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Spaces of innovation: Experiences from two small high-tech firms

Introduction

Today the capability to innovate is vital to enterprises, particularly to high-tech firms focusing on producing innovative products for markets. Global economic competition exploits new knowledge and innovations, which has led to a growing interest in the preconditions for innovations in both science and policy. Also, studies of innovations have developed towards cross-disciplinarity as there is no single discipline that deals with all aspects of innovation (Fagerberg, 2005, p. 3). With its focus on innovation processes and learning, this article bases its framework mainly on social scientific insights.

Studies of innovation processes range from the level of innovations systems (Camagni, 1991; Kautonen, 2006; Lundvall, 1992; Schienstock and Hämäläinen, 2001) inter-organizational networks (Bessant and Tidd, 2007, pp. 81–91; Dooley and O'Sullivan, 2007; Keeble and Wilkinson, 2000; Lubatkin *et al.*, 2001) and firm-level analyses (Lam, 2005; Lazonick, 2005) to the analysis of innovators (Powell and Grodal, 2005) and experts (Parviainen, 2006) as the key figures in the processes. No matter what the level of the analysis is, two themes are common in recent studies: cooperation and learning (Lehenkari, 2006; Pavitt, 2005; Powell and Grodal, 2005). A key issue in understanding and supporting innovation is to approach it as a process – " an extended set of activities that translate new knowledge into something of value" – as John Bessant and Tim Venables (2008, p. 3) define it. In producing new knowledge for the purposes of innovation, communication, cooperation, knowledge sharing and learning together are needed between the different contributors to the process.

The process view allows us to recognize the different stages of the innovation process, starting from the discovery of ideas to their realization and later to the nurturing of the product (Bessant and Tidd, 2007, p. 16; Taatila *et al*., 2006), as well as the differing knowledge and learning needs at these stages. Another issue is to understand innovation as a contingent phenomenon. Innovation processes differ in many respects by the economic sector, field of knowledge, historical period and country concerned, as well as by type of innovation (Pavitt 2005, p. 87). Also the degree of newness of an innovation essentially determines what kind of knowledge is needed. Radical innovations that bring something fundamentally new to the market require different kinds of knowledge seeking, knowledge production and learning than incremental innovations that improve already existing technologies (Dewar and Dutton, 1986, pp. 1422–23).

This article focuses on firm-level innovation processes with the understanding that spaces of learning cross organizational boundaries. The emphasis of the analysis lies on the firm-specific preconditions to mobilize a knowledge base for the service of innovation activities. Since innovation processes take place in business contexts, in their examination attention needs to be paid to the structures, practices and cultures that define the boundaries for innovation activities among other activities in the firm and that may also create a tension-filled context for the activities, as Rosabeth Moss Kanter (1989), for example, has shown in her analysis.

Here we employ the concept of space to capture the conditions for innovation activities in the day-to-day life of the firm. By space we mean the network of relationships, which creates conditions for human action and interaction (e.g. Heiskanen, 2007, 9–14). Following Henri Lefebvre (1998), we differentiate between the mental, social and physical aspects of space and, influenced by Tor Hernes (2004a, b) and his interpretations of spaces in organizational contexts, we pay special attention to the mutual relations between mental, social and physical spaces.

The underlying assumption in this article is that learning is part and parcel of the firm's capacity to generate innovations. Repeatedly occurring needs for problem solving and generation of new knowledge in the innovation process require learning at individual, group and organizational levels (cf. Fenwick, 2003, p. 124; Crossan *et al.,* 1999). Our starting point here is that through the concept of space we can gain insight into the context of innovation activities which shapes along with the innovation process.

Our analysis concentrates on two industrial cases. The field of innovations concerned is medical technology and, more specifically, radiotherapy. The two cases to be presented are in many respects comparable, although one was found in the research literature and the other is based on our own case study. Two small high-tech firms, one in Sweden and the other in Finland, have both developed dose planning software for radiotherapy and gained commercial success; this software, which originated in Finland, is presently the best-selling product of its field in the world. In this article we ask the following questions: What are the key characteristics of the innovation processes in the case firms? How do the mutual relationships between mental, social and physical spaces explain the different pathways in the innovation processes in the case firms? In the discussion we reflect on the significance of the evolving and shaping spaces especially from the perspective of cooperation. One of the key issues in this empirical setting, as also more generally in innovation processes, is the question of combining different knowledge sets into something new. We also discuss the implications of applying the concept of space for promoting cooperation between people with different knowledge backgrounds.

Mental, social and physical spaces

Recent trends in organizational studies have drawn attention to the combinations of various physical, social and mental settings in which knowledge production and related learning takes place. The approaches focusing on spaces or communities of learning

rightfully pay a great deal of attention to the social and mental aspects of the setting (e.g. Bereiter and Scardamalia, 1993; Billett, 2004; Nonaka and Konno, 1998; Wenger and Snyder, 2000); nevertheless, when the focus in general is on innovation processes which not only deal with development activities but also are linked to mainstream activities of an organization (cf. Kanter, 1989, 1990), according to our view, proper attention needs to be paid to the regulatory aspects of the organization as well.

Our work introduced here is based on the concept of space as presented originally by Henri Lefebvre (1998) and applied and further developed in organizational contexts by Tor Hernes (2004a). In his theory Lefebvre has differentiated physical, social and mental spaces. By physical he refers to the material aspects of our surroundings, by mental to the world of theory and meanings, and by social mainly to social relationships. Hernes has used this differentiation of the types, or aspects, of spaces, and given them a definition in organizational contexts. His basic starting point is that the concept of space opens a view to the emerging contexts of action and interaction (2004a, p. 65), while, for example, the concept of organization is a bounded and inward-looking notion (ibid., pp. 4–8).

