology and learning by "struggling to get it to work" is more in line with the empirical findings of this study. However, he does not discuss the changes and effects of implementation to the broader community and its collective work practices (the object of work) or to network relations. In this sense, the idea of learning by trying (Fleck, 1994) differs from the idea of expansion (Engeström, 1987; 2000a) discussed in this study.

The user-seminar data showed the complexity of clinical-user needs and the anticipated transition toward clinical use [1]. Multiple potential user communities and needs, and multiple producer communities with divergent motives, were involved in the local transition. A “trap” was found in the producer-user relations: no community seemed to take responsibility for organizing the new tasks and steps required for clinical use. These findings imply that merely acquiring information about individual user needs – opinions, conceptions and controversies – may not be enough for understanding emerging needs in collective clinical practice. Rather, analysis of the development and contradictions of the user activity and of the producer-user network are needed to capture the complex and multi-voiced character of user needs.

At the time of the study, concrete problems were found in the transformation of the technology into a viable clinical instrument [2]. Breakdown in patient measurement revealed inadequacies in the organization (e.g., division of labour, collaboration) and in the system software features that were incomprehensible to the clinical user who operated the MEG system in a problem situation. These disturbances and the misscommunication between developers and users signalled problems and contradictions in the anticipated transition. The measurement system did not function as a tool for the users, but, instead, it became a problem and the object of their activity.

These findings imply that the shift toward a mature customer-intelligent product driven by co-configuration work may not take place spontaneously [2]. Transition may require a deliberate attempt to resolve the developmental contradictions within and between the developers’ and users’ activity systems. This might involve changes in the organizations’ prevailing patterns of work (e.g., solo responsibility for performing measurements) that were in contradiction with the emerging new object, patient measurement and clinical use.

The multi-voicedness and complexity of user needs found in this study do not correspond with the commonly-held assumption in innovation and management studies that producers merely acquire concise “need messages” or ready solutions from lead users (e.g., von Hippel, 1988). It appears from the present study that all users, not only certain lead users with specialized expert positions, need to be seen as equal partners in developing new products. It is also suggested that, in addition to articulated user needs or user solutions, users’ problems and disturbances in actual use need to be seen as highly important information for producers of new technologies [2]. The articulation and analysis of the problems of actual use could be seen as a way to facilitate their resolution. It was shown that users’ initiatives for solving problems with the new technology and the use environment signalled needs and potential ways of developing not only the technology but also the conditions of use [3].

Hence, acquiring information is not the same as acquiring commitment and responsibility. It was found in this study that, even if the producers acquired information about clinical users’ needs for routine measurement services [1], the ensuing attempt to start the routine service was not negotiated or constructed together with the end users, the clinical communities [3]. This implies that it is not only the user needs but also the practical user activity – clinical services – that should be articulated and constructed in collaboration with users and developers. For instance, the developers need to see the actual, concrete work with real patients, not just be informed about it.

Implementation needs proactive management of transition and collective action from below

The findings of the present study show that implementation, involving a shift from one activity to the next (while still being engaged in the previous one), may not arise spontaneously from the transition. In this respect, the findings do not support the traditional view in the literature on innovation and technology management that characterizes implementation in terms of invisibility, individuality and adaptivity. It is rather suggested that implementation may need proactive management of *transition and collective action from below* within the groups and organizations involved.

The analyses of the implementation processes in the Finnish and American hospital laboratories showed how the implementation of the MEG system into clinical use constituted a major challenge for the individual users and the organizations. The first attempt to start a clinical measurement service and to take MEG into clinical use in the Finnish hospital in 1997 was in trouble from the very beginning, and was temporarily abandoned [3]. The disturbances in providing the clinical service signalled contradictions within and between the key communities. Solo responsibility and performance of the practitioner in building the service, and features of the data-analysis software that complicated the user's work, were in contradiction with the challenges of the implementation. The key communities involved failed to recognize, in essence, that running a clinical service was a qualitatively different activity compared to performing experimental measurements. These findings imply that, not only the implementation as such, but also the *emerging new pattern of work and organization* needs to be constructed as a new, shared object of activity among the key participants. The resolution of historically-accumulated contradictions within and between the key communities is required for the successful emergence of a shared object of implementation and related work practice. Changes are needed in the prevailing patterns of work (e.g., solo responsibility in data analysis and clinical reporting) that are not in line with the requirements for running a clinical service.

