Cacciatori, E. (2008). Memory objects in project environments: Storing, retrieving and adapting learning in project-based firms. Research Policy, 37(9), pp. 1591-1601. doi: 10.1016/j.respol.2008.04.028

Memory objects in project environments: Storing, retrieving and adapting learning in project-based firms

Eugenia Cacciatori

Management Department
and
Center for Research on Business Organization (CRORA)
–
Università Bocconi
Via Sarfatti 25 – 20136 Milano, Italy

ABSTRACT

This paper investigates the role of objects holding representations of knowledge in the transfer of learning across projects. On the basis of an in-depth case study, this paper shows that the way in which relatively simple artifacts, such as Excel workbooks, represent knowledge enables them to act as boundary objects across occupations and as memory devices across projects. It is the *temporal capacity* of these boundary objects that makes them points of juncture in a widely distributed memory system, enabling project-based firms to balance preservation and adaptation of knowledge. The mechanisms for the preservation of learning are not missing from project environments, rather they are less visible and less direct than in other settings, and therefore less docile in the face of managerial action.

Keywords: Project-based organizing, organizational memory, boundary objects, artifacts, construction industry, PFI

Please cite as follows:

Cacciatori, E., 2008. Memory objects in project environments: storing, retrieving and adapting learning in project-based firms. *Research Policy*, *37*(9), pp.1591-1601.

1. Introduction

In recent years, firms have increasingly relied on projects to generate, access and deploy knowledge in complex and uncertain environments (e.g., Whittington et al., 1999; Ekstedt et al., 1999; Lundin and Midler, 1998). Widely prized for its versatility in producing and adapting knowledge, project-based organizing is, however, notorious because differences in output, participants and processes make knowledge accumulation difficult (Grabher, 2004; Gann and Salter, 2000; Scarbrough et al., 2004). Following recent research showing that the competencies deriving from the accumulation of knowledge over series of projects are crucially important for firm performance - even in high-tech, highly innovative and network-oriented environments such as biotechnology (Pisano, 2000), the issue of how knowledge accumulation can be sustained in project-based environments has become much debated.

This paper contributes to the growing body of research on knowledge accumulation in project environments in two ways. Firstly, this paper adopts the 'remembering' rather than the more commonly used 'learning' metaphor. While learning implies modification of the knowledge held in an organization's 'memory' (Walsh and Ungson, 1991), the use of the learning metaphor tends to concentrate attention on the creation or modification of knowledge, taking for granted the processes through which this new or modified knowledge is consigned to and retrieved from the organization's memory (cf. Winter and Szulanski, 2001; Spender, 1996). However, it is precisely the ability to devise 'storage' and 'retrieval' processes that enable the timely retrieval of and adaptation to new contexts of relevant knowledge, that is crucial for firms operating in discontinuous environments such as projects (cf. Bannon and Kuutti, 1996; Paoli and Prencipe, 2003).

Secondly, this paper argues that our understanding of how these 'storage' and 'retrieval' processes work in project environments can be significantly improved by examining the role played by artifacts. The literature on across-project learning has tended to focus on the tacit knowledge held by individuals in the form of expertise on the one hand, or on objects holding codified knowledge, such as 'lessons learnt' databases, on the other hand. In the wake of the information technology revolution, these two forms of knowledge storage have been primarily seen as substitutes. However, recent developments in the literature on knowledge codification and the emergence of 'practice-based' approaches to knowledge have shown that many features of knowledge exchange hinge on how codified knowledge and expertise interact. Furthermore, literature in these fields has shown that the way in which knowledge is represented is central in determining the features of this interaction and of the resulting knowledge transfer. Building on this literature and an in-depth case study, this paper shows that the representational features of relatively simple artifacts, such as Excel workbooks, enable them to perform the dual function of memory devices across projects and boundary objects across professional groups. This *temporal capacity* of the boundary objects observed in the case study makes them points of connection within a widely distributed memory system, spanning the project, the individuals taking part in them, the organization and the professional communities involved. The combination of the community spanning and temporal features of these objects enables firms to build on experience, while maintaining the flexibility necessary to adapt to the specificities of each project.

The paper is organized as follows. Section 2 provides a review of what we know about the mechanisms supporting organizational remembering in project-based environments. Section 3 focuses on the role of artifacts in an organization's memory. Section 4 presents the empirical setting and method. Section 5 presents the case study, which is discussed in 6. Section 7 draws the conclusions.

2. Learning, remembering and forgetting across projects

A large body of research rooted in the resource-based view of the firm (Barney, 1991; Penrose, 1959) and in evolutionary economics (Dosi, 1982; Nelson and Winter, 1982) has shown the critical importance of firm-specific competencies in the survival and growth of firms. From an organizational point of view, competencies are seen as the result of learning processes that 'encode inferences from history into routines that guide behavior' (Levitt and March, 1988, p.517). These routines constitute the main form of organizational memory with regard to a firm's operations, so that, as Nelson and Winter (1982) famously put it, firms *remember by doing*. Higher order routines that are able to alter operational routines are seen as the critical means by which firms are able to adapt their competencies to survive in a changing and turbulent environment (Teece et al., 1997; Winter and Zollo, 1999). At the core both of the normal operations of firms and their ability to produce or adapt to change, there are therefore stable organizational processes.

The literature on projects conducted by former mass manufacturing firms has tended to emphasize projects as ways to build upon existing competencies while avoiding some of their rigidities (e.g., Leonard-Barton, 1992). However, the literature on firms that operate *mainly* through projects (e.g., engineering design firms, producers of complex products and systems, movie makers) has argued that the temporary and often inter-organizational nature of projects makes it difficult to develop routines, thereby precluding one of the main means through which organizations remember what they have learnt (Gann and Salter, 1998, 2000; DeFillippi and Arthur, 1998; Hobday, 2000). The difficulties that project-based organizing poses to knowledge accumulation in firms, and the growing awareness of the importance of interorganizational networks in the production of knowledge (Chesbrough, 2003; Grandori, 1999; Powell et al., 1996), has led us to question whether firms can still be relevant stores of competencies in the new knowledge and project intensive economy (Grandori, 2001). Indeed, recent research has shown that there are viable alternatives to firms as managers of competencies and that industry-wide social networks and institutional arrangements can support distributed social learning in at least some project-intensive contexts such as film-making and advertising (Grabher, 2002;DeFillippi and Arthur, 1998). However, these and other studies also suggest that firms still have an important role when the production of technically complex services or products is involved (Barlow, 2000; Davies and Brady, 2000; Heimer, 1985; Ibert, 2004; Morris and Empson, 1998; Prencipe and Tell, 2001; Scarbrough et al., 2004). In particular, Grabher (2004) shows that, while in the advertising industry individual expertise is considered a key source of competitive advantage, and that industry-wide social networks play an important role in locating and retrieving it, the software industry is characterized by the importance of firms in accumulating technical and organizational competencies. Similarly, the emphasis on 'not reinventing the wheel' is much stronger in software production than in advertising.