Hernes defines physical space to refer to "tangible structures created principally in order to regulate work and interaction" (2004a, p. 71). In addition to material facilities, these include budgets, electronic domains and work schedules, for example, which might also be called regulatory structures (cf. Kalliola *et al.*, 2006). Social space evolves, according to Hernes, "from interactions that form relations of a more predictable nature" (2004a, p. 71). Hernes characterizes social space as a "glue" that is relations-based; some examples of this are trust, social identity, love, dependence, loyalty and behavioural norms. Mental space is, according to Hernes, basically the space of thought, consisting of, for example, knowledge, learning and sensemaking (Hernes, 2004a, pp. 70–72).

An important contribution by Hernes to the discussion of spaces is his explicit attention to boundaries (Hernes, 2004b). He argues that to speak meaningfully about spaces they must be located, represented spatially (Hernes, 2004a, p. 65). For this purpose he introduces the concept of boundaries. He suggests that social organization emerges through the processes of drawing distinctions with the help of boundaries. Further, he argues that the mechanisms that govern what goes inside the boundaries differ depending on whether a space is considered to be physical, social or mental (ibid., p. 80). Physical boundaries are usually tangible and relate to formal rules and physical structures. Social boundaries are largely given by the social bonding between people. Mental boundaries relate to ideas, understandings and beliefs. While physical boundaries are often visible, social and mental boundaries are in many cases invisible and only become manifest in the event of a transgression (Hernes, 2004a, pp. 80–82).

Another noteworthy contribution by Hernes to the theorization and empirical work around space is his notion of spatial dynamics. With the assumption of the emergent nature of spaces, there will always be moves towards something different. Hernes assumes that changes occur as a result of interaction between spaces and presents an illuminating example of this interaction (Hernes, 2004a, pp. 132–133). In the start-up phase when an innovative idea is being turned into a business, social space is needed in

which enthusiasm, trust, mutual support and cohesion prevail. After the idea has been processed into a marketable product, what need to be organized are sales, marketing and production, which in turn increases the need for coordination. Techniques, models and methods required by some processes take over the role of direct social interaction and the evolution towards a physical space of coordination, and regulation starts. The original, shared spirit of entrepreneurship characterizing the mental space formed in the early stages may still prevail among the original group of founders of the firm; most other employees might remain detached from it. At some later stage, perhaps, new social and mental spaces are required in order to keep the innovative spirit alive.

In comparison to the widely cited publications by Lave and Wenger (1991) and Wenger and Snyder (2000), for example, who have written about communities of practice, and the publications by Nonaka and his collegues (Nonaka and Takeuchi, 1995; Nonaka and Konno, 1998) who have written about spaces of knowledge production, the concept of space by Hernes has certain strengths. We consider that his focus on the emergent nature of spaces, on the notion of repeatedly drawn boundaries and on the idea of different types of interacting spaces provides advantages for studying innovation processes that both take place within a bonded organization and transgress its limits.

The context of innovation challenges

The two case firms, Helax and Dosetek, share a common ground as regards the incentives for innovation. At the beginning of the 1980s, both firms participated in a joint Nordic project called the Computer-Aided Radio Therapy (CART) project, among whose participants were researchers, developers and enterprises from Finland, Sweden, Norway, and Iceland. The project, whose activities were funded by a Nordic industrial foundation, set as its objective to develop an integrated information system for radiotherapy (The Goal of CART 1988). The process of producing radiotherapy involves several kinds of machines and equipment, and the challenge was to make the different parts of the process work and communicate with each other. Lack of standards concerning the information flow between different machines magnified the difficulty of this task. Even though a considerable amount of time has passed since the start of the project, the vision of an integrated radiotherapy process is still highly valid and poses challenges continuously. The project participants worked on three processes – dose calculation, image handling and treatment control – and developed a CART standard which included a nomenclature and communication format for radiotherapy. From the point of view of this article, the system of dose calculation is especially interesting, since the main products of both firms relate to it. Dose calculation is needed to estimate the amount of radiation that the tissues of the body can absorb.

The CART project functioned as a learning space with far-reaching results. By organizing seminars and workshops it made possible encounters between research and industry. It yielded both scientific results and new products for markets and gave rise to new enterprises. Through various international activities the project made its achievements and challenges for future development in the field of radiotherapy visible

for both researchers and clinicians. For the participants it provided inspiring experiences and was seen in some sense as an epoch-making process, as the following interview excerpts indicate:

> "It was an exceptional project. Few research projects yield commercial products, but this one did. And it gave rise to industrial enterprises, such as Helax, and, in some sense, also Dosetek. Dosetek already existed but it got air under its wings from the new product." (IT specialist).

