Systems of creation – exploring the dynamics of distributed innovation

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Introduction

The aim of this paper is to analyse where and how learning – and primarily learning related to technology – takes place in distributed innovation. That innovation occurs in increasingly distributed networks – regarding its geographical dispersion as well as the disciplinary fusion of diverse knowledge areas – is widely recognised. In the new economy, no company is an island and the locus of innovation is no longer necessarily within the firm - or within the plant. Firms are becoming increasingly specialised which increases the necessity for them to co-operate as they can no longer produce and manage knowledge on their own. In addition globalized firms do, to a much larger extent than what historically has been the case, source their innovative activities to overseas subsidiaries. Further, the traditional long-term collaborations between for instance a supplier and a customer are increasingly being replaced by more frequent shifts in partnerships. Thus, the relation between the firm and its partners and customers is not

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static – these collaborations change and evolve as new knowledge demands require new knowledge inputs. Relations are increasingly being entered in order to gain a specific competence for a specific task or problem to be solved at a specific point in time. Engeström (2004) refers to this as 'knotworking' – a "temporal and spatial trajectory of successive task-oriented combinations of people and artefacts" (p 155). The need for knotworking comes from the emerging locus of expertise which Engeström describes as a "divided multi-organisational field or terrain of activity" (p 161). This form of distributed innovation places new demands on the organisation and on its ability to acquire and generate knowledge. To understand the evolution of knowledge in distributed innovation, i.e. to capture the 'knotworking' involved in innovation today, a fruitful approach to study the contextual settings in which it evolves is the technological system.

However, there is still a need to further explore the learning processes that contribute to innovation. We adopt a broad view both on the level of analysis regarding the system or community in which innovations take place, as well as on what skills and knowledge that actually influence the innovation process. This paper is primarily a theoretical overview aimed at illustrating the key aspects of learning that contribute to interdisciplinary or interorganisational – that is distributed – development of innovations. The paper is also aimed at providing a tentative outline of the thesis project (ELIT – Experience and Learning in Technology), which one of the authors is about to embark, and which hopefully will result in a PhD thesis.

Although this is primarily a theoretical exercise, some empirical findings will be included from the European research project PILOT (Policy and Innovation in Low-Tech), which focuses on the creation and use of knowledge in low- and medium technology (LMT) industries. The emergence of a "knowledge economy" and the often supposed synonymy between knowledge-intensity and high-tech activities has led to a strong focus on the research intensive sectors of the economy, with R&D as a main measure of innovative activities. In PILOT we claim that this approach fails to embrace the multifaceted and far from unidirectional processes of innovation.

In this paper it is our intention to go beyond the conventional wisdom of what innovation is about, by providing a broader perspective on learning and knowledge formation in technology intensive practices. The work starts from the notion that what is of interest as regards knowledge formation in technology – and in the extension the creation of competitiveness – is not the much focused dichotomy low-tech/high-tech (connected to R&D-intensity). The conjecture is that the demarcation line between complex/non-complex is not identical with the borderline of science based/non-science based knowledge. There is thus – in the science-focused discourse of today – a still neglected area of complex (skilled, professional, experience based, creative) knowledge formation falling outside the conventional wisdom on how technological capabilities are created. In other words, the old distinction between innovative (that is R&D-intensive) and non-innovative activities may lose its relevance, something that is of importance for both the theory of innovation and for organisational structures and learning activities.

The modern discourse on innovation is to a large extent dominated by a learning perspective (Lundvall, 1994). And the modern policy discourse on the knowledge economy is to a large extent focused on the R&D intensive end of innovativeness. Together, these two discourses leave out much of what innovation, in our view, is really about. We claim that in analysing innovation it is necessary to include aspects of creativity, complexity, design and skills to fully capture the dynamic elements in industrial dynamics – within firms but also at the inter-firm level.

Innovation and Learning

The cumulative nature of technological knowledge

The ability to create competitive advantage through new combinations (or recombinations) of both old and new knowledge, i.e. how well firms can alter their products and/or services and leverage the outcomes through the introduction of better or new products, is highly evolutionary. Technological change is the descent and modification, or recombination, or sometimes more radical 'mutations' of fabrication techniques, design or design techniques (Constant, 2000), and is initiated by and generated from current practices. Decisions taken in the past intrude on the present (Leonard-Barton, 1995) and mark the road ahead (Teece et al, 1997). A chosen technology – we may take the production of pulp and paper as an example – sets certain constraints on what a company can perform. A shift in technology from producing paper based on mechanical pulp to chemical pulp would imply major changes and significant reinvestments in both skills and capital goods. Thus, the search for creative solutions to a specific design problem is to a large extent *path dependent* (cf. Tidd, Bessant & Pavitt, 2001).