In those contexts in which firms are important repositories of competencies, the initial response to the perceived difficulty of encoding learning that takes place at project level into stable organizational processes, has been to rely either on individuals[1] or 'technology'. This view perceives competencies as consisting primarily either of firm members' expertise, which is largely tacit and cannot be easily stored, or of particular technological solutions that are embodied in objects (such as databases or software modules) that can be reused and in this way are made replicable and portable. This polarization between the extremely tacit and the extremely codified has introduced the idea of organizational memory in project-based firms into

[1] See, for instance, many contributions in the *Management Learning Special Issue on Project-Based Learning*, **32**(1), 2001.

the debate on the extent to which information technologies (IT) can or cannot be used to store, augment or complement human memory (Bannon and Kuutti, 1996; Paoli and Prencipe, 2003; Schultze and Leidner, 2002; Swan and Scarbrough, 2001). Indeed, there is research that shows that reliance on IT to support organizational memory increases with the degree of standardization in the products and services provided, and that firms that provide highly customized products and services rely more on intra-firm social networks for the location and adaptation of knowledge (Morris and Empson, 1998; Hansen et al., 1999).

Other research, however, shows, both from a theoretical and an empirical viewpoint, that stable intra-organizational processes play a role even in intensely project-based environments. From a theoretical point of view, Gann and Salter (1998) argue that, when looking at project-based organizing, it is important to distinguish between 'project' and 'business' processes. Project processes occur in the context of specific projects and are aimed at the design, production and delivery of specific products. As they need to adapt to the specificities of each project, project processes exhibit a relatively high degree of uniqueness and cannot be immediately transferred to other projects. Business processes, on the other hand, are intra-firm and are usually aimed at co-ordinating the access of each project to firm-specific resources, such as experienced engineers. These processes are likely to be more stable – and are therefore more likely to play a role in the accumulation of competencies. Although not necessarily adopting Gann and Salter's (1998) terminology, there are a few studies that provide empirical evidence supporting the hypothesis that firm level processes play a role in encoding and making project-based learning accessible across projects. Davies and Brady (2000) argue that, despite the discontinuity of project operations, firms are able to develop routines that allow 'economies of repetition' across similar projects, so that bidding and project execution costs diminish for later projects in specific 'lines of business', such as turnkey, outsourcing, Build-Operate-Transfer. Similarly, in their study of IDEO, the largest product development firm in the USA, Hargadon and Sutton (1997: 738) show that "IDEO designers retrieve technological solutions … through established routines for sharing the problem of current design projects with other designers in the organization who have relevant and potentially valuable knowledge". These routines include brainstorming sessions and 'Monday morning' meetings that bring together all the designers.

In addition, several studies, including Davies and Brady (2000), Hargadon and Sutton (1997), Grabher (2004), Prencipe and Tell (2001), demonstrate the presence and interaction of different 'stores' in sustaining the processes of organizational remembering in firms operating through projects. Davies and Brady (2000) and Grabher (2004) show that, in addition to routines and social networks, firms store part of their competencies in modules of the final product that are used across projects. IDEO operates by taking 'solutions' developed in one industry and adapting them to the problems of companies in other industries. Solutions are identified through the practice of assigning IDEO engineers to projects in a wide variety of industries. However, since the finding of solutions does not coincide with the problems for which they could be relevant, organizational memory is needed to link problems to solutions, provided by an "informal reference system [that] equates individual engineers with families of technological solutions" in which "upper-level managers serve as quasi librarians" (Hargadon and Sutton, 1997: 737). Furthermore, objects, in the form of toys, models and other physical artifacts, are used to provide a visually rich environment that supports the memory of designers and promotes its sharing. IDEO's ability to build upon previous experiences in tackling new projects is therefore crucially dependent upon its unique ability to exploit the complementarities between different type of 'repositories', in particular individual expertise, objects and routines.

Overall, existing research suggests that, in order to understand how firms operating in project environments can achieve the required balance between preservation and adaptation of knowledge, what is important may not be 'what' or 'how many' different types of memory work in project contexts, but how these different types of memory interact in enabling the transfer and adaptation of learning from project to project. A 'system' view of memory (cf. Ackerman and Halverson (2004) enables us to better understand how the 'learning boundaries' (Scarbrough et al., 2004) deriving from the uniqueness of the social processes of each project can be, if not entirely overcome, at least made more permeable. In this paper, I argue that a first step to fully develop such a systemic view of organizational remembering is to change the way in which we approach artifacts as part of organizational memory. The next section examines this aspect.

3. Objects of memory

Most existing research on learning in project-based contexts looks at artifacts, implicitly adopting an approach to organizational remembering derived from mainstream psychology, the so called 'computer metaphor of organizational remembering' (Bannon and Kuutti, 1996; Paoli and Prencipe, 2003; Spender, 1996). This approach models memory as an object rather than as a process, and sees the organization's memory as being stored in data banks or knowledge repositories of various kinds including computer systems, filing systems, individuals, procedures and culture (e.g., Walsh and Ungson (1991). Knowledge may or may not be able to be effectively 'retrieved' from these memory banks depending on such factors as the storage capacity of these repositories, their persistence and reliability over time, the quality of their indexing. Accordingly, artifacts embodying knowledge, particularly if IT based, are looked at in terms of the potential benefits they offer over human memory for reliably storing large amounts of factual knowledge. In other words, the emphasis is on the 'storage' part of the process, while retrieval is taken somewhat for granted. Although not explicitly mentioned, this view of objects characterizes Grabher's (2004) and Davies and Brady's (2000) analyses of how solutions to technical problems tend to be incorporated into pieces of the final product, thereby enabling the ‘recycling’ of knowledge across projects. Similarly, Hargadon and Sutton (1997) show that toys and mechanical artifacts act as memory by providing designer’s with visual reminders of possible solutions. This view is consistent with studies on the evolution of technology and professions, which show that, as bodies of knowledge mature and stabilize, they tend to be progressively incorporated into objects - commonly (if reductively) thought of as ‘technology’ (Abbott, 1988; Hutchins, 1995; Rosenberg, 1976).