Another participant says:

> "I must say that during the CART project the window was open, it [the project] was timely in many senses." (Clinical physicist)

The case firms and the data

This study provides a comparative setting in which the results of our own case study are compared to a case whose key characteristics are similar to those of our case. The data concerning Helax is from a case study conducted by Rögnvaldur Saemundsson (2004). His study is based on interviews made within two time periods between 1998 and 2001; seven people working for Helax were interviewed and additional data was collected from the firm's website and from articles in the popular press. For the purposes of this article, and after the publication of Saemundsson's article, information about the events around the firm, such as ownership arrangements, was retrieved from the Internet in 2006–2007 and, in the context of the Dosetek case study, via one informant with cooperation relationships with Helax. To make the comparison possible and understandable to the reader, some core characteristics of the Helax case are described. For analysis the case was read from a space perspective defined for this study, which is one form of a secondary analysis (cf. Heaton, 2004, p. 37)

The data on Dosetek comes from our own case study. According to the tradition of case studies (e.g. Yin, 1989), different types of data were collected: interviews, writings, documents and observation notes. Nine key persons (all men) who worked or had worked in the firm or had close cooperation relationships with it were interviewed, five face-to-face, three via telephone and one who worked abroad via e-mail. The interviews were tape-recorded and transcribed, the length of the interviews varied from 1.5 to 3 hours. If needed, complementary information was obtained via telephone or e-mail. The written material includes ten presentations written for the 25th anniversary of the firm by its employees and co-operation partners, journal articles about the firm, three doctoral dissertations on the technical foundations of the firm's products, and other kinds of documentary material related to the products, as well as reports concerning the CART project. Also the use of the dose planning programme in a clinical setting was observed, and the researchers received a demonstration of how the novel work methods differed from the methods used earlier. The data was collected in the period 2006–2007.

In the interview situation the interviewer had a checklist of themes which varied according to the position of the respondent but, in all other respects, the interviews were more like dialogues than predetermined sequences of questions and answers. The whole data set formed a basis for the analysis of the interviews, which were analysed according to both their holistic content (cf. Lieblich, 1998) and themes.

Key features of the innovation process at Helax

To understand the kind of social and mental space that prevailed at Helax in its early years, we need to go back to the ideas that originally gave rise to the founding of the firm. Helax was founded in 1986 by three staff members of the Uppsala University Data Centre (UDAC) that participated in the CART project. The founders, with university degrees in physics, mathematics and computer science, had experience in the use of computers in medicine. For example, cooperation between the UDAC and Siemens, which is one of the largest manufacturers of radiotherapy devices, had made them familiar with the development challenges of computerized dose planning systems. The founders considered the results of the CART project encouraging and wanted to bring the vision of the project further.

In its early years Helax employed 20 people, 13 of whom had moved over from the UDAC. At the time when the firm was being established, its founders had successfully applied for substantial funding from public and private sources to secure development activities for three years. Both the composition of the staff and the financial basis left their distinctive marks on the social and mental space of the firm. The secured funding enabled the group to continue working according to the values, norms and working habits derived from the scientific community without any pressures from the business world. By the time Saemundsson conducted his research, the situation had become remarkably different. The firm employed about 90 people and was a unit of a Canadian company, MDS Nordion. The arrangement was, however, not as beneficial as it was hoped, and a few years later (2003) new arrangements were made with another company, Nucletron.

Next we illuminate the internal life at Helax with a critical incident (cf. Chell, 2004). The described events took place in a growth period when Helax had succeeded in gaining a footing on the market thanks to its successful partnership with Siemens – a big player in the field of medical technology. We think that this incident presents a key to understanding the dynamics between the physical, social and mental spaces at Helax.

The first four years of its operation the firm focused mainly on developing a product which would promote the CART vision. In 1990, a marketable dose planning product was ready, and its early sales started in hospitals in Sweden and other Nordic countries. Originally the product was tailored to meet customer needs, which was beneficial from the point of view of customer satisfaction and produced customer feedback for further product development. However, when the sales of the product increased substantially, the firm needed to rethink its action model accordingly.

One area that proved to be especially problematic in the face of the new demands was programming work. The programmers felt that Helax gave them no chance to keep abreast of the latest developments in their fields of expertise. For example, they had to do programming work with a language that specialists considered outdated. This was an unsatisfying situation from the point of view of the programmers' labour market prospects as well, and eroded the credibility of Helax as a forerunner firm.

> "This was the dilemma we had … Fortran programmers. You program in Fortran but then you realize that other programming languages are becoming more popular. But you don't need them in order to keep on programming [in the company]. But if I continue to program only in Fortran and [it becomes obsolete], not in the company, I will not be valuable [on the job market] because nobody wants to employ a Fortran programmer." (Saemundsson, 2004, p. 417).

At first the leaders did nothing to solve the dilemma, because their first priority was to secure the conditions for providing products for markets to meet the increased demand. Finally, however, they had to take seriously the pressures coming from both the labour market and the customers. In general, software developers were in high demand in the labour market at that time. Because Helax failed to identify itself as the most sophisticated firm in computer technology, it started to run into recruitment problems. Also its customers followed the new technological development trends and wanted modern programmes and devices.

The wishes expressed by Helax's customers focused particularly on their desire to start using standard PCs with a Windows interface. The solutions sold by Helax were based on the use of special-purpose computers for radiotherapy. As it became apparent that the wishes of the customers had to be taken into consideration, the firm first attempted to respond to them by outsourcing the updating of the dose planning programme to the PC platform and the NT operating system. However, outsourcing proved to be very expensive and, in retrospect, also an unrealistic way to meet the development challenge:

> "We have argued that we could outsource the development process and only provide the specifications of what is to be developed. But it does not work." (Saemundsson, 2004, p. 418).

After the failed attempt at outsourcing, the firm chose another mode of operation to develop programming work and focused on organizational matters by introducing a quality system to make programming work more dynamic, systematic and effective. Deficiency in expert knowledge was also alleviated by recruiting new expert employees for programming tasks.