This role of prior knowledge to a firm's ability to exploit and explore new knowledge is widely recognized. It is stated by for instance Cohen and Levinthal (1990), who argue that "the ability to evaluate and utilize outside knowledge is largely a function of the level of prior related knowledge" (p 128). Further, they argue that related expertise is advantageous as it helps to predict more correctly the nature and commercial potential of technological advances. This shows that 'history matters': new technologies to be used in the future develop along paths shaped or created within the framework of what often is labelled a *technological paradigm.* A technological paradigm entails a definition of the relevant problems that must be solved, the tasks to be fulfilled, a pattern of inquiry, the materials technology to be used, and the basic types of artefacts to be developed and improved (Dosi & Orsenigo, 1988). But it is also so that, as technologies evolve, products and parts of industries, which earlier showed family resemblance, may develop along *different technological paths*; sometimes as a consequence of a radical shift of technology.

The concept of paradigms can – at least in its use in relation to the world of artefacts and technology - be critized for ignoring – or missing – the eclectic nature of technology and over-emphasizing discontinuous change. Disruptive technological leaps are in numbers, and most likely also in economic and technological overall influence, less important than the incremental, smaller steps of refining, retuning and improving existing technologies, routines etc (cf. e.g. Mokyr, 1990). In addition many of those radical innovations, also significant, which are related to technological change are of non-technological nature.

Routines

Nelson and Winter (1982) pioneered the modern discourse of evolutionary economics, and strongly turned away from the equilibrium economic theories. An important foundation in their view of firm behaviour in an evolutionary context is the assumption that firms follow certain routines, routines that embed the historical activities and developments of the firm. Nelson & Winter (1982) describe routines as the memory of the organization, as they argue that 'organizations *remember* by *doing*' (p. 99). As such, routines are one important manifestation of prior knowledge in firms. They make an important distinction between skills and routines, where skills are identified on the individual level and routines incorporate an organization's specific operational knowledge. Although that distinction is not fully developed in their original text the authors have explicitly returned to it later (Dosi, Nelson & Winter, 2000). It might be added that routines and their constituent parts in themselves are important as a unit of analysis in grasping organizational phenomena such as change and learning (cf. Pentland & Feldman, 2005). However, such an analysis falls outside the scope of this paper. Further, without denying that individuals may develop routine behaviour we, in the following, use the concept on organizational level.

Teece, Rumelt, Dosi and Winter (1994) distinguish between two main types of routines. *Static routines* enable the successful replication of previously performed functions, although they add that a routine is never truly static, as they are gradually updated and improved. *Dynamic routines*, in contrast, are focused on learning processes in order to develop new products or processes. For instance, the search routines of firms normally rely on dynamic routines. Routines – as resident in certain interactions that correspond to the successful solution to a given problem – are as such often highly complex. This entails that the knowledge embedded in a certain routine contains a cultural and tacit dimension (Teece et al., 1994). If anything this is what organizational culture is about; that is the development – the "social construction" – of organizational cultures shaping and conforming the behaviour (and mindset) of the members of an organization. Parts of that may be codified but significant parts are not.

In his article *'Exploration and Exploitation in Organizational Learning'*, March (1991) discusses an organization's ability to exploit its existing resources and optimizing current processes – i.e. refinement of existing technology; and exploring new technological or knowledge opportunities – i.e. innovation of new ones. Firms often display a preference towards the former, as the returns of exploitation are more likely positive, proximate in time, and to a higher degree predictable. Returns from exploration, on the other hand, are uncertain, distant and often negative. This is well known from many textbooks on innovation management (cf. e.g. Christensen, 1997). Boisot (1995) argues in a manner similar to March when he discusses firms' technology strategies as either a *war of position* or a *war of movement*. There is necessarily a need for balance between the two: exploitation as effective selection and choice among routines and procedures that assure survival; exploration as generation of variety in a changing environment. In his article, March explicitly stresses the importance of exploration as 'tendencies to increase exploitation and reduce exploration make adaptive processes potentially self-destructive' (p. 73). This statement points out the paradox of routines. As the "memory" of the organization, routines on the one hand have to fulfil the "process of the circular flow" and thus inhibit too much of non-routine activities. On the other hand the routines of dynamic firms/organizations have to support and lay the foundation for non-routine work (March, 1991; Nelson and Winter 1982). March acknowledges very vividly the role of creative exploration in his final words of the article: '[…] knowledge development may depend on maintaining an influx of the naïve and ignorant, and that competitive victory does not reliably go to the properly educated' (p. 86).

