Managing complexity in projects
Cognitive justification for organizational rigidities

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Introduction

In recent years, knowledge has become of prime interest in the organisational literature. Knowledge is considered as the main source of rent generation and of competitive advantage (Prusak, 1996). Organisations need to learn better and faster in turbulent or high-velocity environments (Eisenhardt, 1998). The subsequent question of how organisations learn and how well they perform in changing environments relate to an active literature that has its roots in early developments of contingency theories and the behavioural school of thoughts. The more recent interest on knowledge dynamics in organisations (Kogut and Zander, 1992, Nonaka and Takeushi, 1995, Tsoukas, 1996) emphasises the relationship between organisation settings and management styles with the capacity of creating, capturing, retrieving, processing, transferring, sharing, protecting or re-using knowledge.

Much of the literature concerns itself with developing classifications of different types of knowledge emphasising the Polany's distinction (1967) between codified and tacit knowledge, articulable or non-articulable, formalised or informal, general or specific (Winter, 1987, Leonard-Barton, 1992, Nonaka, 1994). This effort is not surprising since to understand how knowledge might be managed it is necessary to have some understanding about what constitutes knowledge itself. Most of these authors who have developed such taxonomies of knowledge themselves (e.g. Blackler, 1995; Fleck,1996) point out the importance of not only differentiating types of knowledge but also analysing the relationships between these different types, how organisations can manage the processes of creation and transformation of knowledge (Nonaka, 1994, Nonaka and Takeushi, 1995) and how this affects organisations performance (March, 1991, Leonard Barton, 1992, 1995).

These different types of knowledge, however, are not really distinct and appear more as complementary bodies than separate elements (Tsoukas, 1996) particularly because, understanding (i.e. using knowledge) heavily relies on a tacit experience (Nightingale, 1998). Furthermore, learning is a path dependent process so that firms must not only focus on organising and updating existing knowledge and competencies but also on the ability to destroy obsolete knowledge in order for creating new knowledge and building new competencies (Teece et al. 1997). Ortherwise, firms solely concerned by strategising on the basis of existing core competencies may prove unable to perceive environmental changes. Such inertia may be due to the tendency of organisations to underestimate their weaknesses in a changing environment or to overemphasise short-term objectives at the expense of long-term priorities (March and Levinthal, 1993). These 'rigidity traps' (ibid.) may become core rigidities (Leonard-Barton, 1995) when firms rely too much on what they are good at and become unable to question their competencies and thereby fail to adapt new conditions.

Few studies, however, provide an organisational explanation of such rigidities and failures. More precisely, the understanding of the inertia of organisational learning processes , we argue, is still in its infancy and is based on a crude description of the systemic nature of knowledge evolution. The objective of this article is to propose a framework for understanding such dynamics in organisations confronted with fast changing technological environment.

This paper tries to provide further insight in a project management context. The main focus of the paper is on examining the context in which knowledge, of whatever form, is used, acquired and created in complex projects and how knowledge system organise themselves over time. This will enable us to look at the evolution of knowledge systems in teams' organisations as projects evolve. Building on a pattern-recognition perspective we propose a cognitive model in order to specify learning mechanisms that evolve differently according to the complexity of the situation (problem, decision-making, co-ordination etc.) facing organisations. As ideal types, we propose three separate situations: simple situations, problem-solving situations and what we call complex situations where levels of complexity and uncertainty vary and the kind of knowledge utilised and the way knowledge is used is considerably different.

The difficulty for firms is that these three situations often co-exist. Some things are so well defined that the response can be automatic. In this simple situation it is necessary only to use the knowledge required for the task and this is embedded in the system. Knowledge about the system is implicit. Some problems are well enough defined to enable the right knowledge to be 'put together' to solve the problem. Some may say that there are meta-routines in place which help find the right path. In the complex situation the modularity of the knowledge system has to be reorganised. You cannot assume prior knowledge or the existence of meta-routines. You don't know a priori what kinds of knowledge will help, what kinds of competence will be needed. It is context dependent, the path to solution is contingent on the organisation. In this situation new knowledge has to be created to identify and solve the problem.
These concepts will be explored by looking at case studies in the development of complex products and systems (CoPS). CoPS are high cost, engineering- and increasingly software- intensive products systems and constructs (Hobday, 1998). The word complex reflects the number of customised components, the breadth of knowledge and skills required and the degree of new knowledge involved in their design and production. There is often a high level of uncertainty about final outcomes. CoPS tend to be customised for individual customers, produced as one-offs or small batches in projects. We will show how the three situations described above coexist in CoPS projects and how CoPS firms have taken different approaches to using, acquiring and creating knowledge in the different contexts, and how different learning mechanisms are needed depending on the situation.