In the American hospital laboratory, the implementation of the MEG system in 1997 involved the transition from pioneer clinical use to more established adoption into medical practice. It was found that each practitioner group in the hospital laboratory involved in the adoption had a special and partial point of view, and different concerns about the adoption and the ongoing organizational transition [4]. In the laboratory, the system had first been implemented by a pioneer user who was enthusiastic enough to take the first laborious steps and to create the expertise needed for clinical interpretation. Although important, this expertise also had its problems: it remained isolated. The organization was thus facing an urgent need to transfer and expand the individual expertise of a pioneer user to a user collective. It was found that individual isolated expertise and responsibility in applying MEG was in contradiction to the simultaneous challenge of establishing its use in collective medical practice. The patterns and models of individual pioneer work tend to be recurring, although the work organization had changed and the implementation endeavor was broadening and intensifying.

These findings suggest that the transformation of the artifact (neuromagnetometer) from an introductory-type instrument into a collectively-used tool cannot be understood solely in terms of gradual adaptation between the technology and the user organization [4]. It seems that a qualitatively broader integration process – expansion – needs to take place. This involves the emergence of a shared object of activity among those involved in the adoption. The findings also imply that changes in work patterns and organization can hardly be on the sole responsibility of an individual champion or sub-group. Rather, the transition of an innovation into collective use needs to involve the emergence of collective responsibility and expertise through the visualization of work and reflective dialogue.

Findings and implications in relation to learning in producer-user relations and new-product implementation

The findings of this study concerning learning illustrate that, although transformation taking place within producer-user relationships and in the technology did not seem to evolve smoothly or spontaneously, *learning* did emerge within the mundane actions and interactions that took place in the local processes of implementation and use. It showed, for instance, in the users' and developers' attempts to solve problems of implementation. Improvised learning related to clinical use took place mainly individually, not yet within the entire organization, thus affecting individual relationships. A need for, and a sense of, shared learning was emerging, although not very explicitly. These findings illustrate problems in communication and learning. For instance, the users' initiatives for collective action and learning, as a reaction to problems in implementation, were weakly articulated [3]. Accordingly, the developers did not recognize the users' initiatives as significant. These problems call for the development of means - within the communities involved - for collectively recognizing the essential learning challenges in organizations facing critical transitions.

<u>Critical transition is a learning challenge in the producer-user relationship</u>

It seems from this study that transition, as a shift from one activity to the next, is often weakly recognized - and therefore ignored - in the innovation network. In this respect, the study gives support to Eisenhardt and Brown's (1998) related findings concerning managers' tendencies to ignore transitions and the challenge they offer for managerial work. It also indicates that learning needs to be seen as a purposive activity carried out in order to recognize and proactively direct and develop - not only the managers' but also the entire organization's - capabilities for mastering transitions, that is, emerging trajectories and challenges related to innovative activity.

The different local communities within the innovation network heard each other's viewpoints concerning the clinical use of MEG for the first time in the user seminar [1]. They presented to each other their motives, expertise and resources related to clinical MEG. It was found that resources and expertise were dispersed in the network, or that the required knowledge and expertise were still being developed through basic research. The communities also had an opportunity to recognize – learn - the different perspectives and motives concerning clinical use. It emerged that complex relations and also tensions existed between the key actors and communities. Neither a sense of, nor a need for, collaboration was strong. These findings suggest that local transition from basic research use toward clinical use requires transformation of collaborative relationships in the producer-user network. They also suggest that expansive change need to take place in the subsequent user activity. It was shown, however, that the required expertise and responsibility for organizing new collaborative tasks are not ready and available. They need to be constructed through collaborative negotiation and learning.