Thus, innovation is by no means a purely rational endeavor. The early phases of an innovation are characterized by high variety and the design is 'fluid' and product characteristics are in flux (Abernathy & Utterback, 1978). Among a variety of ideas or solutions, most will be eliminated. This phase is necessarily characterized by uncertainty, and chance and trial-and-error processes may play a very influential role in the events that lead up to the point where one technology is selected before others and a dominant design (Utterback, 1994) is eventually established. However, it is clear that it is not necessarily the 'best' solution that is fixed upon, and which will result in dominant designs (cf. Arthur, 1989). Mokyr (1990) also acknowledges the sub-optimality of evolutionary processes, pointing at the examples of the QWERTY typewriter keyboard and the panda's thumb, and states that "[n]ot all problems are solved, and not all possible solutions are achieved" (p 284). Rationality acts under the influence of what we know (bounded rationality), thus already prior to the selection stage path dependency influences the direction chosen ahead. That is, the selection space – or domain – where selection can take place is to a certain extent predetermined by existing knowledge resources.

Distributed innovation requires a new view on learning

Antonelli (2005) gives a good overview on how the economic understanding of technological knowledge and its governance has evolved over the second part of the twentieth century. The understanding of knowledge as a public good (a centralized, top-down view on knowledge), with public provision of scientific knowledge, was prevailing from the 1950s until the 1980s. At the end of the 1980s, the view on knowledge generation is reversed; rather than knowledge generating from the public institutions and applied by corporations, knowledge is now regarded as a proprietary good defined by stickiness and high appropriability and non-tradability (a bottom-up process of knowledge creation). By the end of the 1990s emerged the idea that understanding the economics of technological change requires a systemic approach. According to Antonelli, technological knowledge is now viewed as the outcome of localised interactions by a variety of heterogeneous agents. This novel view on knowledge is mirrored in the theories on clusters (e.g. Porter) and innovation systems (e.g. Lundvall) that emerged at the beginnings of the 90s and that still are influential for the analysis and support of technological knowledge creation. It is acknowledged that a variety of agents and competences are crucial for generating new knowledge, thus highlighting the need for external knowledge as firms today seldom can generate sufficient knowledge on their own. The systemic approach implies that technological knowledge is constructed by bits and pieces of knowledge building upon other already acquired bits of knowledge, acquired both in the same specific context and in other adjacent contexts. Thus, no single agent/actor carries the complete knowledge. Instead, technological knowledge is endogenous to the system in which each agent is rooted (Antonelli, 2005). On two important aspects Antonelli distinguishes himself from e.g. Lundvall and Porter. He states that external knowledge is important "both when it concerns the same module of knowledge and when it belongs to other knowledge modules: intra-technological and inter-technological knowledge flows are both necessary" (pp 63-64). Further, he states that proximity matters (because of bounded rationality and switching costs) in *various* ways – not only proximity in regional space. Also proximity in technical, professional and industrial space, as well as in product space is vital for innovation. In comparison with the cluster and innovation system's models, whose strengths are that they acknowledge the importance of interactions between actors in a geographically and sectorially defined space and that new technologies are initiated, developed and diffused through these relationships, Antonelli's approach to knowledge creation allows for a broader view on where innovation and knowledge creation takes place.

The understanding of knowledge creation as neither a purely top-down nor a purely bottom-up process, but as a highly cumulative practice involving several intra- and inter-technological agents requires a revised view on how learning takes place. It is not restricted to publicly funded institutions or the corporate R&D-department. Further, the perspective must go beyond the geographical boarders that naturally delimit the scope of analysis in innovation systems and clusters. This is not to disregard the importance of spatial proximity, but it is an attempt to find a level of analysis that encompasses *both* the near and the far. Further, it is necessary to analyze knowledge creation beyond the sectorial boundaries as distributed innovation is no longer restricted to occur within a specific industry. The analysis may be done on the level of technological systems: we will return to them on the following section.

Further, in order to fully capture learning in technology practices it is important explore both formal learning processes and informal learning. Formal knowledge is today considered the major contributor to economic growth, and intellectual work is elevated to the top of the knowledge hierarchy. This is mirrored in the current policy focus on science, high technology, academic qualifications and knowledge work. Hager (2004) refers to this as the 'standard paradigm of learning', a paradigm that separates learning from action. It focuses on formal learning, transparency (i.e. explicit or codifiable knowledge) and interiority (what minds do rather than what bodies do). In this view, learning processes involving e.g. tacit knowledge or informal learning are rather a second-rate kind of learning. Such an understanding of learning as the diffusion of explicit, abstract knowledge – *detached from practice* – is insufficient to cover much of the complexities of engineering and technological work (Seely Brown & Duguid, 1991). It also fails to account for the fact that knowledge is highly contextual. Knowledge is not something that can be 'acquired' and carried across space and time; it is embedded in everyday action, not disembodied sets of concepts in our minds – we must 'use it or lose it' (Fenwick, 2005). Hager (ibid.) proposes a contrasting view on learning: 'the emerging paradigm of learning'. This view acknowledges that learning is inherently contextual. Further, it recognizes the importance of action to develop bodily know-how and skills as well as the important notion of judgment. Hager argues that the emerging paradigm of learning, with a more holistic view on learning, better describes the actual learning that takes place in the workplace.