Organizations as learning entities

It is common place to recognise the adaptive nature of firms in changing environments. Contingency theory stresses the necessity for firms to adapt their environment by designing their organisation adequately (Burns and Stalker, 1961, Lawrence and Lorsch, 1972). Further, Galbraith (1982) explains that firms adapt by trying to match the complexity of their organisation's structure with the complexity of their environment. The evolutionary framework reformulates this relation through the lens of a biological analogy. Adaptation is thus the result of the complementary dynamics of variation and selection. While some insist on the process of selection, taking variety for granted

(Hannan and Freeman, 1977)[1] others consider that variety is the result of an internal evolutionary process, that is the selection of the best fitted routines (Nelson and Winter, 1982). In line with this view, Cohen and his co-authors (Cohen, March and Olsen, 1972, Cohen and Bacdayan, 1994, Cohen et al. 1995) model organisational learning as a process of selection of the best fitted routines given a more or less precisely perceived environment. Although stressing different evolutionary dimensions, these frameworks cohere by suggesting some sort of convergence of organisations of the firms operating in similar environments. Experience, however, tends to show that substantial organisational differences between firms in the same sector remain heterogeneous overtime (Marjolijn et al., 1999). This corroborates the observation that firms' performance is more related to firm effects rather than industry effects (Rumelt, 1991)[2]. The co-evolutionary perspective intends to explain this phenomenon by emphasising the variety of sources of variations within organisations as a natural cause of adaptive ability. Organisations then appear as complex systems that are able to generate novelty inducing non linear behaviour (Anderson, 1999) as a result of human intentionality (McKelvey, 1997), while order and stable adaptive behaviour results from the selection of the environment. This suggests that an investigation into cognitive abilities to make decisions and solve problems may provide useful insights into the adaptive ability of organisations to adapt in changing environments.

The organisational learning literature, as developed amongst others by Cyert and March (1963), Levitt and March (1988, 1996), Argyris and Schon (1996), commonly relate adaptive behaviour of organisations to cognitive abilities of both individuals and of collective entities. Organisations are described as learning systems that adapt their structure - organisation design, routines, or capabilities- according to the changes of the structure they perceive in their environment. In this perspective, organisations are considered as information processing systems (March and Simon, 1958) interpretative systems (Delft and Weick 1984), or knowledge processing systems (Fransman, 1994). While different, the common view of these approaches is that

[1] Variety in their analysis consist of observed differences in entry and exit rates (Hannan and Freeman, 1977), firm size (Freeman et al. 1983) or unobserved sources of heterogeneity (Hannan and Freeman, 1989).

[2]see McGahan, et al. (1997) for an opposite view, which supports that industry effects contribute importantly to firms' profitability. It recognises, however, that firms performance is dominantly affected by business specific effects, particularly in certain manufacturing sectors. See also Furman (2000)for a cross country analysis.

organisations are modelled as adaptive systems that rely on the representations of their environment so that learning is a process of transformation of representations according to new information perceived. This presentation of organisational learning is a natural outgrowth of the information processing model of organizations (Galbraith, 1977) and is consistent with orthodox conceptions of knowledge in philosophy and cognitive science, which equate knowledge with abstract representation (Gardner, 1985, B.T. Pentland, 1992). Knowledge is thus considered as a set of representations of the world and learning lays in improving these representations accurately. In this framework, representations are logically related to external entities. In the same spirit, contemporaneous approaches have been to concentrate on organizational structures, such as routines (Nelson et Winter, 1982, Levitt and March, 1988, Cohen et al. 1995). Routines are the genes of organisations (Nelson and Winter, 1982), but, in this learning mechanism, they can be viewed as the organisational expression of representations, that is as symbolic elements stored within the minds of the members of the organisation. It leads to the conclusion that problem-solving and learning processes are understood as an adjustment of given conditions occurring 'out there'.

This model of relation between cognitive mechanisms and organisation behaviour has been initiated by the early work of Simon (1957, 1959). He had the intuition that decision-making processes were to be linked with the complexity of the environment because it generated different cognitive mechanisms. The behavioural school extended this framework to organizational learning processes and emphasised that it was necessary to distinguish repetitive, well-structured problems giving rise to programmed and *routinized* actions and to stable organizational behaviour (March and Simon, 1958) from more complicated problems of a non-repetitive sort, « *involving basic long-range questions about a whole strategy of the firm or some part if it, arising initially in a highly infrastructures form and requiring a great deal of the kinds of search processes listed above* » (Cyert, et al., 1956, p. 238).

This, as a consequences, engenders more complex organisation behaviours with more actors who have to be coordinated, more iterative processes and fuzzy relations between perceiving, planning, acting and adapting (Daft & Weick, 1984, Argyris & Schön, 1996). The change of action is directly related to the magnitude of the change of their environmental representation. And, at the extreme, the essential aspect of decision-making processes is the ability to construct new representations and new problems (Egidi and Marengo, 2002).