However, there is a long tradition in the study of technology which has shown that artifacts play a more complex role in the life of organizations than simply enabling the unproblematic recycling of knowledge across different contexts. The way in which objects ‘embody’ knowledge contributes to shaping and structuring the interactions taking place around them, including the extent and quality of knowledge flows (e.g., Barley 1986, Zuboff 1988). While traditionally this area of research has been concerned primarily with the redistribution of control and power following the introduction of new technologies, recent research has focused on exploring the role of objects in the social processes that underlie cognition and problem-solving. In this respect, objects that incorporate representations of knowledge (such as drawings, procedure handbooks, virtual modelling software) are particularly crucial. A useful analytical framework to explain this is provided by Foray and Steinmueller (2003) who argue that codification has two distinct effects. The first is to facilitate the storage and transfer of knowledge across time and space. While not all knowledge can be transmitted in this way, the availability of knowledge representations can considerably reduce the extent to which knowledge needs to be transmitted within a direct master-apprentice relationship. However, the extent to which the process of knowledge transmission through time and space is facilitated depends on how the knowledge is represented (Carlile and Rebentisch, 2003). People search past knowledge in relation to their present objectives and through the filters of the cognitive frameworks provided by their professional backgrounds and experience. The way in which knowledge is represented needs to 'click' with these parameters for 'old' knowledge to be taken into consideration and evaluated in relation to a 'new' problem. Therefore, the way in which knowledge is represented is central to how much past knowledge can be brought to bear on present problems.

The second effect of codification discussed by Foray and Steinmueller (2003) derives from the fact that the type of codifications that have so far been prevalent in our society entail a symbolic representation of knowledge (including analytical, mathematical and graphical modelling). Symbolic representations can be manipulated, enabling activities such as reordering, juxtaposition and combination – thereby facilitating the creation of new knowledge from old knowledge. The ability to manipulate knowledge afforded by the effective use of symbolic representation has been shown to play an important part in enabling the leverage of existing knowledge when dealing with new problems. For instance, Narduzzo et al. (2000) show that telecommunication technicians found it easier to adapt the setting up switches to suit local needs when the rules describing how to do so were more detailed. Similarly, Adler and Borys (1996) use the analogy of user friendly machinery to describe the property of what they call 'enabling rules', which give people more visibility as to how the system as a whole works and therefore allow them to autonomously develop solutions to unexpected problems. D'Adderio (2001, 2003) found that delegating product and process memory to software often entails a change in the way knowledge is represented and that change in representation profoundly alters, and often seriously disrupts, the processes through which knowledge is reproduced. It is therefore likely that the representational characteristics of the memory objects employed in project-based firms play an important part in enabling them to build on experience.

A key issue that needs to be addressed when looking at ways to represent knowledge lies in the fact that different people, and in particular people with different educational and occupational backgrounds, have different ways to represent knowledge, which are adaptive to the knowledge manipulations needs of their occupations (e.g., Dougherty, 1992; von Meier, 1999; D'Adderio, 2003). ‘Pragmatic’ approaches have been particularly effective in investigating the properties of objects that mediate problem-solving activities requiring the collaboration of individuals with different objectives and ways of framing problems. In this respect, a key notion is that of ‘boundary objects’, i.e.

> objects which both inhabit several intersecting social worlds … and satisfy the informational requirements of each of them. Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. … They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds. (Star and Griesemer, 1989, p. 393)

In order to perform their function as boundary objects, artifacts need to have enough common structure to guarantee consistency, but not too much structure as they need to adapt to local needs. In Foray and Steinmueller’s (2003) terms, these boundary objects need to represent knowledge in a way that enhances its manipulability. However, they also need to be able to produce more than one representation in order to adapt to local needs, while maintaining consistency across representations. The representational capacity of boundary objects is therefore central in enabling them to perform their function. The demands on representational capacity are particularly high for boundary objects supporting knowledge exchange between groups whose knowledge is highly interdependent (so that performances across areas are in trade off), in a context in which the nature of the interdependence is not well understood. In such situations, boundary objects need to enable the joint modification of knowledge in light of the knowledge held by each group (Carlile, 2002, 2004).

Pragmatic approaches have also brought to the fore the complementarities between objects incorporating knowledge ('reifications') and the processes of exchange and manipulation of knowledge through personal interaction ('participation') (Wenger, 1998). Being objects, reifications are portable and facilitate the transfer of knowledge. However, their meaning is not universal as it has been negotiated in a specific context of participation. Therefore, participation is essential to repair misalignments of meaning caused by the diversity of the contexts of knowledge generation and use. At the same time, reification compensates for the excessive fluidity of participation by 'focusing the negotiation of meaning.'

The debate on codification and pragmatic approaches has contributed important insights on the impact of objects, in particular representations, on the social processes through which knowledge is exchanged, especially during new product development projects (Carlile, 2002; D'Adderio, 2001; Orlikowski, 2002; Bechky, 2003; Yakura, 2002), and during the process through which representations are consigned to software (e.g., Henderson, 1991; D'Adderio, 2001, 2003; Ackerman and Halverson, 2004). However, we know little about the *temporal* dimension of boundary objects, i.e. if and how the mediate knowledge exchange across time as well as across groups, and specifically whether and how they play a role in enabling knowledge preservation and adaptation across projects. The case study presented below examines how the representational characteristics of an Excel workbook enable it to perform the dual function of memory device across projects and boundary objects across professional groups, mediating the processes of retrieval and adaptation of knowledge.

4. Empirical settings and method

This paper is based on an in-depth qualitative case study of a large British engineering consulting firm and support service provider (Company DE&FM, an acronym for Design

Engineering and Facilities Management used to preserve anonymity). The British construction industry is an intensely project-based industry, which, although characterized by relatively low levels of product innovation, has undergone major changes in terms of the way projects are procured. These changes are linked to the rapid diffusion, since the 1980s, of a variety of *integrated procurement routes* in response to client demands to deal with a 'single point of contact' with overall responsibility for the project, rather than with a host of specialized suppliers as in traditional procurement. The most integrated among these routes is the Private Finance Initiative (PFI), a controversial public procurement method introduced in 1992 in which a single firm wins a contract covering the phases of a facility's life cycle from financing to maintenance. For instance, in the case of schools, PFI entails a single contract under which, in exchange for an agreed annual payment, a firm undertakes to finance, design, construct and maintain the infrastructure and the mechanical and electrical services of one or more schools, and to take care of waste disposal, catering, security, and other services for a period of 25 to 30 years.

The diffusion of integrated procurement routes has been accompanied by major changes in the organization of the industry, and in particular by a significant increase in size of the largest firms and by a widening of the range of activities they carry out (Cacciatori and Jacobides, 2005). DE&FM, in particular, expanded its activities from the original engineering design core to include project financing, architecture, cost consulting and facilities management, becoming one of the largest British engineering consulting firms. On the strength of its wide range of activities, the case study firm set out to develop competencies in PFI projects. DE&FM, therefore, needed to develop the processes through which what was learnt about PFI projects was consigned to and retrieved from the organization's memory.