Problems in communication – as well as hindrances to new learning - were found in the interactions between developers and users in contexts of concrete use. Misscommunication occurred in the dialogue between the developers and the users in the ensuing problem-solving situations after the measurement breakdown [2]. The distinct and separate perspectives of both parties hampered mutual problem solving, negotiation and construction. The user introduced broader problems (the continuity, and acquisition of clinical data for research) than the specific measurement issue, while the developers focused on the actual situation with the measurement system. Although re-mediation (shared learning) about the emergence of the breakdown and the entire problem-solving situation finally happened, it did not cover the broader, systemic problems of patient measurements. Both parties, but especially the developers, failed to recognize that the measurement system should not have constituted a problem in the first place, but should rather have been seen as a tool to enable the users to go on with their work.

These findings have two important implications for learning in the producer-user relationship. They suggest, first, that within the critical phase, the place and meaning of the technology need to turn from the object of the designer into a tool for the user [2]. The developers need to recognize, for instance, that users are not interested in the specific technology as such, and rather consider it a potential tool to help them to develop and continue with their own work. The ability of developers and users to discriminate between tool and object, and to play with their relationship, is a vital feature of an innovation network open to learning and change. Second, the findings imply that the ability to distinguish between tool and object does not seem to develop spontaneously from often rare interactions. Therefore, shared meta-tools (e.g., a common language) are needed for facilitating learning and for dialogical diagnosis, problem solving and redesign.

<u>The individual expertise of a product champion is not enough for adoption – expansion of expertise and responsibility is also needed</u>

The present study illustrates the complexity of implementation involving several organizations and various occupational groups. It also shows how challenging endeavors to introduce a complex artifact into a complex organizational environment can be to the individual users and groups who engage in it. It challenges the expectations that are placed on the role of an individual product champion or a boundary spanner for successful adoption (e.g., Schon, 1963). The findings are more in line with suggestions that a champion role should change over time (Maidique, 1980), or that a product-champion team (Leonard-Barton & Kraus, 1985) or several champions on different levels of the organization (Rice & al., 1998) are needed. More than pointing to a simple lack of change in the champion's role, the results reveal fundamental limitations of the isolated expertise and responsibility that may be associated with a product champion or a centralized champion team within an organization. In this respect, the idea of a macro-actor (Rip, 1995) comes close the idea of expansion by pointing out a need for collective agency in the introduction of new technologies. The discussion of a macro-actor, however, misses the problem of shared mediational (dialogical) means necessarily needed in the construction of collective agency.

The users in the Finnish hospital laboratory initiated improvised but weakly-articulated attempts to resolve some problems of implementation [3]. Expansive learning emerged individually, but not within the entire organization. It is clear that the problems calling for resolution were questions not only of the individual competence of the users and managers involved, but also of collaboration between the key communities. It was shown, for instance, that an individual user's chance to become an effective boundary spanner is poor if the role of the one who tries it is not recognized within the organizations. This implies that the perspectives of all the key participants involved in the implementation need to be expanded through collaborative learning and reflective dialogue.

In the American hospital laboratory, the perceptions of the practitioners concerning the ongoing transition indicated expansion as well as constraints concerning the new phase of implementation [4]. They revealed an urgent need – but also the difficulties involved – of transferring the individual expertise of a pioneer user to a user collective. It was also shown that the role of an individual champion could become dysfunctional as the adoption proceeds. Expertise easily becomes isolated and personified. It seems that even a powerful product champion may not be enough for adoption or for sustaining the product in a given user activity. The implication is that expansion, or expansive learning, and collective responsibility may be needed. Expansion means that the practitioners should recognize and discriminate between the different objects of the various phases of implementation and adoption. Shared meta-tools are needed for facilitating collaborative learning and reflective dialogue between practitioner groups.

Findings and implications in relation to the research framework and methodology

The innovation process offers a laboratory context in which to study transition and change. The anticipated development from idea to product and commercial success is built in to the process. The activity-theoretical framework applied in this study offers sensitive theoretical and methodological resources for studying a particular, critical, phase of the innovation process. The time dimension and the developmental dimension provided by the activity-theoretical framework offer a new perspective for studying evolving, developing producer-user relations and ongoing implementation processes. The present phase and challenge of the innovation is seen in the light of the history and of the potential future challenges and directions. The framework also offers analytical resources for studying concrete actions and interactions within and between the organizations involved in the innovative activity. It helps to analyze and concretize problems, as well as to assess the possibilities for new learning and development inherent in the activity.