The context of creativity

In exploring where technological knowledge is created it is obvious that this can be studied on a number of different levels. It is also obvious that depending on which level of analysis is chosen, the approach to how learning processes can be studied also differs.

Within a discipline, it may be fruitful to use the communities of practice concept introduced in the early 90s (cf. Wenger, 2000). The communities of practice approach is sometimes criticized of under-appreciating the role of formal modes of learning (cf. Smith, 2003). Further, it focuses on apprenticeship-like learning in rather stable situations and, according to Engeström (2004) thus overlooking the impact of radical change in the work situation. Wenger's concept can also be criticized for having a too narrow scope, as he focuses on small groups of professionals, with daily physical interaction. Professional and academic communities of which any are global in character, falls outside Wenger's type of community: for instance, the learning that takes place among and between co-workers on a shop-floor. Even so, the concept of community may be useful in several ways. First of all, and perhaps the primary contribution it makes, is that it focuses on the role of participation in learning. In this view, the important processes of informal learning are highlighted and it acknowledges the community as an important locus for the acquisition of knowledge.

In the context of distributed innovation, one issue brought up by Wenger (2000) can be useful. He stresses the importance of the learning that occurs at the boundaries of communities. Wenger argues that boundaries offer learning opportunities, as across boundary interaction exposes a competence to another, foreign competence. Such reconfiguration of competence is at the core of what innovation is all about. This is in line with Schumpeter's (1911/1934) definition of innovations as new, creative combinations that upset the equilibrium state of the economy. It is also close to the discussions of Gibbons et al (1994) on t*he new production of knowledge*. Here, these authors argue the role of interdisciplinary – or in their terminology 'transdisciplinary' – connections and relations for knowledge creation and innovation. The other dimension of their discussion is the necessity for connections between academia and industry and the important knowledge transfer between these two worlds. The work of Gibbons et al has had great impact, not the least among policy-makers. It should be mentioned, though, that this work has received some objections as to the novelty of the discussions, and for being founded on very limited empirical research. It is also argued that they are too academic – the integrative ways of creating new knowledge that Gibbons et al describe has de facto been rather typical for a large part of the industry for significant time (for instance is the polytechnic engineering education and culture an apparent representation of this interdisciplinarity).

Today, innovation increasingly requires a multidisciplinary approach as products and processes may integrate several scientific and technological disciplines. Thus, innovation depends on both specialist knowledge and an ability to exploit and explore other competencies, farther from one's own core. As Wenger (2000, p 234) puts it: "In social learning systems, the value of communities and their boundaries are complementary. Deep expertise depends on a convergence between experience and competence, but innovative learning requires their divergence". As firms today see the necessity to focus and specialize their activities, narrowing their scope of activities and competence, the importance of interaction with others is increasing. The approach to study learning using the communities of practice may thus be a useful tool when focusing on the knowledge creation within a specific discipline. However, it does not allow for the complete understanding and analysis of the knowledge created in distributed innovation, as this knowledge is not localized within one discipline or even within one organization. As stated above, distributed innovation involves combining bits and pieces of knowledge which together create new products or processes.

Where Wenger is focusing on the learning within a community of shared practice, Sawhney and Prandelli (2004) introduce another approach to the community view. They discuss 'communities of creation' which encompass multiple actors from varying disciplines that not necessarily share competences but they have a common goal. A community of creation, according to Sawhney and Prandelli, involves suppliers, customers, competitors and other more or less central actors. According to their definition, the community of creation is an overlap between communities of production and communities of consumption. The community approach emphasizes the sociological view on learning and knowledge creation (cf. Sawhney & Prandelli, 2004; Wenger, 2000). Thus, it necessitates the recognition of the relevance of social interaction in knowledge creation. The focus is on the ability to combine different competences and knowledge to achieve new knowledge. According to Sawhney & Prandelli (ibid) it is necessary for firms to realize that '[t]he locus of innovation is no longer within the firm; it is within a *community* of members in an opportunity area'.