Building new representations is not straightforward, however. This literature has stressed the problem that organisations encounter when confronted to unusual or unstable environments. In particular, organizations may fail to learn and adapt effectively because they prove unable to implement the fittest actions. Rather than adjusting and adapting when external conditions change, organizations may be trapped into behaviors that prove ineffective in the long run, (while possibly efficient in the short run) because they tend to underestimate their weaknesses in new environmental conditions or to over prioritise short term objective over long term ones (Levinthal and March, 1993).In other words, successful learning is considered as a correct updating of representations of the environment. The more difficult the problem to solve, the more radical the changes in representations. On the other hand, organisation failures, that is inability of organisations to adapt properly, are ascribed to path dependency affecting the capacity of organisation to build the correct representation of the true world, that is to 'understand' what the problem is.

Another perspective contesting this representationist view of learning has recently developed. Situated action and the subsequent 'communities of practice' approach stress the role of collective action in problem solving and learning action (Brown and Duguid, 1991, 1998, Lave and Wenger, 1991, Wenger, 1998 Cook and Brown, 1999, Orlikowski, 2002). In the spirit of Vygtosky's concept of 'zone of proximal development', the idea is that competence and cognitive skills proceeds through the same collective action learning process: individuals become more competent by participating in activities beyond their competence with experts. This perspective emphasises the local contextualisation of knowledge, which is partly embodied in human (and not only localised in the brain) and embedded in social relation. Knowledge, therefore, cannot be defined as pure symbolic representations.

This perspective suggests three important analytical conclusions. Firstly, in a way, it rediscovers the phenomenology of Merleau-Ponty, recognising the role of action and experience in the constitution of consciousness and stressing the role of sensori-motor processes in learning (therefore putting bodily sensation at the heart of learning, Damasio, 1994, 1999, Lackoff and Johnson, 1999). As a consequence, learning cannot be considered as a pure mental act and is necessarily dependent on contextual elements such as emotions. It also strongly rely on the similarity of the situations of the specific learning with previous similar or close learning situations. Secondly, this approach suggests that abstract knowledge (supposedly general and decontextextualised) is only the result of a long process of implementation in different specific situations. Furthermore, general abstract knowledge is meaningful only if still applied in specific contexts (Lave and Langer, 1991), or if it permits to develop knowledge more specific to particular situations of actions as we shall develop further in the next section. Thirdly, learning cannot be understood as the result of a linear process going from perception to action. Again, the representationist view considers learning as the result of representation updating when information is perceived from the environment, permitting a better deliberation process, whose output is the selection of the best fitted action. Here, the process relies on a pattern recognition framework, whereby perception is dependent on the level of recognition of the situation. And recognition is dependent on experience, that is on available actions proved to be adapted to similar or close contexts. Perception is therefore an *enacted* system (Varela et al. 1991), that is a reflexive process between the structure of the cognitive system and the environment. Perception, is not directly dependent on environmental stimuli. It is rather the expression of an ability to perform in specific contexts (Varela, 1987, 1992). It follows that problem solving proceeds differently depending on the capacity to recognise the problem, that is the capacity to relate the apprehended problem to known solutions or known paths to solution.

While learning in familiar situation means relating and improving known actions, most of the time by observing and imitating experts who know more, what is at stake is primarily the ability to create new actions when the problem cannot be related to known solutions. These new actions are necessary to create new cognitive structures, new categories of knowledge relating recognised situations and fitted behaviour and thus be "aware" of the situation. It follows that failures or rigidities result from the incapacity to create actions that permits to give a meaning to a question or a problem. The absence of action equate to the incapacity to pose the question. This perspective is more in line with organisations' inertia explained in terms natural tendency to remain stuck on competencies that were strategic in the competitive success of firms and that become 'core rigidities' regarding the new conditions (Leonard-Barton, to create and adapt functions and components, driven by the only aim to maintain itself as a unity, not to adapt from the 'outside' environment (Varela, 1980, Maturana and Varela, 1992). Adaptation must therefore be interpreted as a capacity to create actions in order to maintain the organisation's identity. Adaptation results from a learning process relying on the capacity to relate situations to possible solutions/answers, or to a combination of different answers/solution that may prove complementary in the context of the situation and therefore attribute meaning to the situation. Organisations fail to adapt when they prove unable to create actions, or to combine bodies of knowledge (Kogut and Zander, 1992) that enable the organisation to make sense of unknown events, problems or situations (Dibiaggio, 2000). It follows that different situations require types of collective learning. In the following section, we rely on projects team behaviour to suggest that organisational failures are due to the incapacity of teams to recognise the gap between the apprehended situation and the faculty of their cognitive system to recognise the level of complexity of the situation they are in. We show that this lack of awareness capacity is often due to the rigidity of knowledge systems.