> The activity-theoretical framework is sensitive to the study of the "ethnography of change"

Although the fact that change does not appear the same to everybody may be common-sense wisdom in organizations, its significance and consequences have not been pointed out in empirical studies within innovation and technology management.

The activity-theoretical framework and methodology applied in this study offer an *ethnography of change* that helps to reveal the dynamics of transition and change within a given organization or network. It was shown how the activity-theoretical analysis of work activity can highlight the possibilities and contradictions faced by individual users attempting to reconfigure technology as it is implemented and put to use. This capacity to act may be circumscribed and limited, but it nevertheless exists and can be clarified and potentially also strengthened. The framework could be used to trace in concrete and "on-line" contexts how anticipated (strategic) change is implemented and diffused. It therefore has the potential to be applied and further developed within the ethnography of intervention.

In this respect, I will briefly discuss and reflect upon (1) the relevance of the activity-theoretical concepts or methods developed in the articles, (2) the significance of the key finding (revealed with the help of the concept) in each article, and (3) the implications of these findings for the studies of implementation. My aim is to evaluate the activity-theoretical framework as a potential new approach for studying implementation processes of technological innovations.

The scheme for identifying and analyzing *collective user needs* was developed and tested in the first [1] article. The testing of the two-level scheme (use value of the product, on one hand, and situated practical use, on the other) revealed that an additional level of analysis was needed. That was the creation of the complementary tools and services that make the implementation and use of the product possible. It was shown that this scheme, inspired by activity-theoretical framework, is relevant and applicable as a dialogical means of articulating emerging and collective user needs. The key finding that no community alone was either capable or willing to take on the responsibility of organizing the new tasks required for clinical use, is significant for the anticipated transition to clinical use. This was a surprising and unfortunate finding, from the point of view of the developer firm and its strategic target. This "trap" and major contradiction was for the first time revealed to and discussed among the parties involved. The analysis of the historically constructed expertise and resources of the parties, inspired by activity theory, was used to identify the trap, which would obviously have remained unrecognized in the key organizations without the analysis. The applicability (generality) of the scheme for analyzing user needs has to be – and is currently – tested in other cases. I assume that the scheme will be applicable especially in the originally new products involving cooperative expertise in use. I also believe that current theorizing on user needs and implementation is likely to benefit from such concept of user needs that focuses on the evolution of collective user activity and the emergence of complex network relations.

The method for analyzing the situated use of a complex technical artifact and the complexity of producer-user interaction was developed and tested in the second [2] article. The activity-theoretical concepts of *disturbances* and *contradictions* were applied to the analysis of a breakdown situation in the patient measurement. The framework of the analysis proved useful for analyzing how the measurement system shifted from a tool to a problem and the object of the work. The data of the ensuing conversation between the product developers and the users provided a unique opportunity to test the concept and model of an *activity system* (comprising interactive activity systems) for the analysis of the object-oriented and historically constructed systemic conditions of the producer-user interaction. The key finding, the inadequacy in the organization of measurements (division of labor) and in the system software (tool), which was incomprehensible for the user, is important for the further development of the neuromagnetometer as a clinical tool. Also the finding concerning the evolution of misscommunication in producer-user interaction is significant for the organization of the company's R&D function and customer services. The finding called for rethinking the division of labor and means of communication within and between the key organizations. The analysis proved useful for revealing the shortcomings of, and the new requirements for, the routine clinical use of MEG in the hospital environment. The entire complexity of the new object, real-patient measurement, was for the first time recognized by the developers and managers involved. The activity-theoretical analysis helped represent the shop-floor "reality" with its conflicts to the developers for mutual reflection and discussion. The analysis showed how mutual understanding of the new object was mediated by tools, rules and division of labor which, however, were not the same for all the participants. The developed framework contributes to the current theoretical and methodological understanding of the significance of interaction and collective learning in implementation.