This may a logical point to adopt the concept of *technological systems* (e.g. Bo Carlsson, Rickard Stankiewicz) as the unit of analysis. Sawhney and Prandelli's view on knowledge creation shows strong family resemblance with the technological system as an approach to explore where learning occurs in distributed innovation. In taking a technological system's approach as the point of departure for analysis, we can also include actors within competing, complementary or neighbouring areas; for instance rival firms within the same industry (equally positioned in the horizontal value chain) and suppliers or customers formally located in other industries. Three important features make the technological system an attractive point of departure for analyzing learning in distributed innovation. First, it focuses on (generic) technologies rather than industries. This enables us to map the important interactions and interdependencies, and consequently learning processes, among dispersed actors. With this approach we can include seemingly diverse but potentially equally important actors such as suppliers, users, institutions, industrial designers etc. Analyzing learning from a system's perspective allows for both central and more peripheral actors to be included. Further, the delimitations of geographical boarders or industry sectors are eliminated. In short, we can include all carriers of competence and skills that participate in technological innovation, regardless of their disciplinary domicile or centrality/non-centrality in the system. Second, the technological system's approach emphasizes the fact that systems evolve over time, in terms of participating actors and institutions and the relationship between them (cf. Carlsson, 1997). Thirdly, it opens for a cognitive space integrating different industries and firms and uniting them in a (partial) professional, disciplinary community with a common worldview similar to what may be labelled a paradigm. This has been analyzed by Laestadius (2000) in relation to the technological system for pulp and paper which in itself includes several industries, firms, countries, disciplines and professions. Thus, in order to study the learning that occurs in distributed innovation it may be fruitful to attempt to apply the systems approach.

Spatial proximity is important for successful knowledge transfer and exchange, as cultural and social aspects such as common language, norms and rules etc. may facilitate the speed and ease of transfer, and shorter physical distances lower the transaction costs. But other aspects are equally and sometimes more influential than geography. The important dimensions of proximity raised by Antonelli (2005) – i.e. the importance of technical, professional, industrial and product related closeness – must also be included in the analysis. Partially, these dimensions are closer to what we may call a *cognitive* proximity – i.e. a shared worldview, shared terminology and a common tradition of technological understanding. We may also add the notion of a shared goal or area of opportunity. Stankiewicz refers to such common domains of knowledge creation and search as design spaces (Stankiewicz, 2000). These spaces shape the problem-solving processes by offering the possible search paths for finding a solution (ibid.). Thus, bonds may be localized, as they are in Wenger's communities of practice concept, but many bonds depend on spatially 'stretched' connectivity building on common knowledge (i.e. design) spaces (Amin & Cohendet, 2004).

Even though the number of possible paths that can be taken ahead is constrained by past choices – there is a (pre)defined and limited 'search space' for solutions – the array of possible alternatives to either select or reject can still be vast. Thus, one must know where to search and how to select the most feasible among a variety of options. This directed search must be accredited the existence of prior experiences and knowledge. This involves the existing – internal as well as external – knowledge, the accumulated learning processes (and their connectedness to situated learning as well as essential (formal) skills), a professional 'literacy' and judgment. These set the basic conditions for the search process.

Hence, the design space available to a firm is partly defined by its historical records. It is also partly set by its position in the technological system (Stankiewiczs, 2000). The technological system offers building blocs of knowledge and technology to be applied and combined in innovative ways.

Innovations beyond learning

It is clear that the creation of knowledge does not occur in abstraction from current abilities. Which solutions that will be achieved depend on the evolutionary track a certain industry or firm is moving down. However, perhaps the most intriguing and interesting part of technological knowledge creation, but also conceivably the most difficult to study, is the knowledge that is created by chance, serendipity or even false assumptions. Mokyr (2000) states that one of the most challenging issues of technological knowledge is the apprehension of engineering problems and the roads to their solution, and the examples of a design preceding the understanding of its operational principles are numerous throughout history (cf. e.g. Kline & Rosenberg, 1986).

Innovations *per se* create imbalances as they to a greater or lesser extent break routines. In the Schumpeterian definition of innovation – creative destruction – some of the old rules, skills or norms will necessarily need to give way in order for the new to come about. In this context, it is important to explore the role of routines for non-routine work – as both enablers and inhibitors of innovation.

To some extent this implies that innovations also occur beyond learning. It may even be argued that innovations are related to *un-learning*. Innovations occur when common assumptions, beliefs or understandings of the world and its workings are in some way altered, interrupted or falsified. Novelty necessitates the ability to un-learn and re-learn, as some knowledge become obsolete and may even obstruct the generation of new knowledge (referred to by Leonard-Barton (1994) as 'core rigidities' as opposed to 'core capabilities').

In the context of un-learning and re-learning, the concepts of communities and technological systems are interesting units of analysis to explore. At the border of communities, within the technological system, knowledge is stimulated and created and new solutions are identified – the interconnection of disciplines in new constellations acts as a creative driving force (cf. Amin & Cohendet, 2004; Wenger, 2000). A certain 'cognitive distance' (cf. Wuyts et al, 2005) challenges conventional beliefs and offers opportunities for the creation of novelty.