Learning dynamics in projects

An important body of literature has emphasised the high rate of failure in projects driven in particularly complex industries and large engineering projects, the focus being made on projects (Turner, 1978, Perrow, 1984, Rothwell et al. 1974, Rothwell, 1976, Miller et al. 1995, Lessard and Miller, 2001, Hobday, 1998, Hobday and rush, 2000) on organisations (Weick, 1987, Hobday, 1999) or on cognitive dimensions (Rasmussen, 1990). In organisational contexts, authors often stress the necessity to increase capacities of attention, enlarge the scope of detection in order to detect unusual signals coming from a high variety of sources (March et al. 1991; Weick et al. 1999). The question of how organisation may improve this cognitive capacity remains unclear. The first step is to understand how learning proceeds in innovative teams. Innovation in an organisational context is generally considered as a problem-solving process starting from a well-known objective and evolving along a path to approach a solution (cf. Simon, 1981, Vincenti. 1990, von Hippel, 1994, Iansiti, 1998)[3]. As such, innovation is understood as a learning process, which tries to relate problems to fitted solutions. More generally learning is the path relating questions to answers, problems to solutions and knowledge, thus, represents the relation between a question an answer, between a problem and a solution (Dibiaggio, 1999). The more consistent and reliable this relation, the more robust knowledge. The weaker the link to more knowledge is a belief or an hypothesis. In the representationist approach, the pathway is linear and knowledge results from a corroboration process whereby representations, hypotheses and beliefs are tested when information is perceived (by observation or experimentation). In the situation recognition approach, the process is circular since answers both precise the understanding of the question and possibly open up new questions that enlarge the research process. It follows that before a problem is well specified, dedicated knowledge has to be developed or transmitted from reliable sources. Learning, when the question is not well specified or even meaningless, is of a different type than learning when a path to a solution (or a path to a solution) is clearly recognised.

These are important observations. An increasing body of researchers analysing knowledge dynamics in industrial environments (Nightingale, 1998, Orsenigo et al. 1999, Constant, 2000, Stankiewitch, 2000) emphasise the distinction between innovation processes when a problem is well identified (whatever the complexity of the problem) and a situations where the problem is loosely defined, most of the time because there is no existing (or common) representation of it. They also make clear that learning is not a matter of information processing. Rather, it is a question of defining a stable context that allows teams to recognise similarities with previous experiences. Creation and knowledge dynamics is then described as a process research for internal consistency of knowledge systems.

Knowledge system's structure

The previous section suggests that the relationship between problems and solutions are not necessarily unidirectional. Although, a solution is traditionally considered as

[3] This can be extended to any kind of the cognitive process underlying the well-known learning curve. Von Hippel and Tyre (1995) explain that in a production environment, learning lays in identifying and finding solution of problems. As such the learning curve results of the knowledge creation that improve actions and find solution to identified problems.

the output of a problem solving process, knowledge and experience also provide the basis for new questions, new problems to be raised, and then for new knowledge generation. This dynamic tends to organise knowledge systems in terms of relations between a class of problems and a class of solutions to form a *problem space* (or a *design space* in an engineering context, cf. Stankiewitch, 2000). Knowledge systems are thus delimited by their domain of application that comprises knowledge of the properties of elements and the relationships among them (ibid).

Structural and specific knowledge

In organisations, the emergence of a *problem space* is the result of recursive practices of scientists and/or engineers, in repetitive phases of tests and selection of relevant knowledge (Constant, 2000). Once defined, these sequences of trial and error, similar to the Popperian "recursive falsification" process, result in strongly corroborated *'foundational knowledge'*, or structural knowledge, i.e. "*knowledge that is implicated in an immense number and variety of designs embodied in an even larger population of devices, artefacts and practices, that is used recursively to produce new knowledge*" (Constant, 2000, p. 221)[4]. As structural knowledge becomes common knowledge, it becomes the language of the organisation, i.e. it provides an interpretation system that gives a meaning to new problems. Structural knowledge is self-contained and essentially independent of the context of specific problems. While a big part of it can be codified, it is mainly embedded in organisation routines and individuals practices. Structural knowledge is a language that provides the capacity to classify consistently specific knowledge.

Specific knowledge, on the other hand, is knowledge related to specific problems. While complementary with structural knowledge (i.e. they are consistent with the knowledge base) it is not self-contained and relies on specialised expertise. More generally, specific knowledge is the capability to make information meaningful in a specific context. Thus, it is context-dependent and relies on human sensorial perception. For example, if I raise my hand, the meaning will be different in a classroom, in the street and in a stock market. Structural knowledge is analytic in

[4] Structural knowledge is often based on scientific knowledge, which progress "simplifies" the problem space by selecting robust knowledge and eliminating assumptions or beliefs proven to be wrong (Nelson, 1959, Arrow, 1962, David et al. 1992, Nightingale, 1998, Orsenigo et al. 1999)

nature and is mostly a-contextual[5] whereas specific knowledge is context dependent and strongly related to practices in a precise domain. For instance, all Integrated circuit (IC) designers master structural knowledge of electronics. But designers specialised in IC software design have developed specific modules that are not shared by IC hardware designers. Specific knowledge is the knowledge counterpart of communities of practices (Brown and Duguid, 1991, 1998). Knowledge systems, thus, can be considered as hierarchically organised: structural knowledge is foundational and specific knowledge structure consists of categories.