The processes of organizational remembering in relation to the new PFI projects are particularly observable during the *bid preparation* phase. As the market is perceived to be competitive and there is little room for renegotiation once the contract is awarded, cost and quality advantages deriving from experience in projects of the same type need to be incorporated in the offer at the bidding stage. At the same time, the task of developing a bid package for a PFI project is significantly more complex than in the 'design only' projects that were the traditional domain of design consultants. Unlike traditional, sequential procurement, PFI projects provide strong incentives to reduce costs or improve quality by exploiting synergies between design, construction and maintenance, typically by designing buildings that can be built and maintained more easily. Identifying and exploiting the opportunities for cost reductions or quality improvements requires collaboration between designers, cost consultants, contractors and facilities managers. However, in traditional procurement, these actors worked sequentially and with very little interaction. Therefore, developing competencies in integrated PFI project meant, at the bidding stage examined here, (a) incorporating the experience gained in previous PFI projects on the process of collaboration between the professionals involved (e.g., who needs to meet with whom to discuss what and at what stage) and (b) making sure that particular features of the building incorporating the result of this inter-professional collaboration become stable across projects (e.g., that all PFI school fire systems have adequate space for operators to carry out maintenance). The preparation of a bid for PFI projects, therefore, involves an observable organizational remembering process at both the process and product level, in which the knowledge developed on previous similar projects is retrieved and adapted to the new project, as firms attempt to develop 'economies of repetition' for this kind of projects (cf. Davies and Brady, 2000). The case study investigates in particular the role of an Excel workbook used to carry out 'whole-life costing', in enabling DE&FM to take advantage of previous experience when bidding for PFI projects.[2]

Information about the characteristics of the bidding process under traditional and alternative procurement arrangements, including PFI, was gathered through 26 semi-structured interviews, and documentation pertaining to the submission of specific bids, manuals, checklists, project intranets, project drawings and general information available on the company intranet was scrutinized. The characteristics and structure of the whole-life costing tools developed by company DE&FM and their evolution was carefully examined. The evolution of the whole-life costing tools was reconstructed partly through direct observation and partly through the company's internal documentation e.g. manuals, presentations, material available on the company's intranet. This was complemented by 14 additional interviews conducted over two years with the developers, users and other actors involved in the calculation of whole-life costs, and attendance at three meetings involving representatives of the company and the whole-life costing system's developers, and other actors.

5. The case: remembering how to bid for PFI projects

In DE&FM, the preparation of the bid for a PFI project involved four distinct organizational units, the Design Division, the Cost Consulting Division, the Facilities Management Division

---

[2] 'Whole-life costing' refers to the estimation of costs across the life cycle of the building, therefore including financing, design, construction and maintenance.

and DE&FM Invest, a corporate unit that acted as the investor for PFI projects and provided the bid managers and part of the financial and tax consultants.[3]

5.1 *Early efforts*

In its first PFI projects, to support the identification and pursuit of synergies, DE&FM relied mainly on workshops including designers, facilities managers, cost consultants and contractors. In these workshops, drawings and sketches played an important part, as discussions were based on them.[4] In the words of interviewees:

> It is very much a matter of others commenting on our design [DE&FM Designer].
>
> You need at least a sketch to start discussing [Head of PFI Bidding Unit, FM Division].

An example of how the process worked is provided by the following recollection of the Head of the FM Division PFI Bidding Team:

> One thing we need to pay a lot of attention to is the way in which services are designed. For instance, this is just an example of a recent bid, on the … project the fire engineer designed the fire systems with partitions that need to be reset by hand. … A fire system has partitions that come down in the service tunnels to make sealed compartments and slow down the

---

[3] Despite the considerable increase in the number of activities carried out by the major firms, no individual firm in the industry possesses the full set of competencies involved in PFI projects. Therefore, firms, including the case study firm, form consortia to bid for these types of projects. Within these consortia, usually one of the participating firms has the largest share of investment and 'drives' the whole process, providing the bid managers and most of the staff working on the bid. The case study reported here refers to PFI bids for which DE&FM played this leading role.

[4] The important role of sketches and drawings in enabling professional to exchange and modify knowledge has been documented in several studies (e.g., Bechky, 2003; Bucciarelli, 1988; Henderson, 1998)

> fire. Having to reset them by hand means that every time there is a fire drill an engineer has to go through all of them – in the service conduits, which are narrow - and put them back into place … it's uncomfortable, lengthy, dirty and it costs a lot of money.

DE&FM was encountering difficulties in committing to its organizational memory these types of 'lessons learnt' from previous PFI projects. In particular, designers tended to be from DE&FM's offices that were local to the proposed project. Therefore, the designers working on PFI bids might be new to this kind of project, and the 'current' memory of the design professionals working in DE&FM might not incorporate issues relevant to the other professional groups involved. To compensate for the difficulty of storing the lessons from experience related to the product in the form of designers' expertise, various bits of 'codified knowledge' began to emerge. In particular, the Facilities Management Division had produced building-type manuals of specific design recommendations for designers, outlining requirements such as adequate access to mechanical and electrical systems, office space for facilities managers on site, suitable spaces for storage and loading and unloading, and the type of carpeting to be provided in order to facilitate cleaning.

> Nowadays, this [the design guidelines manual] is the first thing we give to designers when we meet them. We shake their hand, we say 'This is what we need' and we give them this [Head of the PFI Bidding Unit – FM Division].

Beyond learning how to integrate 'technical' competencies, bidding for PFI projects requires increased collaboration with other professionals. One example of this is legal advice. Designer firms, as DE&FM originally was, are not used to relying on legal advice during contract preparation, as contracts for professional services are relatively simple, comparatively open ended and rarely challenged in court. However, contracts that specify the 'level of service' in terms of response time for fault repair or maximum number of hours during which a given part of the building is unavailable, need to be very detailed and are extremely complex, and provide fertile ground for legal disputes. DE&FM had encountered problems on several ‘new procurement’ projects because of its lack of awareness of contractual issues. In an effort to commit to memory the lesson from experience, DE&FM had begun to develop check lists specifying under what conditions and at what stage of the bid preparation bid managers should seek legal advice.

5.2 Memory objects as boundary objects: The double life of an Excel workbook

The manuals and checklists described above provide a glimpse of the variety of objects used to support organizational remembering and the development of economies of repetition in PFI projects. These objects were essentially fulfilling the first aim of codification, i.e. facilitating knowledge transfer outside the master-apprentice relationship, without any attempt at enabling project-specific adaptation of knowledge. Among the objects developed to deal with the demand for collaboration between professionals, however, there was one particular tool whose role was different. This was an Excel workbook employed to calculate costs across the life cycle of the building. Initially, this Excel workbook had simply been an assembly of individual worksheet produced by the cost consultants, facilities managers and financial and tax consultants with the objective of calculating the total cost of the building from the design stage to hand over at the end of the contract, the temporal profile of expenditures, and consequently the most convenient financial and tax arrangements. The LCR Model was made of three major sections.

- The first section estimated *Capital Cost and Life Cycle Replacement Costs*, i.e. the cost of construction and the periodic replacement of capital items such as boilers. This followed the standard quantity surveying classification for capital costs based on “building elements”. This section originated in the Cost Consulting Division.