It is our conjecture that the strong focus on learning in innovation theory has led to a neglect of this issue. There is too much interest in learning, and too little attention paid to creativity. Being innovative is to a large extent about the ability to handle the unknown and new to the world – it is always to some extent an exercise of the imagination. The role of creativity, design and complexity are aspects that we argue need to be included to wholly capture the dynamic processes of innovation.

Creativity and innovation can often be seen to be used interchangeably, but rather than being substitute terms, creativity is a building block for innovation (von Stamm, 2003). The concept of creativity adds a still neglected dimension to the analyses of learning and skills as well as of innovation. But skills – acquired through formal or work-place, situated/local learning – do not necessarily entail creativity. To be creative implies going outside what is already known, thinking beyond the traditional routines and practices. It is the ability to find new ways of applying knowledge from different areas – be they new to the world or already known and used for other purposes. In fact, reintroducing the first part of the Schumpeterian definition of innovation – creative combination – reminds us that not even R&D people and scientist are necessarily creative or innovative.

Engineers do not learn all the time – they create, i.e. do engineering work which go beyond learning. In the literature, the engineering activity is most often described in one of two ways: engineering practice is essentially about *design* (cf. e.g. Faulkner, 1994; Petroski, 1996); or it is a *problem-solving* activity (Vincenti, 1990). However, at the working level in engineering, problem solving and design can be taken as synonymous, and thus we will handle them as such in this paper. The most common understanding of design is probably the one (in Swedish literally called 'form-giving') referring to appearance/ergonomics/industrial design (Walsh et al., 1992). However, Walsh et al. describe design as not only a subjective concept based on individual taste. Design also has an important, socially and economically, objective role as it involves combining function with materials into an efficiently manufacturable product that will appeal to potential customers. This conception of design focuses on the creation of the object or artefact itself, and is what the engineering thought style tends to focus most strongly on (cf. Petroski, 1996; Vincenti, 1990). In the context of Faulkner and Vincenti, design represents the set of goals defined to be achieved and the processes by which those goals are produced. The design process thus connects the complexity of engineering components and systems, of processes and products. The design process is to a significant extent tacit. It is related by most analysts in this research field to "judgement". Judgemental skills, i.e. the ability to seek out solutions and weigh technical considerations in relation to the demands and constraints of the social context (i.e. economic, social, personal etc.), are mostly tacit and are learnt only through practical experience (Schön, 1983; Vincenti, 1990. Cf. also Petroski, 1994).

Following Alexander (1965), the essence of every design problem is achieving fitness between two entities: the *form* and its *context*. The context initially defines the problem, whereas the form is the solution to the problem. Thus, in this sense, when speaking of design, it is the ensemble of these two entities that is of concern. (A similar ensemble is discussed by Fleck (2000), who emphasises the connectedness between the *artefact* and the set of human *activities* that sustain the use and development of the technology related to it.) Achieving fitness between form and context is often a highly complex process. Designing solutions is a synthesizing activity, where diverse knowledge – existing as well as new – is integrated into new artefacts or processes. This is the essence of engineering practice, as opposed to scientists who are mainly concerned with analysis (Simon, 1970/96). This complexity (in the set of knowledge and skills as well as in the network in which they operate) is also what creates high-performance innovative skills, which in their turn create a competitive advantage within a given or emerging market.

Skills beyond innovations

Competitive advantage and economic growth cannot solely be connected with innovations. Much of professional activity concerns maintaining the competence of the organisation. Certainly some activities are concerned with design and creative exploration, but in many corporations a large part of work is concerned with exploiting current expertise and competence, as a means to assure successful replication of previous processes or products. The ability to perform work perfectly can be equally important for the growth of the firm as being innovative and introducing new artefacts on the market place.

In fact, innovative ability is not always desirable or necessary. For instance, the expectation on a heart surgeon is that he or she is extremely skilled at performing advanced surgery. We do not except – or wish – the surgeon to attempt anything innovative while operating on us. Considering the growing sector of knowledge intensive business services (KIBS) is another example of activities that are characterised by skill-based routines – but they are not necessarily innovative.

It is our belief that skilled behaviour has got lost somewhere in the widespread focus on innovations as primary growth engines in today's economy. Further, to assume that skilled behaviour is tantamount to formal knowledge is a major simplification.