In the third [3] article, I applied and further developed the model of *interactive activity systems* used in the second article for analyzing the first attempt to implement MEG to clinical use in the Finnish hospital laboratory. The activity-theoretical concept of *contradiction* was applied to the analysis of the construction of a new, emerging object of activity, that is, the building of clinical measurement service. The analytical framework and method which focused on the concrete actions and their key turning points on the laboratory shop-floor proved useful. It helped trace the evolving perspectives of different actors on implementation and to reveal the disturbances and innovative initiatives of the users in the critical pilot phase of the implementation effort. The important key finding was that the sole responsibility of the physician-implementor for building the service was in contradiction with the organizational and technical complexity of the implementation. It is noteworthy that the users, the physician and the nurse, initiated attempts to solve the problems of implementation which pointed to the key systemic contradictions within and between the key organizations. Another important finding was that these improvised but relatively weakly articulated initiatives remained unrecognized as significant in the community. This indicates problems in communication both horizontally and vertically, and calls for a dialogical means for identifying and strengthening the actors' capacity to act for expansive change. The activity-theoretical framework used in the analysis appeared powerful enough to reveal how individual and collective actions are connected to the broadening of the user network and of the patterns of use during implementation. In this respect, the article contributes to the understanding of complex multi-organizational implementation processes, which is currently a theoretical and methodological challenge in implementation studies. It also helps identify collaborative-learning challenges within and between organizations and the groups involved.

In the fourth [4] article, I continued to test the framework for studying particularly the *changing object* of implementation started in the third article. I applied and further developed the *dimensions of expansion* introduced by Engeström (1987; 2000a) for analyzing the implementation of MEG in the American hospital laboratory when it was moving from the pioneering phase of implementation to a more established adoption to clinical use. To study the implementation of a technically complex system which also needs to be integrated to other existing or developing medical systems, I reformulated the dimensions to encompass also "artifactual" expansion to show how an artifact or systems of artifacts need to be developed and transformed in the context of the transitional activity. Different practitioner groups involved in the adoption were analyzed as activity systems, and the systemic *contradictions* of their expansive efforts were examined. The method of analysis which focused on the practitioners' expansive perceptions concerning the ongoing transition proved useful. It helped reveal the multi-voiced character of implementation and showed how difficult it was for the practitioners to create a shared understanding of what was going on in the process. The important finding, similar to the one in the third article, was that the expansive perceptions of the practitioners remained separate or isolated. It is also remarkable that application expertise seemed to be dispersed or isolated rather than shared among the practitioners. This indicates problems for the anticipated transition, and calls for a dialogical means to facilitate collective learning between the groups. The empirical findings gave support and strengthened the theoretical idea of implementation as a critical transition from one activity to another. The framework helped reveal how the implementation of an originally new tool calls for qualitative change in the pattern of work and organization. The analysis showed that perceiving the immediate and individual object of implementation is not enough. Instead, people need to understand and "re-invent" (expand) the entire pattern of work that often emerges with the new tool. The article suggests an additional or alternative understanding of implementation processes that are currently understood as adaptative.

To sum up, the study produced several empirically useful insights and new understanding on the social contexts of technological innovation, especially on the learning processes taking place in the producer-user relationship and implementation. The activity-theoretical framework appears relevant and applicable for studying the interactive processes of innovative activity. It is especially useful for studying implementation processes of originally new products involving collaborative expertise in use. The study is, however, only an opening and a first thorough introduction of an activity-theoretical approach to studies on innovation and implementation. The framework needs to be further tested with other cases in forthcoming empirical studies.

The key findings and implications of the articles are presented in Table 3.