- The second section estimated other *Occupancy Costs* – i.e., the costs connected to using the building, in particular the cost of repairs due to breakdowns in cleaning, catering, etc. In this section, costs were not organized on the basis of building elements but in categories such as "utilities," "security," and "repairs and maintenance" and expressed on the basis of total floor area. This section originated within the Facilities Management Division.
- The third section, based on several standalone sheets, gathered information for the estimation of *tax and financial costs*, and originated within the Finance Unit of DE&FM Invest.

This Excel workbook emerged because, in the context of high pressure to keep costs low, design choices typically involved a trade off between capital costs (sustained during construction) and occupancy costs (particularly maintenance). For instance, in the case of the fire system discussed above, the issue could be reframed (and often was) in terms of whether it would be worth spending more at the construction stage to purchase a system with an automatic reset in light of the savings in maintenance over the life-span of the system. Information on both capital and maintenance costs was therefore central in determining how construction and facilities management expertise was incorporated into design.

Addressing these trade offs in design choices required drawing on the organizational memory of possible design solutions and of the costs associated to each of them. This was not a trivial operation, as knowledge about costs was heterogeneous and dispersed, both within and outside DE&FM. Cost consultants, who in England are members of a profession dating back to the end of the 1800s, had developed a standard classification for *capital* costs. This is based on a nested structure of 'building elements' such as roof, foundations, walls, furniture and fittings. In the English construction industry, this way of classifying capital costs is taken for granted by cost consultants, designers and general contractors, as it was traditionally and pervasively used as the means to translate a design into a list of materials and prices against which to evaluate contractor's bids. This was the cost classification employed in the first section of the LCR Model, dealing with capital and, by extension, capital replacement costs, which were seen as deferred capital costs.

The structure for memory provided by a pervasively used classification system enabled cost consultants to manage the content of memory at the level of both the *individual* and the *professional community*. The professional body of cost consultants maintained cost databases using the standard classification of building elements. The data contained in them were averages calculated from the settling of accounts for projects in determined regions (e.g., South West of England) for certain types of buildings (e.g., schools). This type of average and publicly available information was mainly used as a baseline, as it was perceived to lack competitive edge (cf. also Ashworth (1996). In addition to these data, individual consultants maintained records of cost estimates and the settlement of accounts for the projects on which they worked, in this way building *stockpiles of instances* of costs of specific projects (rather than averages). This was an important part of the memory of costs which was a *de facto* property of individual consultants, made available to the projects on which that consultant worked. Indeed, very often cost consultants started out with the Excel workbook from a project that they thought was similar.

Facilities management is an occupation that has only begun to approach the status of a profession since the 1980s. Unlike in the case of cost consultants, who could access databases maintained by the profession, DE&FM facilities managers relied on *organizational* memory of costs, which was dispersed among the different DE&FM offices that dealt with different services (e.g., energy procurement, waste management, catering) and in local offices dealing with individual contracts. Cost information for facilities management services was therefore not collected in a standard way. In order to estimate costs for PFI bids, the person responsible for assembling the facilities management section of the bid relied on consultations with colleagues in other parts of the company and external subcontractors over the telephone, and produced on this basis an overall cost per square meter for broad cost categories such as 'repair and maintenance', 'utilities', 'catering' and similar. Indeed, it had become second nature for facilities managers to know how much a "typical" shopping mall would cost to maintain for a year –based on its size. Facilities managers, therefore, tended to express costs per square meter, and not on the basis of building elements. Information in the second section of the LCR Model was therefore expressed in this more aggregate format and not on the basis of building elements.

The structure of the Excel workbook used to calculate the costs over the lifecycle of the building reflected these differences in the structure of memory and the practice of remembering among the two occupational groups. As it worked at a cross-road among designers, cost consultants and facilities managers when decisions on the trade offs in design choices between capital and maintenance costs were made, this Excel workbook was not only a memory object through which cost memory was managed, but also a potential boundary object between designers, cost consultants and contractors, used in addition to sketches and drawings. However, because of the trade-off in performances among the groups (lower maintenance and replacement costs often mean higher capital costs), to work as a boundary object this 'memory object' needed to provide a representation of knowledge that could be better manipulated (cf. Carlile 2004).

In order to improve the manipulation of knowledge, the Excel sheet underwent several changes. A first set of changes was largely emergent in nature, a gradual, project by project enlargement of the information contained in the worksheet on the part of the cost consultant who usually worked on DE&FM PFI projects. The effect of these changes was that the Excel workbook begun to shift from a tool representing an individual building for the purpose of pricing it, to a tool enabling comparison among several potential building design – i.e. into a tool enabling off-line experimentation (Thomke 1998a,b) in a context, construction, in which experimentation is highly constrained (Gann 2000). This was achieved by the addition of commonly used alternatives for building elements. In particular, worksheets related to the capital cost component began to incorporate possible options for certain elements, which traditional capital costing tools did not. For instance, in the case of roofing a list of alternative materials such as tiles or profiled sheeting was provided accompanied by costs, and the cost of a given configuration was calculated by setting to zero the quantity of the material not used. This approach made it possible to begin to compare the cost implications of different specifications of the building elements. However, the specification of alternatives was not consistently applied either through all elements or for individual elements across the different worksheets. Furthermore, the range of alternatives provided was very limited, and updated of the specifications needed to be carried out by hand.

As cost information began to be perceived as an important part of the process of managing collaboration between the various professionals involved in bid preparation, corporate funding was made available to improve the tools. This led to several more changes. Prominent among these were the development of automatic updates across worksheets (so that changes in the choice of elements would not need to be copied manually into the other sections), and, crucially, the development of a central database in Access which contained a wide range of alternatives for each element together with cost information. The Excel workbook was linked to the database through a drop down menu, giving different options for the choice of building elements.

The changes in how the knowledge was represented increased the quantity of memory that was accessible directly through the tool – enhancing its ability to act *across time,* and not only across groups. At the same time, the changes increased the manipulability of the knowledge representations of building structures and costs contained in the tool. Although the heterogeneity of cost classification with facilities managers continued to be an issue in comparing different solution, these changes improved the Excel workbook's performance. The new tools began to be used in the early meetings, even before drawings were developed, to examine and compare the implications of broad design options on construction and maintenance. Interviewees, including one of the architects, reported an improvement in the quality of the interactions that occurred in projects that used the new tools.

5.3 Objects of memory in DE&FM

What had been learnt from experience in bidding for PFI projects was encoded in a variety of different objects, including design recommendation manuals, checklists and the Excel workbook for the estimation of whole life costing – and that these objects performed complementary functions in supporting DE&FM efforts to commit to memory and retrieve experiential learning related to PFI projects. What do the characteristics and evolution of these objects tell us about the role of objects for storing and retrieving experience in project-based firms? We can see that these objects can be grouped in two broad categories. The first includes objects such as the Facilities Management Division design guidelines and the various checklists developed in the firm. While these can be updated, they are meant to contain advice that is valid for every PFI project related to a particular type of buildings (e.g., a school). They also incorporated representations of knowledge that are relatively fixed and unchanging across all projects. They are a *static* form of memory.