According to our interpretation, the internal crisis resulted from a collision of different mental spaces. The core personnel who had been involved in the activities of the firm already at its founding stage defined radiotherapy as its core knowledge and competence. In that framework, the new programming language was a secondary development area,

and this line of thinking finally led to differences in the mental spaces of the core group and the technical staff.

Since the identity of Helax had originally been formed by the firm's core founding group, the latecomers did not carry the same weight as members of the firm as the core group did. Consequently their problems and wishes were not taken into consideration adequately. The firm took the dilemma seriously only when the image of the firm and its possibilities to hire programmers were at stake.

Key features of the innovation process at Dosetek

Dosetek was founded in 1980 as a one-man firm. Based on its founder's earlier experiences in the field of radiotherapy, the firm's main task was to produce equipment for radiotherapy. At first it produced radiation beam scanners, although its own strategic vision did include a broader product and service range from the start. The founder kept his eyes and ears open for new possibilities. This openness to new opportunities also came to characterize the social and mental space of the firm. A window of opportunity opened when a large American medical equipment producer Varian was seeking an agent to sell its products in Finland. Dosetek had a good knowledge of equipment and people in the field of radiotherapy, which probably resulted in the fact that it won the competition over the agent position and gained the agent contract.

Cooperation with Varian started to play a big role on the development path that Dosetek pursued. As an immediate impact of this, the gains from the sales of Varian's products to hospitals improved Dosetek's financial situation and provided resources for developing its own products. For product development the firm hired a physicist with basic qualifications in computer science. The physicist was prepared to stretch his expertise and enter into fields where crossing disciplinary boundaries was needed. He worked at Dosetek as its owner's right hand in the period 1984–1999. This cooperation relationship between the owner and the physicist (called production manager in the excerpts) can be interpreted to be a factor that contributed essentially to the development of the mental space in the firm towards a climate that allowed experimenting and risk-taking in connection with innovations.

What generated product ideas at Dosetek was its employees' good knowledge of the equipment and needs of the customers in radiotherapy clinics, which in turn brought about plans for new measurement and calibration devices for radiotherapy. With these products Dosetek gained access to hospitals although its sales figures were not high enough to ensure financial resources for product development in the long run. Consequently the firm started already at a relatively early stage to look for possibilities to export its products to other countries. Along with its efforts, Dosetek clinched a deal with Varian, according to which Varian added Dosetek's products on its own product list and started to represent them worldwide.

Even though the agent contract with Varian was financially highly beneficial for Dosetek, the firm could not rely too much on selling another firm's products for its future survival.

Among the boundary conditions it had to take into account was the life cycle of its products. For example, linear accelerators used for radiotherapy normally have a life cycle of 15–20 years, which is a fairly long operating time and concerns also many other products. For a firm selling these kinds of products this means that it either has to find new markets for the existing products or plan and develop new products to sell.

At that point, Dosetek needed ideas for new products. The Nordic CART project provided a forum for exchange of ideas and experiences between research and industry, and thus Dosetek joined the CART community.

Another Finnish partner, the Medical Technology Laboratory of Technical Research Centre of Finland (VTT), also participated in the CART project and it was through CART that VTT and Dosetek ended up in a cooperation relationship. VTT had developed a dose planning system to be used via computers. The basis for this development work at VTT was a Dutch calculation algorithm for estimating the absorption of radiation into tissues. Finally VTT sold its dose planning programme to Dosetek in 1986 and the contract started a new phase in Dosetek, even though its effects on the firm's day-to-day life and economic results became fully visible only several years later.

That was when Dosetek had to make important decisions about the further development stages of its dose planning system. The solutions it chose reflected the mental space of the firm, in which the leading principles were to optimize the conditions of product design and to pay attention to practicality but at the same time to prepare mentally to live under risk. Making a choice between IT technologies was among the risk-prone decisions with far-reaching consequences. Other producers of dose planning programmes typically used VMS computers and tailored image processing systems. Dosetek chose a commercial platform which included sophisticated image-handling. The presentation of X-ray and CT-images had proved to be a substantial challenge for the designers of dose planning systems, and each one had developed their own solutions to it. However, Hewlett-Packard had for the purpose a commercial product that Dosetek decided to utilize.

From the point of view of technology, the choice of the computer was not a total leap into the unknown: "We had earlier experiences of these workstations" (manager). But, thinking of the marketing perspectives, the decision implied a considerable risk.

> "We were thinking about the marketing risk. Does the hospital accept this kind of UNIX machine among the VMS machines? It [the machine] is then a strange fowl [among the other machines]." (Production manager)

The dose planning programme resulted in a need for new human resources. In 1986, Dosetek employed five people and in 1989 as many as nine people. New kinds of efforts and solutions were needed also in marketing. The sales of the programme got a good start, but it was evident that the resources of this small firm were not enough to boost worldwide marketing. Finally Dosetek's business relationships with Varian offered a route to a stronger foothold first in Europe in 1992 and later in the USA in 1996.

Dosetek's business relationships with Varian proved out to be highly beneficial. In 1993, the two firms' ties were tightened when Varian bought Dosetek. Selling the firm was not an easy solution to the founder of Dosetek, who nevertheless considered it necessary for the future perspectives of the firm and sarcastically commented on the situation as follows: "[The firm's] soul is lost, but money is coming in". The firm started a new period under a new name Varian-Dosetek as a unit of the international company. It continued its radiotherapy equipment production as well as further development of the dose planning system. However, the context of doing the work changed fundamentally. The new ownership arrangement resulted in a growth period, during which the number of the unit's staff gradually increased from 9 to 60. The working environment became more international, and the unit gained a number of international cooperation partners. In economic terms, the new period was very successful. The development of the dose planning programme proceeded favourably, and the product became the best-selling software of its field in the world. For the staff, however, the new context was not unambiguously a positive experience. Formalization of activities and the felt presence of the parent company changed the rules of organizational action and culture.