	Findings and implications related to problems of producer –user relations and implementation	**Findings and implications related to critical learning challenges in the innovation process**	**Findings and implications related to the research framework**
[1]	Complexity of user needs and transition. Multiple users and user needs, and multiple producer communities with divergent motives were involved. A "trap": no community took responsibility for organizing the new tasks required for clinical use. Information about (individual) user needs may not be enough for understanding emerging needs in collective clinical practice. Analysis of the development and constraints of user practices and the producer-user network is needed.	Expertise was dispersed in the network, or it was still developing and emerging. Complex relations existed between key actors and communities. Expertise and responsibility for organizing new collaborative tasks are not ready and available: they need to be constructed through collaborative learning and negotiation.	The analysis showed the complex and multi-voiced character of user needs. The analysis framework (applied in the user seminar) could be used and further developed as a dialogical means of articulating emerging and collective user needs.
[2]	Critical transition of the technology from developers to users. Measurement breakdown revealed inadequacy in the organizing of measurements and in the system software that was incomprehensible for the clinical users. The system did not function as a tool for the users, it became a problem and the object of their activity. The shift toward a mature customer-intelligent product driven by co-configuration work may not happen spontaneously. It may require a deliberate attempt to resolve the developmental contradictions of the developers' and users' activity systems.	Misscommunication in the problem-solving situation. The distinct perspectives of developers and users in the situation hampered problem-solving conversation. The ability of developers and users to discriminate between tool and object is a vital feature of an innovation network capable of learning and change. Shared meta-tools are needed for facilitating learning and for dialogical diagnosis, problem solving and redesign.	The analysis showed how producer-user relations (also misscommunication) are both historically embedded and situationally constructed. The framework could be used to identify collaborative-learning challenges in the transitional phases of innovation. It provides the analytical means to analyze the possibilities and problems of interaction and tool use.
[3]	Critical transition from experimental use toward clinical use. The first attempt to implement MEG in clinical use at the Finnish hospital was interrupted. The sole responsibility of the physician (implementor) in building the service was in contradiction with the complexity of the implementation. Implementation needs to be constructed as a new, shared object of activity among the key participants. The resolution of historically accumulated contradictions within and between the key activity systems is required.	The users initiated improvised but weakly articulated attempts to resolve problems of implementation. The problems concerned not only questions of individual competence among the users and the managers involved, but also questions of collaboration betweerthe key activity systems. The individual user's potential as a boundary spanner is limited if the role is not recognized within the organizations. The participants' perspectives need to expand in the process through collaborative learning and reflective dialogue.	The analysis showed how individual and collective actions are connected to the broadening of the user network and of patterns of use during implementation. The framework provides a sensitive means of identifying constraints and learning challenges in complex multi-organizational implementation processes.
[4]	Critical transition from pioneer use to more established adoption. Each practitioner group at the American hospital had a partial point of view toward the adoption. Recurrent isolated individual expertise and responsibility were in contradiction with the challenge of establishing adoption to medical practice. The transformation of the artifact into a collectively-used tool may not be understood solely in terms of gradual adaptation between technology and organization. A qualitatively broader integration process - expansion – needs to take place.	The practitioners' perceptions indicated expansion in the object of implementation. Expansion revealed the urgent need for – but also the difficulties in –transferring individual expertise to a user collective. A product champion is not enough for sustaining the use of the artifact – expansion is needed. Expansion involves the practitioners recognizing the different objects of implementation and adoption. Shared meta-tools are needed for facilitating learning and reflective dialogue between groups.	The analysis showed the multi-voiced and multidimensional character of adoption, consisting of heterogeneous occupational groups and multiple organizational contexts. The framework provides a complementary perspective on the key processes of learning in the adoption of complex technologies.

Table 3. Key findings and implications, presented in relation to problems of producer-user relations and implementation, critical learning challenges, and the research framework and methodology.

Drawing together and interpreting the findings in terms of the developmental process of implementation

In the previous section, I discussed the findings and implications reported in the articles mainly independently from the transitional process, or developmental trajectory, that they highlight together. The articles were said to open four different windows into the implementation processes of the neuromagnetometer. The "windows", however, represent also different developmental stages of implementation when moving from experimental research use towards clinical utilization. The first three articles followed a local developmental trajectory from experimental clinical use, carried out by individual physician-researchers [2], to the first attempt to organize clinical measurement service [3]. This attempt was triggered by the clinical user seminar reported in the first article [1]. The implementation in an American hospital reported in the fourth [4] article represents a step forward in the implementation process, namely the challenge to consolidate and expand the introductory-type clinical use. When related to the local Finnish process, the stage of implementation in the American hospital represented to me a medium to observe the systemic conditions of the forthcoming developmental phase of the implementation to clinical use, not to make comparisons between contexts of use (i.e., cultural differences). What do the articles, in this respect, tell us about the developmental challenges of the implementation of an originally new high-tech device such as the neuromagnetometer? In what ways are the findings in the articles similar or support each other?