Implicit knowledge and organisational incoherence

In business organisations, a large part of structural knowledge is implicit, because it is embedded in organisational processes, routines and individuals cognitive structures. As such, while necessary to develop new knowledge, it is no longer used explicitly. Shannon theory is not explicitly used to develop new algorithms but those algorithms rely on the existence of Shannon theory. Then, although implicit, this structural knowledge (as a language) must be shared by all communities that have to work in a same context in organisations. This is particularly true for project organisations that group together members with different expertise. Common structural knowledge ensures a common understanding of problems and of solving strategies. Procedures such as New Product Development Process (NPDP) or standardised procedures favour this 'simplification' of the environment in order to make practices coherent (complementary with each others) and meaningful (they are useful in a given context).

But it may happen that teams encounter problems that are meaningless because they are out of the problem space covered by the structural knowledge. Particularly for teams working in system integration projects requiring the combination of different structural knowledge (cf. Kogut and Zander, 1992, Iansiti, 2000, p.11), it may be that structural knowledge does not provide a relevant interpretation system to 'represent' the problem effectively. These situations cause difficulties to engineering teams because problems cannot be solved by using usual routines. This is particularly true when problems reside at the intersection of different knowledge base that do not

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[5] Structural knowledge is the knowledge about the rules of the system (e.g. what is a classroom and how pupils and teachers are supposed to behave in a classroom).

cohere in a common structural knowledge. This give rise complex problem solving involving different forms of learning.

Situation types

The previous section leads us to the conclusion that learning is context specific both at individual and at collective levels. We define a typology of contextual situations that affect the nature of the cognitive process as it is implemented. We put forward *simple, problem-solving* and *complex* situations as three archetypes of decision-making or learning situations that generate particular cognitive processes. The *situation-type* depends on the familiarity of the agent with the question he has to answer, the problem he has to solve or the situation in which he has to behave. Thus, it depends on the capability to interpret a situation and to define an intentional purpose regarding the past experience of the agent in a similar context[6]. The level of complexity of the situation determines the nature of the causal relation between representation and action (from the observer's point of view) and the level of implementation of deliberation.

In case of full certainty, that is when an available answer is directly available, there is no deliberation process. We are in a case of 'pavlovian' stimulus-answer process such as stopping when the red light shows. This is a "*simple situation*", that is a situation characterised by perfect and automatic recognition of the problem and perfect and automatic answer. This is a pure routinised process. This situation is described as the level zero of learning by Bateson (1972). Simple situations are characterised by a perfect knowledge of the consequences of all possible actions to relate the standard economic decision making theory. As such, agents can be considered as rational agents provided with complete access to available information. However, note that a situation is *simple* relative to a specific agent (or group of agent) in a specific context. A simple situation for chess master can be *complex* for a novice, and the situation is simple for the master playing with a novice, whereas it becomes complex when playing with another master.

The success of companies' strategies is often related to the capacity to simplify and standardise activities. Production lines, Just-in-Time and the Kanban method, EDI and electronic commerce are all techniques that permit unit cost reductions and economies of scale by simplifying and standardising actions. The new economy is no exception. Michael Dell based the success of his company (Dell), on the standardisation of the relationship between customer specific demands (through the Internet for almost 50% of orders) and the assembly of computers (probably the best example of mass customisation processes). Further, in each company, a large part of the business consists of simple situation, from accounting to logistic and delivery services.

When the problem is recognised, but there are no automatic available actions to solve it, then a deliberation process is required. A _problem-solving situation_ is characterised by a *closed problem space* (and known to be closed by the problem-solver), procedural rationality is implemented as defined by Simon (1976, 1982) and inductive reasoning is required. Since the question is clear and the solution is known to exist but cannot be reached automatically, then the problem is decomposed in sub-problems that can be solved independently and sequentially. This is a means-end procedure that needs deliberation and strategy because (working) memory's capacities are limited. The more the *problem space* is important, the more solving capabilities are bounded by the limits of memory.[7] The case of an engine failure is a good illustration. If you are an expert, you are able to implement the relevant procedure to find the source of the failure and to procedurally solve the problem. If you are not an expert, you have to learn explicitly the procedure to find the source of the problem and learn empirically the way to solve it. Then tacit knowledge is required since new structures have to be constructed. If the problem solver has no knowledge at all about engines, the situation becomes complex because the *problem space* is recognised as open.