The second type, the Excel workbook for cost estimation, is a different kind of tool. Firstly, it is a form of product memory that is *reconfigurable across projects*. The availability of the 'same' parts to represent a building across projects provides a framework within which to compare the current project with past ones. As the product changes across projects, the memory of the costs associated with each configuration is carried over through a simplified representation of the specific product, constructed through the recombination of relatively *immutable components* provided by the building elements and facilities management cost categories.

Secondly, the Excel workbook it is not a 'stand alone' memory object like the Facilities Management Division design guidelines. It works by connecting a distributed memory system operating simultaneously at the levels of individual consultants, occupations, organizational units and projects. Relatively stable cost categories used in every project are complemented by other long-term memory stores, in the form of databases in which the actual costs are recorded according to the cost categories employed by the tool for cost consultants, or in the form of an organizationally dispersed collection of individual expertise in the case of facilities managers. Furthermore, the 'recombinant' properties of the tool provide a route for the contribution of designer's expertise. This configuration allows the maintenance of a range of different memories that can be called on as needed, including collections of instances of the workbook for specific projects and data sources dispersed both within and outside the firm. This reconfigurability combined with the ability to maintain distributed (but connected) memories are key in balancing the preservation and adaptation of experience.

Thirdly, and crucially, the main objective of the first type of tools is to replace participation with reification, for instance, to avoid the need, in every project, to ask designers to modify drawings to allow for space for maintenance operators. The Excel workbook, however, does not replace participation, but works to enhance it by linking knowledge held in the form of tacit individual expertise (primarily designers') to this distributed memory system. In addition to enabling reliance on a wide system of distributed product memories (often called 'repositories'), the list of elements and of facilities management cost categories select what aspects of buildings will be the objects of choice in projects, thereby providing an infrastructure that focuses attention towards certain aspects of the building and away from others (cf. Bowker and Star (1999). This is probably more clearly demonstrated by the things that the Excel workbook does not easily enable. Most notable among these was the lack of facility to calculate the contribution that a well designed building can make to client's operations, for instance, how much a well designed classroom would contribute to the quality of teaching (and, hopefully, learning) taking place in it. As it was, the Excel workbook made it easy for cost consultants, contractors and, to an extent, facilities managers to contribute their expertise, while partly silencing designers, who found it difficult to contribute the part of their expertise that had to do with 'value' rather than 'cost', and that typically felt compelled to design to minimize costs as opposed to optimize functionality. How the product is represented in the workbook, therefore, is crucial not only to enable meeting participants to retrieve and make sense of the knowledge contained in the tool (Carlile and Rebentisch, 2003), but also because it opens (or closes) opportunities to participants to contribute their experiential knowledge. Product memory therefore performs a function that goes well beyond the simple 'recycling' of pieces of the final product (Davies and Brady, 2000; Grabher, 2004), as it influences the mode and extent through which knowledge held as individual expertise is retrieved.

Finally, to enable the retrieval and adaptation of learning, both occupational boundaries and discontinuity of products across different projects need to be bridged. Thus, the Excel workbook worked as a boundary object across occupational boundaries – essentially enabling access to professional experience; and as a cross project memory through the use of simplified representations of the product. The characteristics of the Excel workbook as a 'memory object', and in particular both the type of representations adopted and the extent to which it incorporated memory, had a crucial impact on how it functioned as a support for knowledge exchange, and therefore how the participants' expertise was retrieved. The new configuration of the tool following the introduction of the Access database changed the characteristics of the workbook as a memory object, allowing incorporation of more memory in the form of a fuller list of alternatives for each element. The increase in the amount of product memory stored in the Excel workbook was instrumental in making it more manipulable. In facilitating the identification of important interactions by comparing different solutions, the changes in the Excel workbook facilitated collaboration among the professionals. Therefore, the final characteristic that distinguishes the Excel workbook from the other 'memory objects' considered in the case study is that it combines both memory and boundary crossing features. These two features are crucially intertwined, as the quality of interaction that the tool supported as boundary object improved as a consequence of the increase in both the quantity of memory directly accessible by the tool and its increased combinatorial abilities through drop down menus of elements and automatic updates across worksheets. Organizational remembering in project-based contexts, therefore, requires boundary objects with a *temporal capacity*.

6. Discussion

The view of objects afforded by recent contributions to the debate on codification and on pragmatic approaches enabled this study to pick up on a range of subtle - but nonetheless fundamental - roles that objects play in enabling project-based firms to build upon their prior experiences. In particular, objects can do more than merely embody technical solutions which can be recycled across projects, as suggested by Grabher (2004) and Davies and Brady (2000). Nor do they act only as visual reminders or cues, as suggested by Hargadon and Sutton (1997).

The combination of the use of manuals, checklists and the Excel workbook bounded the process of collaboration between professionals by helping them to define what would be discussed and at what stage. This bounding was an important component of the benefits that later projects derived from experience in the process of collaboration. While checklists are a memory of the process, the product memory contained in the Excel workbook contributed to encoding and transmitting learning about how to collaborate across projects by offering 'paths of least resistance' for the contribution of expertise, similarly to what procedural memories, such as procedures embedded in software, have been shown provide (D'Adderio, 2003: 329). The case study presented here shows that objects storing product memory, by defining what aspects of the product can be discussed, also act to bound processes. Furthermore, product representations may be the key to explaining how routines can be sustained even in discontinuous project environments. In particular, objects holding memory of the product that also act as boundary objects across occupational or organizational groups, appear a critical point of junction between business and project processes, as they help firms carrying over both product and behavior across projects. Business and project processes, therefore, are possibly less sharply separated than suggested by Gann and Salter (1998). However, further research is needed to fully unpack the mechanisms through which this occurs.

While we know quite a lot about the representational features that make good boundary objects (Carlile, 2002, 2004), this case study shows that the temporal capacity of boundary objects is a central mechanism through which knowledge is preserved and adapted in project environments. In particular, the case study shows that across-projects memory features are important in determining the performance of a tool as boundary object across communities. The study of how memory and boundary spanning features interact is likely to yield further insights on the processes through which knowledge is adapted and put to use across changing contexts. In particular, in the case study discussed here, an increase in 'memory' brought about an improvement in the performance of the tool as a boundary object. However, this may not always occur; it is conceivable, for instance, that a tool incorporating ‘too much’ product memory may be too ‘structured’ in local use to work as a boundary object.