All the articles showed, in different ways, the multiplicity and complexity of the critical transition. The analysis of the user seminar [1] opened up various preconditions for clinical use, that is, a need for standardized procedures for interpretation and collection of reference and control data. The shortage of, and the urgent need for, such collective means and shared rules of interpretation became apparent in the practical use situations and in the practitioners' concerns reported in the other articles. The local Finnish attempt to organize clinical service became hampered and waned partly because these intermediate means, or more likely the expertise and resources needed for their construction, were dispersed in the network, and because the key organizations were unable to collaborate for the creation of those means [3]. Interestingly enough, the problem of standardized procedures was not resolved in the American hospital either representing the "next" stage of implementation, as was revealed in the fourth [4] article. This indicates the significance of the *standardization of procedures* for the establishment of MEG as a clinical tool. It is not only a question of local collaboration but also a question of the entire MEG community.

Not only was the urgent need for intermediate practical means and procedures revealed, but also the need for a shared means of identifying the critical transition as well as a means of common sense-making in terms of the emerging new object of activity. It is noteworthy that, when looking at the everyday work actions, the organizations and their practitioners performed in the implementation processes as if separate entities. This observation was striking not only in the case of the local Finnish process [2,3], but, to some extent, also in the American hospital laboratory [4]. Why is that?

It was shown in the articles that the participants had separate, partial or isolated perspectives toward the ongoing transition [3, 4]. Separate and partial perspectives were due to divergent historical backgrounds and positions that the participants carry with them to the implementation processes. This affects, for instance, the participants' image of themselves and others as having a voice and a capacity to act as change agents in their circumstances. The second [2] and the third [3] articles revealed that the developers and managers typically did not "see" and "hear" the problems or innovative initiatives of the shop-floor users. The users themselves tended to under-estimate the power of their actions. The findings indicate both horizontal and vertical problems of communication. It was shown that dialogical means of communication are needed as a first step to start creating shared perspectives and in this way overcome the contradictions within and between the activity systems. The need for common sense-making does not wane but intensifies as the implementation proceeds and new communities and other related technologies join in the process [4].

All articles showed that the prevailing individual work pattern related to the experimental research use was in contradiction with the new requirements of clinical use, calling for more collective and collaborative patterns of work. I assume that this contradiction shows so clearly partly because of the specific case in question in which one of the key requirement for the established clinical use is the mutually negotiated and accepted set of clinical standards. The series of the articles reveals also how the emphasis on the developmental process of implementation moves – or needs to move – from the discrete and isolated tool use toward integrated use as part of a tool system meant to serve particular medical practice. This process, conceptualized as expansion, constitutes a major collaborative-learning challenge for both the developer and the user organizations and cannot be understood solely as a gradual adaptation between the technology and the user environment. It is suggested that the critical learning-challenge during implementation is to understand, simultaneously, the dual role of the device both as a tool in a particular work practice and as an object of product development. Development toward integrated use may also indicate a need to rethink the strategic business position and the core expertise of the developer company, currently focused on the development and sales of the neuromagnetometer only.

Challenges for further research

The present work is an empirical case analysis. I studied a trajectory of a technological innovation (the neuromagnetometer) and its early implementation into clinical use in two hospitals (one in Finland and one in the United States) during a certain limited period of time (1996-1997).

The study provides some new insights into the opportunities of a boundary spanner or a product champion to resolve problems involved in complex implementation processes. I observed from the literature that the broker function of product-champion roles and the interface function of boundary-spanner roles are not distinguished when it is the role of the key individuals and groups in the innovation process that is under scrutiny. These roles were not the main focus of research this study. Interesting opportunities for more systematic further research involve questions of how champions and boundary spanners in and between organizations emerge, evolve and transform over time, and what constitutes the constraints and limitations of these organizational functions in the innovation process.