The problem solving situation is also well illustrated by the Rubik's Cube (Dosi and Egidi, 1991, Dosi et al. (1996). Even if an optimal path exists, it is not rationally efficient to search for it. It is more efficient to adopt a procedural rationality: the problem is decomposed in sub-problems that can be solved independently and

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[6] We define elsewhere (Dibiaggio, 1999) how the context is defined, taking into account individual experience, history, etc., social dimensions such as conventions, the structure of the language etc. and the contextual apprehension of the problem.

[7] Interesting psychological experiments on he working memory have explored the way working memory performs in different situations and how learning can occur implicitly, i.e without using explicitly knowledge stored in memory (knowledge stored in long term memory is not evoked in working memory) (cf. Reber, 1989). It is also shown that creation is the result of memory limitation or that creation and learning are possible thanks to the capability to forget.

sequentially. This is a means-end procedure. Each sub-problem is set up in coherence with the general problem so that compatibility and consistency is ascertained. This is the most frequent situation in development activities, such as customised products and process innovation.

Finally, a *complex situation* results from an ill-defined problem, a desired end-result solution of which cannot be found by implementing logical transformation rules or heuristics from initial conditions (cf. Nightingale 1998). The goal is an expectation in the sense of Schackle, i.e. it is related to entities created by *imagination*[8] and not from the objective position of the observer. The problem space is open, i.e. there is a Knightian uncertainty about the existence of a solution. The existence of a solution is pure conjecture. As there is no relevant cognitive structure in the system, the strategy followed is the use of lateral learning, i.e. of analogies and research for similarities from previous experiences models, rules etc., or of metaphors in order to create relevant concepts (Richard, 1995). Lateral learning consists in creating links between two independent structures and constructing new meanings, that is new knowledge (ibid)[9]. This associative capability is tacit knowledge, context dependent since emotions can be a central variable.

Knowledge creation emerges out of the set of rules previously known. This process can be compared (but is not always equivalent) to different learning processes mentioned in the management science literature such as 'combinative capabilities' (Kogut and Zander, 1992), 'integration' (Grant, 1990), 'configuration' ([Henderson, 1990]), the concept of 'ba' (Nonaka and Konno, 1998).

Illustrative case

To illustrate the co-existence of the three situations and the associated implications for learning and knowledge we will examine the case of Telco, an international

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[8] Shackle define the concept of imagination as the capacity to conceive an infinite list of possible alternative actions. The role of imagination is to create elements that will allow the decision maker to build his choice (cf. Littlechild, 1990).

[9] This use of metaphors , or lateral learning is defined as abduction as opposed to inductive or deductive reasoning. «The abductive suggestion comes to us like a flash. It is an act of insight, although of extremely fallible insight. It is true that the different elements of hypothesis were in our minds; but it is the idea of putting together what we had never before dreamed of putting together which flashes the new suggestion before our contemplation » (Charles Senders Peirce, 1934, p. 113). As the quote suggests, abduction has sympathies with the intuition and imagination but there are several controversies about the cognitive mechanisms of abduction. (cf. Simon, XXX, Chomski, XXX on one side and XXX)

manufacturer of telecommunications equipment with customers in more than 100 countries. Telco's technical development activities are decentralised in 40 different development centres in 20 different countries. It has a corporate culture which is customer oriented in focus, and emphasises an open and consultative style of working. Telco has 5 business areas which share a common technology - digital switches: Radio Communications, Public Telecommunications, Business Networks, Components, and Microwave Systems. Three types of projects are carried out in the Radio communications division: mature product installations, new development projects, and turnkey projects.

Mature product installations are small projects for the design and installation of solutions for specific customers. They are carried out by local Telco companies where the customer is located. They involve the use existing technology which is tailored to customer-specific demands. The risks incurred are low since Telco has huge experience in carrying out similar projects. *New development projects* are usually large projects to improve component or interface technologies. They are directed at finding generic improvements in cellular designs and involve dispersed development efforts - group R&D, local Telco companies, key customers are also involved. Telco both develop new technology and integrate it with older technology. The risks incurred are high financial ones. *Turnkey projects* include all activities needed to design, construct and install cellular systems ready for service. The customer, a mobile telephone operating company, hands over responsibility for all activities - system integration and project management - to Telco. They tend to use the existing technology base but Telco has to develop new organisational arrangements and develop new capabilities (to enable then to carry out activities which the customer used to do). The risks incurred are high commercial ones.

The first type of project - an installation of a mature product for an existing customer -involves little or no new knowledge. A standardised process is used for the installation. It is an example of the a *simple situation* as described above. The structural knowledge is stable, the specific knowledge is stable. We will now examine examples of the two other types of project, a new development project we shall call Newdev and a turnkey project, we shall call Cellphone to show how they share the characteristics of the problem-solving and complex situations described above. Both projects involved mobile telephone network technology.