Dosetek's mental space was vitalized via the new international cooperation partners. It had already earlier actively participated in different kinds of development projects and appreciated the possibility to have a wider international cooperation, taking it as an opportunity and challenge. Even though these new incentives in the mental space were valued, this positive effect did not compensate for the fact that the physical space – rules and procedures – started to intrude into Dosetek's internal autonomy.

During the firm's first years under Varian's ownership, Dosetek's employees were able to resist too strong an influence exerted by the parent company by guarding well the boundaries of their own social space. Although the company headquarters held the reins and all plans needed an approval from California, some amount of independence in decision-making remained within the unit. The situation changed in 1999 when Varian reorganized its activities worldwide and continued under the name Varian Medical Systems. As a result of this, the unit in Finland was renamed Varian Medical Systems Finland Oy. Both symbolically and concretely this meant breaking the historical ties with a company called Dosetek. Despite this, the firm continued to grow; at the time of writing this article, the number of its staff amounts to about 90. From the viewpoint of the staff, who felt that regulation by the parent company penetrated the unit's all activities and culture and that the logic of the quartal economy became the guiding principle of its activities, the growth period did not bring with it only positive effects. Feelings of dissatisfaction increased among the staff and finally some key persons left the unit, including some of the most qualified programmers and the production manager, who had worked as the founder's right hand from the beginning of the firm.

Product development at Varian Medical Systems had proceeded towards the early CART vision, i.e., the integration of the radiotherapy process with the information system, and gained commercial success in that development path. However, Dosetek's employees were sceptical about the usability and technological properties of the information system.

They considered that the system had become too huge and too difficult to install and maintain. They were also sceptical about the possibilities of the company to develop more elegant technological solutions and were of the opinion that it would require going back to basics and taking a fresh start towards new technological solutions. The founder of Dosetek, however, did not consider this to be possible within the present organizational context:

> "It should be written anew but this kind of company that lives according to the cycles of the quartal economy does not invest in anything entirely novel."

Innovation processes and the dynamics of spaces – A comparison of the cases

The two case firms, Helax and Dosetek, are similar in many ways. They are both small high-tech firms that realized their cooperation potential in product development in a joint Nordic forum in the 1980s; they had similar main products, and during their development path they both eventually ended up as units in large international companies. Here we, however, pay attention to the factors that made them substantially different as contexts of innovation activities. We interpret these differences through the concepts of physical space, social space and mental space, and the mutual relationships between the three spaces.

The financial basis of the firms at the start contributed directly to the form of their physical space and indirectly to their social and mental spaces. In its start-up phase, Helax had venture capital that enabled the firm to run its operations for three years without revenues, which in turn created a physical space from the perspective of development activities. This is to say that the tangible outer limits for activities allowed and were supportive of development, innovation and science-based orientation without much attention to business-like affairs. At a later stage when more attention had to be paid to financial matters, customers, markets and organization of production, the physical space had to change, and it did change with tension-filled consequences.

At Dosetek, the situation was different. From the beginning it had to make money for its development activities by selling its products and services. Thus, Dosetek sought innovations within its physical space which was originally formed for running the business and taking care of interfaces with customers and market issues but which at the same time also had to acknowledge the need for innovation. At different stages of the firm's development path, its market prospects gave an impetus to innovation activities. The following excerpt exemplifies one of such situations:

> "Then became a stage that we had sales but it was decreasing in Finland. The radiation products business proceeds [in cycles]. Almost all [clinics] buy at the same time new machines and equipment. It goes in 15–20-year cycles. Then one has to wonder what to do when the sales finishes. One doesn't live only on [producing and selling] measurement equipment [which were the first products of Dosetek]." (Manager).

Human bonding always shapes social spaces. In this case, both Helax and Dosetek had a relatively strong firm identity, which gave their social spaces a particular character. There were, however, some substantial differences in their identity formation, which in turn affected interaction between different expert groups. At Helax, the divide between the core group and the others led, even though largely unintentionally, to the emergence of inclusion/exclusion mechanisms. The "we" did not refer to the entire staff but to the core group, as the following reflective statement, for example, reveals:

> "Then we took a look at our employment records…this company has had a turnover of new people that is one and a half times its size in the last five years. But we say that in this company nobody leaves. Why do we say that? Because the 20 core people, they never leave. These are the people that express the mission, these are the people that ARE Helax." (Saemundsson, 2004, p. 418).

At Dosetek, the relationships between different groups were more about differences in competences than about differences in the meanings related to the importance of the specific expertise for the firm. The owner-manager, who had good experiences of having one of the physicists as his right hand but who also recognized the high value of the IT experts' work for the success of the firm, expressed openly his admiration for both groups. One example of the success was an invention (concerning reverse dose planning) made by one of the IT experts, which gave competitive edge for the firm. The following excerpts illuminate how the experts themselves saw the situation.