These questions could be connected to broader issues concerning the dynamics between individual and collective expertise in the innovation process. The problem of moving further from the pioneer phase of innovative activity - dominated by individual practitioners or centralized groups - is typical. The dynamics of "collectivization" – or expansion - of expertise and responsibility within a certain interactive process are not analyzed in detail in studies on innovation and technology. Interesting questions for further research include what facilitates - or hampers – the emergence of shared meanings, responsibility or expertise and, particularly, how shared meanings can be facilitated and strengthened in an organization or a network.

Studies of innovation have somewhat neglected agency in terms of ordinary practitioners and shop-floor workers. In the present work, concrete efforts by users to cope with the new technology are documented, and the developmental potential of their problem-solving initiatives is analyzed. They have practical – contingent – knowledge about the implementation. This "non-technical" knowledge may be vital for successful adoption, and it should be carefully acknowledged. It is suggested that all practitioners – not just high-ranking experts – need to be seen as partners in product development. An important question for further research concerns how the users' agency, or capacity to act, could be identified, clarified and strengthened. Equally important is the issue of how developers' capabilities for recognizing user problems and initiatives can be strengthened.

In my study, various learning challenges within the innovation process were identified and opportunities for facilitating learning were sketched. The research strategy was not consultative, however. During the research process, the preliminary findings and analyses were discussed with representatives of the organizations in question. Although these presentations and discussions were not considered interventions in terms of a particular intervention strategy or method, or of a specific schedule, they could be seen as preliminary interventions in terms of representing the significance of shop-floor problems or facilitating shared understanding about the problems among the participants. Nevertheless, these occasions were dialogues rather than purposeful interventions by the researcher.

Although the participants considered the user seminar and various other meetings held in conjunction with the present research useful, developing methods of dialogue and intervention in order to purposefully facilitate learning is clearly a matter for further study. Significant questions for further research and development include how shared meta-tools for facilitating learning and dialogue could be developed and applied "on-line" during an innovation process.

Another interesting question is whether the problems found in this case were unique to this innovation and setting, or whether they are common to other types of innovation and products. This particular innovation, a new measurement instrument for brain research and diagnostics, is a complex system integrating leading-edge technology and data acquisition and analysis software. User competence is significant for the development of clinical application, and for the organization of the services. The device is an example of a product which allows for and requires continuous readjustment and reconfiguration – co-configuration - in use (Victor & Boynton, 1998). However, medical equipment and computer software systems may not be the only industries in which co-configuration is beginning to define the competition. Customer-related problems in learning co-configuration work also need to be studied in the production of new services and in technical products which integrate services.

Fundamentally, studying the specific transitional phase of the neuromagnetometer innovation was for me a medium to apply, test and develop, on a concrete and empirical basis, a potential new research framework for studying innovations and innovative activity (Eisenhardt, 1989). My thesis is not that the results are empirically and statistically generalizable to certain population of implementation processes. Rather, I have tried to apply this framework not only to reveal complexity, but also to make sense of it. By building on theoretical and empirical literature on innovation and technology management, and drawing on a theoretical framework sensitive to systemic relationships, I have tried to assess what are the most important phenomena and relationships in the implementation process, and what was simply idiosyncratic. I hope that this introductory essay has shed light on what I found to be the most important issues.

I am unwilling to “raise the level of generality of the theory” (ibid.) if the criterion is to suggest the framework is a “grand” theory of innovation. That is not my intention. I have produced suggestions about phenomena such as producer-user relations, implementation and learning within the innovation process. Such suggestions, or theoretical arguments, are likely to be testable and empirically useful. To their credit, many of these suggestions tie into theoretical issues such as development, learning and organizational change. In this work, I developed the conception of critical transition from developers to users as a potential new, dynamic perspective to integrate the above-mentioned classic themes of innovation. My work with these questions will continue.

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