Some empirical findings

For our empirical material, we draw from four qualitative case studies on Swedish firms in mature industries, which have been a part of the wider European PILOT project (Policy and Innovation in Low Tech). The PILOT project comprises about forty case studies in eleven countries, and its theoretical grounds and empirical results are presented in Hirsch-Kreinsen et al. (2005). The Swedish case studies comprise four manufacturing firms, classified as low-tech or medium-low-tech in the OECD taxonomy: Bahco – a high quality export oriented manufacturer of tools; Ostnor – a domestic market leader in water taps; Lammhults – a highly design focused provider of office furniture; and Hallsta – an internationally oriented producer of newsprint and improved qualities for catalogues. For a more thorough account of the results of these case studies, see Gustavsson & Laestadius (2005).

From the case studies some examples can be extracted to show how the ability to creatively combine different types of knowledge – old as well as new, internal as well as external – is a basis for innovation. The adjustable wrench (which has had basically the same design since its invention in 1892) is combined with (much more recent) scientific studies in ergonomics, and the water tap is equipped with advanced flow control systems and temperature regulation. Paper production is certainly not new to the world, but scientific findings in e.g. chemistry and biochemistry allows for new application areas for the product. Lammhults has recently launched a product in a revolutionary new material called Cellupress. The technique of pressing wooden fibre together under high pressure gives a material that can be manipulated in similar ways as plastics, which allows for new shapes in wooden furniture. The first product – the chair 'Imprint' – has already gained several prestigious awards for its design and technological novelty.

The need for additional knowledge and skills places great demands on the firms' ability to creatively source knowledge. It may be so that in the industrial transformation that we are experiencing, the ability to be creative will become a crucial capability. In this context, creativity implies the skilled search for solutions and ability to create new combinations by drawing from dispersed – new and old, external and internal, scientific and non-scientific – knowledge sources. Achieving this 'fit' between entities has an inherent complexity as it usually involves the combination of descent, sometimes craft-like, technologies – restricted to certain lock-ins – with new scientific findings or radically new design solutions.

The case studies also allow us to take a look at the relation between formal schooling and experiential learning for our firms' high-performance skills. Informal, situated learning has proved to constitute an important aspect of competitiveness for the firms we studied. Knowledge acquired through situated learning, by apprenticeship systems, firm-specific experiences and know-how etc., are crucial in all four cases. Some crafts depend entirely on internal transfer of knowledge, such as the forging of the raw material at Bahco, the casting of the master founder at Ostnor and the competence in cutting, sewing and upholstering of fabrics at Lammhults. Although these are conventional technologies, based on rather unsophisticated technology, they are highly localised, difficult-to-trade and specific to the companies' production processes.

The case studies also reveal that the level of formally skilled staff is relatively low in all four companies. The majority of the shop-floor workers have completed upper-secondary school, which implies that in the conventional view of knowledge-intensity these firms score quite low. Still, the internal creation and transfer of knowledge is a very important way to secure and diffuse firm-specific knowledge, due largely to the lack of formally educated people in the region and the specificity of the production processes. The organized use of apprenticeship systems was recognised in two of the studied companies. At Lammhults, most of the trades are taught in-house as the appropriate vocational training does not exist. At Ostnor, new recruits start as apprentices to senior shop-floor staff. Even where apprenticeship systems were not applied, learning on-the-job was crucial on the shop floor. Furthermore, the turnover of personnel at these companies was very low which has allowed for knowledge to be passed on from seniors to new recruits without the necessity of formal learning efforts. It is fair to say that the major part of the knowledge acquired by the shop-floor workers was obtained through informal learning processes.

However, our cases do not fully substantiate the assumption that the knowledge economy may lead to a diminishing distinction between innovative and non-innovative activities. The innovative activities in several of our successful case firms were not located on the shop floor. What can be concluded though, is that neither are these activities restricted to a limited R&D group. First of all, it is necessary to acknowledge that not all firms have an explicit R&D department (e.g. Hallsta), or it is of very limited size. Does this mean that such firms are less innovative? Certainly this cannot be argued. The case studies suggest that a changing environment and new demands on the companies create needs for new and/or complementary skills, many of them external and often science-based but also an increasing involvement of other internal skills in the development process. As innovation activities in fields such as design and branding has intensified, former mainly technology-driven sources of innovation are supplemented or even replaced by more market-oriented sources. Thus, the need for new skills involves not only additional disciplines within the natural sciences but also skills in marketing, design and logistics for instance. This indicates a shift from traditional engineering skills to more 'hybrid' skills in the innovation process, and people from dispersed knowledge areas – not only the engineering profession – are directly involved in the innovative work. The innovation activities also exceed the boundaries of the firms. All four companies provided evidence of how the locus of innovation was not within the firm – new machinery, material for products, new designs etc. were developed in close collaboration with external actors.

What can be concluded from this brief summary of our case studies is that both high-performance skills and innovative ability exist and are important for competitiveness of these companies. Nevertheless, they are not necessarily connected to one another. The highly situated skills in the crafts of forging, casting etc exhibited in the companies were strongly connected to their competitiveness. But these skills were generally not involved in the innovation process.