Newdev was a large development project carried out over a period of three and a half years which was responsible for developing a new generation of technology, based on the GSM platform, for Personal Communication Networks (PCNs). Newdev was regarded as one of Telco's most complex projects in terms of the range of technologies and number of local companies involved. The project was organised and mainly undertaken by Telco's Radio Communications business unit and central R&D facilities. However, important work was carried out by local companies' design offices located in nine European countries and at the sites of major customers who were closely involved in all stages of the design and production of new technology. Several component technologies were developed at the same time before being integrated into the final product. Design and development of the system involved around 800,000 person hours of effort over a period of three years.

By incorporating several software functions in custom designed integrated circuits, Telco was able to make BTSs (base stations) considerably smaller, cheaper and more quickly. Moreover, the BSC in Newdev had to be one-project 'backwards compatible' with the previous generation of GSM technology. This requirement had knock-on system effects in other related components. As in all of the company's projects, the project adopted a number of formal and informal management tools.

Problems in the project

There were several problems in the Newdev project. At the organisational level, the main obstacles were the difficulty in co-ordinating activities across Telco's companies in different countries and the problems of co-ordinating resources allocated to project activities in the matrix organisation, e.g. development of BTS products in a multi-project environment. There was a perception that line managers at the node level had too much control over resources and that more control should be placed in the hands of project managers. In terms of technology management the major problems were parallel design changes and effective communications, and product availability. In Newdev, the design of the BSC node was delayed because the BSC technology failed to work effectively with the new generation of mobile handsets. This had knock-on effects for development of OSS software, which had to be adjusted to comply with the new requirements of the BSC. As a result of these problems, the Newdev project was reorganised, creating fewer, more simple organisational interfaces to improve the communication between the BSC/BTS nodes and OSS node, and providing each organisation with clearer objectives.

Newdev, was very complex, even for Telco, but the problems fell largely into areas where they had experience of solving them before. The major problems they experienced were not technical but organisational. The 'solution' to the technology problem was to reduce the level of functionality in the released product in line with practice from previous development projects. In addition they made a reorganisation to reduce some of the complexity of the project by creating fewer, more simple organisational interfaces to improve the communication between the different components, and providing each organisation with clearer objectives. Once the problem became clear they were able to utilise their problem-solving capabilities to come up with a suitable answer to the problem. In Newdev there was stable structural knowledge but dynamic specific knowledge. In this situation they were able to use their experience to formulate solutions according to established previous practice.

Lastly we look at an example of a complex situation which was revealed in a turnkey project Cellphone.

The Turnkey Project

In 1995 Telco became one of the first telecommunications equipment suppliers to provide turnkey product in an advanced industrialised country. Previously Telco had only been involved in turnkey projects in developing countries where operators lacked the experience and competencies to build networks.

Prior to the turnkey project Telco was already involved in the design and installation of its latest technology in the Mobitel mobile telephone network, Cellfone, which entered service in July 1993. Mobitel was responsible for all major system integration activities including cell planning, transmission planning, site acquisition and civil builds, with Telco responsible for the supply of the equipment.

At the time, it was the largest telecommunications turnkey project undertaken in Europe. Under the terms of the contract, Telco took over responsibility for the entire range of activities entailed in the provision of a full turnkey solution: cell planning, network design, site acquisition, civil builds, installation, test, acceptance and project management activities.

The objective of the project was to help accelerate the roll-out by installing around 1,500 base stations and 15-20 mobile switching and base station controller sites in the

Cellfone network by the end of 1997. The turnkey project was being implemented in parallel to the existing rollout programme and two further contract variations awarded to Telco during late 1995 and early 1996.

Telco drew upon its existing competencies in project management, network design, manufacture and supply of equipment, and implementation and support of equipment, software and services. While Telco had considerable experience in project management and systems integration (as shown in Newdev project above) the turnkey project raised new and unknown organisational problems. To carry out the turnkey solution Telco's cell planning resources had to be developed and new competencies had to be acquired in site acquisition and site construction.

Project implementation

The contract was won by the Telco local company responsible for cellular systems but the contract specified that a new organisation had to be established to manage the project. Telco created a new organisation called 'Turnkey Projects Group' to set up a project management organisation and acquire and develop a new set of competencies in cell planning and civil builds. The project gradually expanded to reach of a peak of 80-100 employees by May 1996. Around 50 per cent of the project employees had to be recruited from outside of the group to establish the new areas of competencies.

Problems in the project

Telco had sufficient in-house experience in project management and system integration to install equipment in the Cellfone network. It was in unfamiliar areas - such as project reporting in a project of this size and complexity, cell planning and site acquisition using sub-contractors - which gave rise to new and unknown problems and more than 20 changes in organisational structures to remedy them.

The major problem, however, was in the area of sub-contractor management. In an optimal situation, the turnkey project would follow the nominal cell and transmission plans. In practice, the rollout and configuration of the network is driven by the process of site acquisition, which one manager compared to the difficulties entailed in 'arranging to buy a house a thousand times'. The potential difficulty in acquiring sites was identified in its pre-contract risk assessment, but Telco failed to guard against future delays, problems with reporting mechanisms and other issues in the writing of the sub-contractor contracts. The problem was compounded by Telco's lack of civil builds knowledge at the time the contracts were drawn up. The overall project manager's time was dedicated to solving problems with this sub-contractor and a new project manager was brought in to oversee other project activities.