7. Conclusions

The case study presented in this paper has provided an opportunity to unpack the role that objects holding representations of knowledge play in enabling firms operating in project environments to build upon their experience. This paper has shown that objects with representational capacity do more than simply store knowledge and enable it to be recycled across projects. Drawing on the literature on codification and on pragmatic approaches, this paper has shown that the way that knowledge is represented in objects working as *product* memories influences the *processes* by which past knowledge is accessed. In particular, the paper has shown how apparently simple objects, such as workbooks for the calculation of costs, work as both memories storing experience about a specific product across projects and as boundary objects across different occupational and organizational groups. These two functions are intertwined and this intertwining is key to integrate lessons from experience stored in the form of databases with lesson from experience stored as individual expertise. These types of tools therefore, do not only embody product memory, but also act as catalysts for a distributed memory system operating at the level of occupational groups, organizational units and individuals, thereby influencing the process through which past knowledge is accessed. Central to the ability of these objects to act in this way is a simplified, recombinable representation of the product based on a stable classification system. The classification system enables access to memories held by a wider professional community, while at the same time ‘channelling’ the contributions of those employing them. This both operates to select what type of experience gains voice in the process (e.g., the Excel workbook described in the paper effectively silences considerations of ‘value’) and provides individuals with the leeway to select, through recombination of parts, the more relevant parts of experience, and adapt them. This *temporal capacity* of boundary objects, obtained through careful, partial codification of knowledge, is therefore central in balancing the preservation and adaptation of knowledge in project-contexts. The case study also suggests that, rather than being sharply separate entities, business processes tend to replicate project processes through the use of objects developed at firm level into projects – at least in those projects that have a clear lead partner (cf. Engwall (2003). With some authors stressing the ‘uniqueness’ of each project (e.g., DeFillippi and Arthur (1998) and others claiming that projects share ‘quasi-genetic’ traits (Warglien, 1999) and economies of repetition (Davies and Brady, 2000), the role of artifacts in the reproduction of processes across projects offers a promising avenue for future research.

Finally, the view of objects as part of the process of organizational remembering presented here has significant implications for firms operating through projects. It suggests that there may in fact be far less amnesia entailed in project-based organizing than is commonly believed. Rather, the mechanisms of transmission of experience are more subtle and less explicit, and therefore less ‘docile’ in the face of managerial action. The case presented here suggests that objects may be a useful methodological point of entry for the individuation and mapping of the processes through which individual firms manage the accumulation of the experience. As several other contributions have shown, a mapping and understanding of these processes is necessary in order to avoid managerial action disrupting existing processes without being able to replace them (e.g., D'Adderio, (2003), Henderson (1991).

The case study presented here is specific to an industry that is characterized by relatively modest product innovation – although the paper has shown that innovation in the process of procuring the building led to innovation in product features. The role of objects in supporting the storage and retrieval of learning in project environments may be different in other contexts, as the relative stability of the product across projects is probably a key condition for the development of simplified representations based on recombinable elements. The extent to which similar solutions to balance preservation and adaptation of knowledge can be adopted in other, more innovative industries, such as biotechnology, is open to question and necessitates further research.

Acknowledgements: I wish to thank Ed Steinmueller, David Gann, Stefano Brusoni, Andrea Prencipe, Anna Grandori, Joe Tidd, Ghassan Aouad, Jennifer Whyte and Ammon Salter for insightful comments on a previous version of this paper. The usual disclaimers apply. Financial support from the EPSRC and the Italian Ministry for University and Research (MIUR) is gratefully acknowledged.

8. References

Abbott, A., 1988. The system of the professions: An essay on the division of expert labor. University of Chicago Press, Chicago.

Ackerman, M. S. and Halverson, C., 2004. Organizational memory: Processes, boundary objects, and trajectories. Computer Supported Cooperative Work: The Journal of Collaborative Computing 13 (2), 155-189.

Adler, P. S. and Borys, B., 1996. Two types of bureaucracy: Enabling and coercive. Administrative Science Quarterly 41 (1), 61-89.

Ashworth, A., 1996. Estimating the life expectancies of building components in life-cycle costing calculations. Structural Survey 14 (2), 4-8.

Bannon, L. and Kuutti, K., 1996. Shifting perspectives on organisational memory: From storage to active remembering. IEEE HICSS 96, Hawaii. III, Information Systems - Collaboration Systems and Technology. IEEE Computer Society Press, 156-167.

Barley, S. R., 1986. Technology as an occasion for structuring: Evidence from observations of ct scanners and the social order of radiology departments. Administrative Science Quarterly 31 (78-108),

Barlow, J., 2000. Innovation and learning in complex offshore construction projects. Research Policy 29 (7/8), 973-989.

Barney, J. B., 1991. Firm resources and sustained competitive advantage. Journal of Management 17, 99-120.

Bechky, B. A., 2003. Sharing meaning across occupational communities: The transformation of understanding on a production floor. Organization Science 14 (3), 312-330.

Bowker, G. C. and Star, S. L., 1999. Sorting things out - Classification and its consequences. MIT Press, Cambridge, MA.

Bucciarelli, L. L., 1988. Engineering design process, in: Dubinskas, F. A. (Ed.), 1988. Engineering design process. Temple University Press, Philadelphia, pp.

Cacciatori, E. and Jacobides, M. G., 2005. The dynamic limits of specialization: Vertical integration reconsidered. Organization Studies 26 (12), 1851-1883.

Carlile, P. R., 2002. A pragmatic view of knowledge and boundaries: Boundary objects in new product development. Organization Science 13 (4), 442-455.

Carlile, P. R., 2004. Transferring, translating and transforming: An integrative framework for managing knowledge across boundaries. Organization Science 15 (5), 555-568.

Carlile, P. R. and Rebentisch, E. S., 2003. Into the black box: The knowledge transformation cycle. Management Science 49 (9), 1180-1195.

Chesbrough, H. W., 2003. The era of open innovation. MIT Sloan Management Review 44 (3), 35-41.

D'Adderio, L., 2001. Crafting the virtual prototype: How firms integrate knowledge and capabilities across organisational boundaries. Research Policy 30 (9), 1409-1424.

D'Adderio, L., 2003. Configuring software, reconfiguring memories: The influence of integrated systems on the reproduction of knowledge and routines. Industrial and Corporate Change 12 (2), 321-350.

Davies, A. and Brady, T., 2000. Organisational capabilities and learning in complex product systems: Towards repeatable solutions. Research Policy 29 (7-8), 931-953.

DeFillippi, R. J. and Arthur, M. B., 1998. Paradox in project-based enterprise: The case of film making. California Management Review 40 (2), 125-+.

Dosi, G., 1982. Technical paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. Research Policy 11 (3), 147-162.

Dougherty, D., 1992. Interpretive barriers to successful product innovation in large firms. Organization Science 3 (2), 179-202.

Ekstedt, E., Lundin, R. A., Söderholm, A. and Wirdenius, H., 1999. Neo-industrial organising - renewal by action and knowledge in a project-intensive economy. Routledge, London.

Engwall, M., 2003. No project is an island: Linking projects to history and context. Research Policy 32 789-808.

Foray, D. and Steinmueller, W. E., 2003. The economics of knowledge reproduction by inscription. Industrial and Corporate Change 12 (2), 299-319.