> Interviewer: "The firm is in the field where the know-how of physicists and IT experts (programmers) is needed. How has it worked?"
>
> Physicist: "I studied myself computer sciences on the side of physics. We were no computer gurus. One can say that my skills [in computers and programming] were not good but somehow satisfactory for the tasks…When the calculation lasts long [the IT people] share it to many processors, they optimize it. We [physicists] make the rough code. We say that the calculation task would be this…this should be calculated quickly, we can do it slowly."
>
> IT expert: "Mainly the physicists have worked on the borderline between the firm and the customers, while the programmers have built the programme. This is a fairly reasonable division of tasks… But when the physicists have taken over the customer borderline, the programmers did not have sufficient knowledge of the needs of the customers. Some physicists were awkward code makers: intelligent enough to make their programmes work in spite of crucial in-built errors in them. The difference between a bad code maker and a physicist is that an ordinary programmer cannot make the badly planned programme function but for a top-physicist everything is possible…Fortunately many [physicists] finally became quite skilful in their work."

In the shaping of the mental space (or, in fact, mental spaces) at Helax, two starting points were decisive. One was the CART vision to which the founders and the early stage staff were committed and of which they had a shared understanding. The latecomers did not have the same passionate commitment, which led to differences in mental spaces. Another starting point was the background of the founders and their colleagues in the scientific community. The development of algorithms illustrates tellingly the norms and ambitions derived from the scientific community.

> "They tried in algorithm development to get more complicated calculation methods, the kinds that would give the absorbed dose distribution more exactly. To date, Helax has not been able to utilize the extremely effective algorithms that they have developed. At first the calculation capacity was not sufficient. It took even six hours to make the dose plan if one wanted an exact absorbed dose distribution. Such a concept doesn't do well in interactive working… Dosetek's concept was lighter. They applied algorithms which had been found reliable." (Clinical physicist)

For many years Dosetek had been a one-man firm. The orientation of its founder had played an essential role in the formation of mental space at Dosetek, whose characteristics included active search of opportunities and openness to new ideas with a focus on product development. These features remained with the firm throughout its growth period. An illustrative example of the characteristics of Dosetek's mental space was the founder's orientation to keeping abreast of technological development.

> Manager: "One thing is that one must run after those who make the hardware at a reasonable price. [But] it must be most updated technology. I myself read pretty much many kinds of journals and magazines…For example, about the development of Windows NT, I read about it much ahead."
> Production manager: "Peter (the manager) has had a habit of buying the most sophisticated machines and equipment. It has been a distinctive feature in that work environment."

As pinpointed earlier, what gave Dosetek its competitive edge in comparison to Helax were the choices made in acquiring IT technology. Another example of the characteristics of its mental space was its employees' willingness to accept risks in development projects.

> "These co-operation partners… Some of these [projects] have been the kind that do not yield anything for the products, but we have had nets in many directions […]. Looking at this matter in retrospect, one can see that we have been involved in many (kinds of activities). It felt natural, and new co-operation partners appeared, and even more would have been willing to co-operate [...]. I have a feeling that we succeeded pretty well in many of them. Some total misses have occurred […] but nobody can do these without any failures […]. Funding from TEKES [Finnish Funding Agency for Technology and Innovation] made it

> possible to start tentative projects, which perhaps did not always lead to anything […]. [Such funding] allows even misses along the path." (Production manager)

Although spaces are, according to Hernes (2004a, p. 127), ever-emergent, stages of relative stability and stages of change can be seen in them. The integration of both Helax and Dosetek into large companies was a stage at which interaction between the spaces brought about changes in their physical as well as social and mental spaces.

For some employees, the firms' new positions as parts of large companies changed very concretely the physical conditions of work. Internationalization, for example, increased the number of some people's travel days substantially:

> "At that time the normal pace of work was to take a flight from Helsinki to New York on Sunday… and to be in Palo Alto in the evening at 23:00. In the morning at 7:00 there was a meeting. Three days, Monday, Tuesday and Wednesday [work]…on Friday morning back in Helsinki. Then on Monday maybe to Holland or Switzerland. Probably it was just the [travelling] which made it a heavy job." (Production manager)."

But even more than this fact, the change in social and mental spaces was affected by the changes in the forms of control and in financial control in particular. As Hernes (2004a, p. 94) writes, " in fragmented reality where actors are interdependent, while at the same time being institutionally and physically displaced from one another, financial control becomes an almost universal substitution for other forms of control". At Helax and Dosetek, financial control was concretely visible in the time span and priority setting of activities. The following extracts from interviews conducted at Dosetek reveal that also conditions of innovation activities were affected:

> Interviewer: "Was it so that these guys who went to work for Google saw that they no longer had a sufficient number of challenges [to meet] in these conditions?"
> Managing director: "Well, yes, and another reason obviously is that a company that is managed as efficiently as this is to such nerds too pressing a place… First there is such a steady growth the whole time, no new innovations come, and then there is the continuous panic […] work is done in panic and panic.
> Production manager: "I too have such a feeling […] what's stressing in this kind of development is the rush from hurry to haste."

At both Helax and Dosetek, consciousness of the boundaries of social space increased, as did also willingness to guard the boundaries, which was done principally by protecting autonomy to the extent it was possible under the given conditions. The protection of autonomy extended also to mental space, especially in issues of priority.

After becoming a unit of MDS Nordion, Helax was given a new focus: instead of concentrating on radiotherapy only, the firm needed to cover also other cancer therapy

methods. In spite of this, the new focus did not structure the day-to-day activities of the firm. As Saemundssen (2004, p. 421) states, the original CART vision "continued to thrive and dominate the activities of the firm." One obvious explanation for this is that the CART vision formed such a strong basis for the identity of the key staff that in the changed situation they would not give it up, because it would have meant sacrificing their identity as Helax's employees.