Another major problem for the Cellfone project was the inadequacy of IT support tools and a proliferation of stand-alone databases. Under the terms of the contract, Telco had to make use of Mobitel's database for reporting requirements. In this database all the products were broken down into components and every component had a part number. This detailed breakdown was unnecessary for many project reporting activities but it meant that standard project management software was inadequate to deal with the large number of events.

Other IT project management tools proved to be problematic because of the size and complexity of the Cellfone project. As a result there was a proliferation of tools in Telco consisting of stand-alone databases for cell planning, project reporting, customer interface, transmission plans and site acquisition. The problem was exacerbated by the sub-contractors each having their own databases. In the end what emerged was a "Tower of Babel" with information being conveyed in many different tongues, with no-one really sure which information was correct at any particular time. The lack of an integrated system had major knock-on effects for the financial control of the project - it became virtually impossible to extract a set of accounts for the turnkey project.

The complex situation was exhibited in the Turnkey project which was the first time Telco had undertaken such a project in an industrialised country and required knowledge of areas previously unknown to the company. Even though the technology being implemented was known (it was to use the products developed in the Newdev project) the whole area of site acquisition and civil builds was alien to Telco employees and presented major difficulties in finding out what the exact problems were let alone solving them.

In Newdev, Telco had adopted the usual mechanistic management structure (Burns and Stalker, 1961) that it used for its development and supply projects, involving a hierarchical structure of authority, control and communication which was adapted to complex but relatively stable technical and commercial conditions. In contrast, the Turnkey project involved more uncertainty with changing market conditions and contractual problems which could not easily be broken down into functional roles defined within an hierarchic structure. A more organic management structure had to be put in place. The turnkey project was the first-off of a new kind of project for the organisation. Being the first-off there was no previous experience reflected in both the formal or informal organisation. In such circumstances it is not surprising that mistakes are made, that there are efforts to crowbar the new unfamiliar circumstances of the new project into the well tried and well known structures and procedures of the previous 'normal' way of doing things. In this unknown world Telco was like a blind person groping about for some familiar reference points. The numerous changes in organisation can be seen as a series of responses to this as they struggled to find an appropriate structure for the new circumstances.

The Turnkey project also generated many problems associated with spanning organisational boundaries. Whereas typical Telco projects were often spread around its global divisions and development organisations there was a shared approach which meant that common understanding of the situation. In the Turnkey project there were major problems in relation to the management of sub-contractors in the Turnkey project, and the requirement to interface with the customer much more closely. The stories and myths that Telco people were familiar with related to their traditional telecoms projects. Their expectations were based on this shared view of history. They had no previous experience of working with the very different culture of the site acquisition and civils build world. They assumed that business behaviours in the two areas were the same. This was a major factor in the failure to have proper contracts with their sub-contractors and the subsequent problems they had in managing the situation. . In the course of the Cellfone project new people were taken on who had experience of the construction industry. This helped Telco develop a solution to their problems – the co-location of a Telco manager with the major problem subcontractor. In line with it being a complex situation, in the Turnkey project the structural knowledge was unstable their existing practices and structures proved inappropriate. Furthermore, the specific knowledge was unstable – the kinds of knowldege needed to solve the problems was very project specific. There was strong knowledge obsolescence Telco people had to learn a whole new way of doing things. Experimentation was necessary at almost every level of the project.

Conclusion

The aim of this paper was to show that organisation rigidities have some explanations in the organisation and the evolution of knowledge systems in organisations. We have proposed a definition of knowledge as dynamic system of action that organises itself according to specific context of problem solving experienced by the teams involved in projects. As knowledge becomes more general and a-contextual it becomes structural knowledge, that is knowledge that structures defines categories and makes sense of more specific knowledge. Structural knowledge tends to be implicitly used in the context of specific projects. We have also proposed a typology of situations suggesting different cognitive behaviours regarding the complexity of events, questions or problems encountered by collective entities.

Our contention is that organisations fail to adapt not necessarily because they lack the competencies to solve new problems or because they lack the ability to select the relevant action, but also because they are unable to recognise the type of situation they are in. In particular, when project teams face complex situations they do not recognise that the structure of the knowledge system is to be questioned. This is because they fail to recognise the necessity to adapt structural

The projects within Telco illustrate the difference between simple, problem-solving and complex situations as referred to above. Each of the three project types required different sets of specific competencies, that had a balanced effectiveness according to the complexity of the situation. It turned out that the more serious project failure did not occur in the project that was recognise as the most challenging, at least technically, but the one that was induced complex situations as defined above.

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