The dynamics – what creates competitive advantage and growth

In the end, the discussions on the knowledge society and innovations have one common, fundamental goal - analysing and explaining the dynamic processes that can create competitiveness and economic growth. Innovation theory has exploded in the last decades and innovation processes are analysed by sociologists, economists, business/management theorists, economic geographers and historians among others. And innovation concerns policy makers within the OECD and the EU as well as within most countries and in corporate strategies. Innovation is a core concept (often related to R&D policies) in strategies for the transformation to a "knowledge based economy" and embedded in an "innovation system" concept it is a foundation for much of policy on (regional) industrial transformation and competitiveness. In short, innovation theory and research it is about finding ways to upset the equilibrium state of the economy in order to achieve a (temporary) competitive advantage.

We are no different in that respect. However, our intention is to go beyond the dominant design of innovation research. We claim, at this preliminary stage of this work, that the relationships between learning, innovations and skills and routines may be more complex than the conventional wisdom acknowledges. We believe that much of the discussions have become too narrow, as they fail to encompass – or do not emphasise explicitly enough – some important elements of learning and innovation. When analysing economic growth and competitive advantage, it is our conjecture that it is important to emphasize the complementarity between deep expertise (skilled behaviour) and innovative ability, i.e. the balance between exploitation and exploration, position and movement, replication and recombination. We believe that the strong focus on innovations and their role for economic growth has overshadowed the importance of skilled behaviour when writing the action plans for achieving growth.

The extension of this focus in innovations as creating advantage has lead to an almost exclusive concentration on connecting innovations with formal knowledge, high technology and R&D. The conventional wisdom is that innovations generated by such processes are inherently more complex, more difficult to imitate and consequently more likely to provide a competitive advantage. By all means, this is true in many cases. However, we argue that this is still a too simplistic understanding of both innovations and what generates a competitive advantage. Complexity is not restricted to R&D and high-tech activities. To illustrate this argument we may take two of Sweden's most successful companies – H&M and IKEA. These companies rely on an outstanding ability to orchestrate a worldwide complex web of logistics operations that enables lead times – from the fashion shows in London and Paris and the Milan furniture fair to the clothes racks and store shelves in hundreds of locations around the world – to be pushed down to only a few weeks. These firms are far from the high-tech race that the industrialised European countries are supposed to join in order to stand the competition from the developing countries. The conventional wisdom that high-tech would lessen the threats of imitation and latecomer catching-up phenomena can be put to critical scrutiny by looking at the current expansion of the software industry in India and the extremely rapid development of new telecom technologies in China. These latecomers are no longer merely 'the world's factories' but they are running advanced research and development activities – nationally, but also on an increasingly global scale.

We challenge the innovation concept in two ways. On the one hand, we argue that learning is given a too influential role in innovation theory and research. This, consequently, leaves out aspects of creativity that are essential to innovation. Thus, we argue that innovations can go beyond learning. If we go back to the Schumpeterian definition of innovations – creative combinations on all levels – there is no necessary connection to recent scientific findings and academic knowledge. Innovation is about perceiving what is still unknown to the world – and consequently cannot be taught by formal education. Problem solving requires some imaginative, intuitive ability that is connected to skilled behaviour, practice and contextual knowledge – an ability that not necessarily accompanies the development of formal learning. In fact, the act of creation sometimes is breaking the rules, looking beyond experiences and having the courage to do so. It is more about the art – and act – of the imagination.

On the other hand, we argue that skills go beyond innovations. Competitive advantage and economic growth cannot solely be connected with and explained by innovations. In fact, innovative ability is not always desirable or necessary. Here, our heart surgeon is an illustrative example of where skill – not innovative ability – is required. It is our conjecture that we must include the role of skilful replication of activities, artefacts, and processes if we discuss the creation of competitive advantage and economic growth. Learning is evidently important for the development of skills, which provide the basis for high performance organisational routines (these routines, consequently, lay the foundation for subsequent successful innovations). For instance, a hospital gains its reputation for its highly skilled staff and providing high quality health care. Equally, the KIBS sector relies on its highly skilled employees. However, in the strong focus on innovations and achieving an innovative enterprise, the focus on skilled and professional behaviour may partly have got lost. We argue that innovations are not the only road to growth and competitiveness.

Concluding comment

Certainly, our statements are only preliminary and it remains to be verified or rejected whether there is substance in what we are claming. This will require substantial empirical research – which, at this point, we presume will foremost be of a qualitative character. So if this paper leaves some loose ends, we will hopefully be able to fill at least some of the gaps with the assistance of theory as well as corroborating our claims with empirical studies.

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