Dosetek's integration into Varian meant that its development plans were scrutinized by Varian's headquarters. One area in which these plans differed from those in Varian included matters related to information technology. Dosetek's employees had planned to write a computer programme to be used by personal computers (PCs), while Varian opposed these plans:

> "We had to fight pretty much with Varian about going into the PC world. The Swiss had made all verification systems into UNIX…of course they did not want to start to use PCs. It was a crusade that we made." (Manager)

Since Dosetek's development plan was based on its staff's interpretation of customer needs and development trends in technology, they were committed to fight for their possibilities to continue along the route they had chosen. They won the battle, and in retrospect, their line was the right option. From the perspective of financial control, it was, however, a risky decision. A move to PCs took altogether 8–9 years, which was more than anyone involved could have expected.

Even though we can identify the same strong reaction in both firms to guarding the boundaries of their social and mental spaces, we can also identify differences in their modes of action. At Helax, autonomy was protected to the extent that it closed doors to interaction with the parent company and was perhaps one reason why the expected benefits of the merger could not be reaped. At Dosetek, interaction with the parent company and its units took place on many levels and the merger proved out to be financially successful, even though also more pessimistic tones could be heard, especially in issues concerning innovation perspectives.

Discussion

In this article we employed case study methodology. Comparing the two case firms in question, which are quite similar to each other with regard to their field, main product, size and geographical location, helped us to highlight their divergent conditions for innovation activities. The case firm Helax was examined through a secondary analysis by taking a different perspective from that in the original study (cf. Heaton, 2004). The case of Dosetek is based on an in-depth study conducted by the authors. In both studies

different kinds of data sources were applied, as is the customary practice in case studies (Yin, 1989). The comparative setting enabled us to put into perspective the meaning of certain factors and choices made by the firms which shaped the development paths of the firms.

This study has a contribution to make to the understanding of how innovation activities can be supported or hindered in small high-tech enterprises. It illuminates especially three aspects that are of importance both for research and management.

Firstly, through the process view the study underlines the variation in the requirements and conditions for innovation activities at the different stages of the innovation process. The case of Helax represents a typical innovation process in a small high-tech firm that starts from an idea created by a few devoted people and proceeds through growth periods to nurturing its product(s) on the market. Dosetek differs from this pattern by both selling its services and products and generating new ideas in parallel already from the start. The process view brought forth the continuity of the innovation process and presented it to be a more complicated process than a customary presentation of the development stages starting from having an idea that leads to production and finally to the market (e.g. Taatila *et al*., 2006). The dose planning products of the firms can be characterized as radical innovations. However, they were in a very different shape at the time of the research than when they were first launched to the market. Such product shaping is typically called incremental innovation. The cases illuminate that the border between radical and incremental innovations can be fuzzy. The degree of newness of knowledge that according to the definitions differentiates radical and incremental innovations is only a suggestive criterium (e.g. Dewar and Dutton, 1986). There are differing degrees of newness also in incremental innovations. For example, the move to personal computers in dose planning required basically new thinking in programming work and was a lengthy process which required solving a big number of technical problems.

Some writers rightfully draw attention to the tension between continuity and change, or as Crossan *et al*. (1999) define it, to the tension between exploitation and exploration. A further development in problem posing would be to simultaneously ask questions about the tension between continuity and change and about the tension between innovation activities and the mainstream activities (cf. Kanter 1989, p. 45), i.e. the already established and already understood ways of running a business. The cases presented here represent examples where hardly any stage of a development path can be accurately described as having been steady. The turbulent environment caused by the development of IT technology pushed both firms towards smaller or bigger changes over the years.

Secondly, the study illuminates how the structures for innovation activities shaped along with the development phases of the firms. We approached these structures by differentiating physical, social and mental spaces. The cases conform roughly to the pattern of the dynamics of spaces through organizational evolution as sketched by Hernes (2004a, pp. 132–4). The comparison of the cases shows, however, that the internal lives of two relatively similar firms are not similar and thus deserve more nuanced approaches from research. As a generalization we suggest that the adherence of the founding group

of Helax to the firm's original identity as a counter-reaction to coordination, regulation and control might be the case also in other spin-off firms and that the strong personal influence of the founder of Dosetek on the firm's social and mental spaces might describe also other firms starting as one-man firms.

Thirdly, the study contributes to the field of studies of product development and particularly to the issues of cooperation in development work. In her study of design engineers, Kaija Collin (2006, p. 405) characterizes product design and development as collaborative and "messy" practices in multi-professional teams. According to her, such a context and such demands form an innovative and creative practice requiring continuous learning. As she says, "learning subsumes in design practice itself" (ibid., p. 409). Her study showed that shared problem solving and shared practice place special demands on the social life and maintenance of sense of community in an organization and play an essential role in learning. We consider that the three-pronged distinctions between the aspects of space provide useful conceptual tools to grasp empirically the organizational prerequisites of the social life and sense of community in organizations. We argue that this kind of conceptual framework is widely usable in questions of workplace learning, i.e. also in other fields than innovation activities. Here we refer to the challenges posed by Stephen Billet (2004) concerning workplace learning. Central to his view of workplace learning is to see it through participation in workplace activities and interaction and, based on this understanding, he proposes that "more than seeing workplaces as physical and social environments, they need to be understood as something negotiated and constructed through interdependent processes of affordance and engagement" (ibid., p. 321). The concept of space presented here might provide a view not only on the regulation and affordances of work activities (or using Billet's term, participatory practices) but also on the shaping of the spaces along the engagement of those doing their work.