Gann, D., 2000. Building innovation - Complex constructs in a changing world. Thomas Telford, London.

Gann, D. and Salter, A., 1998. Learning and innovation management in project-based, service enhanced firms. International Journal of Innovation Management 2 (4), 431-454.

Gann, D. M. and Salter, A. J., 2000. Innovation in project-based, service-enhanced firms: The construction of complex products and systems. Research Policy 29 (7-8), 955-972.

Grabher, G., 2002. Cool projects, boring institutions: Temporary collaboration in social context. Regional Studies - Special Issue on Production in Projects: Economic Geographies of Temporary Collaboration 36 (3), 215-214.

Grabher, G., 2004. Temporary architectures of learning: Knowledge governance in project ecologies. Organization Studies 25 (9), 1491-1514.

Grandori, A., (Ed.), 1999. Interfirm networks: Organization and industrial competitiveness. Routledge, London.

Grandori, A., 2001. Neither hierarchy nor identity: Knowledge governance mechanisms and the theory of the firm. Journal of Management and Governance 5 (3-4), 381-399.

Hansen, M. T., Nohria, N. and Tierney, T., 1999. What's your strategy for managing knowledge? Harvard Business Review 77 (2), 106-116.

Hargadon, A. and Sutton, R. I., 1997. Technology brokering and innovation in a product development firm. Administrative Science Quarterly 42 (4), 716-749.

Heimer, C. A., 1985. Organizational and individual control of career development in engineering project work, in: Stinchcombe, A. L. and Heimer, C. (Eds.), 1985.Organizational and individual control of career development in engineering project work. Norwegian University Press, Oslo, pp.

Henderson, K., 1991. Flexible sketches and inflexible data bases: Visual communication, conscription devices, and boundary objects in design engineering. Science, Technology and Human Values 16 (4), 448-473.

Henderson, K., 1998. The role of material objects in the design process: A comparison of two design cultures and how they contend with automation. Science, Technology and Human Values 23 (2), 139-174.

Henderson, R. M. and Clark, K. B., 1990. Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. Administrative Science Quarterly 35, 9-30.

Hobday, M., 2000. The project-based organisation: An ideal form for managing complex products and systems? Research Policy 29 (7-8), 871-893.

Hutchins, E., 1995. Cognition in the wild. The MIT Press, Cambridge (MA).

Ibert, O., 2004. Projects and firms as discordant complements: Organizational learning in the Munich software ecology. Research Policy 33, 1529-1546.

Keegan, A. and Turner, J. R., 2001. Quantity versus quality in project-based learning practices. Management Learning 32 (1), 77-98.

Leonard-Barton, D., 1992. Core capabilities and core rigidities: A paradox in managing new product development. Strategic Management Journal 13, 111-125.

Levitt, B. and March, J. G., 1988. Organizational learning. Annual Review of Sociology 14 (reprinted in M. D. Cohen and L. S Sprull (eds) (1996) *Organizational Learning*, SAGE Publications, Thousands Oaks.

Lundin, R. A. and Midler, C., (Ed^), 1998. Projects as arenas for renewal and learning processes. Kluwer Academic Publishers, Boston Dortdrecht London.

Morris, T. and Empson, L., 1998. Organization and expertise: An exploration of knowledge bases and the management of accounting and consulting firms. Accounting Organizations and Society 23 (5-6), 609-624.

Narduzzo, A., Rocco, E. and Warglien, M., 2000. Talking about routines in the field: The emergence of organizational capabilities in a new cellular phone network company, in: Dosi, G., Nelson, R. R. and Winter, S. G. (Eds.), 2000.Talking about routines in the field: The emergence of organizational capabilities in a new cellular phone network company. Oxford University Press, Oxford, pp. 27-50.

Nelson, R. R. and Winter, S., 1982. An evolutionary theory of economic change. Harvard University Press, Cambridge, MA.

Paoli, M. and Prencipe, A., 2003. Memory of the organisation and memories within the organisation. Journal of Management and Governance 7 (2), 152-162.

Penrose, E., 1959. The theory of the growth of the firm. Oxford University Press, Oxford

Pisano, G. P., 2000. In search of dynamic capabilities: The origins of R&D competence in biopharmaceuticals, in: Dosi, G., Nelson, R. R. and Winter, S. G. (Eds.), 2000. The nature and dynamics of organizational capabilities. Oxford University Press, Oxford, pp. 129-154.

Powell, W. W., Koput, K. W. and SmithDoerr, L., 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Administrative Science Quarterly 41 (1), 116-145.

Prencipe, A. and Tell, F., 2001. Inter-project learning: Processes and outcomes of knowledge codification in project-based firms. Research Policy 30 (9), 1373-1394.

Rosenberg, N., 1976. Perspectives on technology. Cambridge University Press, New York.

Scarbrough, H., Swan, J., Laurent, S., Bresnan, M., Edelman, L. and Newell, S., 2004. Project-based learning and the role of learning boundaries. Organization Studies 25 (9), 1579-1600.

Schultze, U. and Leidner, D. E., 2002. Studying knowledge management in information systems research: Discourses and theoretical assumptions. MIS Quarterly 26 (3), 213-242.

Spender, J. C., 1996. Organizational knowledge, learning and memory: Three concepts in search of a theory. Journal of Organizational Change Management 9 (1), 63-78.

Swan, J. and Scarbrough, H., 2001. Knowledge management: Concepts and controversies - editorial. Journal of Management Studies - Special Issue on Knowledge Management 38 (7), 913-921.

Teece, D. J., Pisano, G. and Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal 18 (7), 509-533.

Thomke, S. H., 1998a. Managing experimentation in the design of new products. Management Science 44 (6), 743-762.

Thomke, S. H., 1998b. Simulation, learning and R&D performance: Evidence from automotive development. Research Policy 27 (1), 55-74.

von Meier, A., 1999. Occupational cultures as a challenge to technological innovation. IEEE Transactions on Engineering Management 46 (1), 101-114.

Walsh, J. P. and Ungson, G. R., 1991. Organizational memory. Academy of Management Review 16 (1), 57-91.

Warglien, M., 1999. The evolution of competences in a population of projects: A case study. DYNACOM, Paris.

Wenger, E., 1998. Communities of practice - learning, meaning and identity. Cambridge University Press, Cambridge.

Winter, S. G. and Szulanski, G., 2001. Replication as strategy. Organization Science 12 (6), 730-743.

Whittington, R., Pettigrew, A., Peck, S., Fenton, E. and Coyon, M., 1999. Change and complementarities in the new competitive landscape: A European panel study, 1992-1996. Organization Science 10 (5), 583-600.

Yakura, E. K., 2002. Charting time: Timelines as temporal boundary objects. Academy of Management Journal 45 (5), 956-970.

Zuboff, S., 1988. In the age of the smart machine - The future of work and power. Basic Books, New York.