We acknowledge that empirical studies of the qualities and dynamics of spaces as conditions for innovations are complicated and that our study also leaves room for improvement. We assume, however, that attention to boundaries circumscribing spaces might provide a fruitful basis for further studies on some key questions of learning and cooperation in innovation activities. Boundaries could be studied in all types of spaces, and the functions of the boundaries in each of them could be delineated. Boundaries could also be studied on the basis of the dimension of their tightness and permeability. According to our observations, tightness or permeability is not unambiguously a good or a bad thing. In favourable conditions tight boundaries in mental and social spaces might generate coherence, which might motivate high-level performances. An example of this is the scientifically ambitious development of algorithms at Helax. Nevertheless, tight boundaries can become barriers to innovation activities if a need arises to seek new opportunities beyond the existing knowledge base or if a knowledge mix is necessary. The dose planning programme provides an example of a product concept in which the need for integration of different knowledge bases is in-built. At Dosetek, the permeability of boundaries in the mental and social spaces of different occupational groups provided a better possibility to mix various knowledge bases in the planning process than at Helax. For example, at Helax, physiological knowledge related to radiotherapy was valued,

while IT expertise was seen to play a supportive role only. Dosetek, instead, did not have such priority settings between these knowledge areas and, partly due to this, for example, got a chance to celebrate a breakthrough in reverse dose planning, which was made possible through an invention by an IT expert.

We have here dealt with spaces within firms. As far as innovation activities are concerned, it is important to be aware of the fact that spaces do not remain within an organization but extend beyond its borders. From the start the CART project functioned as a learning environment for both firms and created mental and social spaces in which representatives of the firms were present as participants. In the course of time, different kinds of development projects created other kinds of mental and social spaces, which also extended beyond the borders of the firms. Within the confines of one article we need to limit our view on the inside processes of the firms and do by no means claim that this is the full picture of all the influencing factors and conditions. When innovation activities are looked at from inside the firms, it seems that paying special attention to the boundaries of spaces and interaction between the spaces would increase our understanding of the questions of cooperation and learning around innovation processes, but the framework can also be exploited in exploring the relationships external to the organization.

Conclusions

Innovations and the capability to innovate are vital in knowledge societies and in global competition where new knowledge and innovations play a crucial role (e.g. Castells, 1996). Nations and international organizations (e.g. the OECD and the EU) have launched programmes to support innovations and to increase research and development activities related to them. As a multidisciplinary field, research on innovations has succeeded to generate relatively many research activities in some areas, e.g. in questions of networking, while some others have received minor attention. In-depth studies of innovation processes belong to the latter category, particularly studies containing theoretical tools that help to transfer the lessons learned from a special case to other cases. The concepts of physical, social and mental spaces were used here to facilitate the understanding of the structural, social and mental settings that may support innovations but that may also set barriers to them or create a tension-filled context for innovation processes and related learning as well as knowledge activities.

Our study suggests that support strategies and support measures for innovations would benefit from the perspective of spaces in examining the organizational prerequisites for innovation processes. These innovation processes are not similar everywhere but differ by, for example, sector, field of knowledge and type of innovation. There, however, are some generic processes which in Keith Pavitt's (2005, p. 109) words are "coordinating and integrating specialized knowledge, and learning under conditions of uncertainty". Researchers on innovations emphasize that innovations today are not solo acts but require multiple players both inside an organization and across its borders (e.g. Bessant and Tidd,

2007, p. 20). Innovation processes need to be managed and organized and they need to have some strategic bearing among the other activities of the organization. Researchers on learning could contribute to the management issues involved in innovation processes by drawing attention to the differentiated demands of integrating specialized knowledges at different stages of the process. In the case examples, the contributions of two expert groups consisting of physicists and IT specialists were of vital importance for the innovation processes.

The cases showed that different types of knowledge can be integrated both through mediation by management and through different levels of cooperation between the experts. We should not place in advance any self-value for direct cooperation and shared practice but where they are needed or when they are productive we should pose further questions about the conditions of cooperation. Following Crossan *et al.* (1999, p. 534), we might ask "What impediments are there to integrating individual perspectives?" The advice derived from our case examples would be to pay attention to the boundaries and especially to the permeability of boundaries within social and mental spaces while seeking supporting and inhibiting factors in the conditions of innovation-related learning and cooperation.

What we can learn from the cases presented here is that transformations in spaces are sensitive to changes in the strategic emphases of the firms. Concerning the case firms, such turning points were the heavy growth periods during which new products gained a stable footing on the market and the period when the firms merged with large companies. Transformations in spaces can be both productive and counterproductive. Therefore we recommend that management should pay attention especially to the following four issues to avoid the counterproductive effects.

Firstly, it is important for the firm to allow its employees reasonable autonomy and degrees of freedom in their creative actions. Secondly, it is advisable to treat delicately the need for group identity, which, at its best, may increase the sense of community, but which may also create barriers to cooperation and broadening the knowledge base. Thirdly, the management system should recognize the strategic value of knowledge of each employee group as well as each group's need to have opportunities to learn and update knowledge for the innovation process. Fourthly, where immediate cooperation across different knowledge areas is vital, the existing barriers to cooperation should be brought down. As suggested here, these barriers might relate to social and/or mental spaces, or as it is often defined in common usage, to organizational culture. Such issues result from social processes and cannot be influenced simply by rational planning. However, as we suggested, the dynamics of spaces is bound to changes occurring in strategic thinking in organizations. In these circumstances, priority setting can influence the formation of spaces, which eventually makes it the key task of management.

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