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Full Length Research Paper

Influence of the technological innovation degree on knowledge creation: Evidence from a Brazilian firm

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The aim of this paper is to analyze the process of knowledge creation when developing high technology products in projects having various innovation degrees. The main contribution to the literature is the systematization of an approach to analyze knowledge creation during the product innovation process. Three innovation projects developed by a company specialized in industrial automation systems were investigated using case studies. The knowledge creation processes, which took place in these three projects, were analyzed comparatively. As a distinctive result of this paper, the main features of the knowledge creation processes influenced by a degree of technological innovation are identified.

Key words: Knowledge creation, innovation, development of high technology products.

INTRODUCTION

It is widely known that companies are increasingly required to be innovative. This fact is particularly relevant for organizations which compete in markets where products have a short life cycle and high technological complexity. Therefore, approaches which attempt to interpret the mechanisms which lead to innovation are focused on.

There has been a lack of consensus about the meaning of innovation. However, researchers from different areas now seem to agree on the definition of this term as the development and production of new products and services, which can achieve commercial success (Garcia and Calantone, 2002). According to this definition, it should be recognized that this term involves two fundamental dimensions: novelty and feasibility to create innovation. Therefore, an activity has to be strongly orientated by these two conceptual guidelines: providing new possible alternatives and working towards a feasible solution (Leonard and Sensiper, 1998).

The first dimension - novelty - is linked to coming up with new ideas and solutions. It is linked to creating new ways of interpreting reality and solving problems. The concepts involved in this dimension lead to approaches which attempt to understand organizational processes in the subject of resource “knowledge” (Grant, 1996; Nonaka and Takeuchi, 1995). The second dimension, linked to technical and commercial feasibility, is based on the process of transforming inventions into products required by markets. Converting ideas and concepts into new products and services is widely explored in scientific studies in the area of new product development (NPD).

The aim of this paper is to integrate theories linked to NPD and the knowledge creation process which take place in organizations during the product innovation process. Thus, the process of knowledge creation found in projects linked to high technology product development having different degrees of technological innovation is described. Afterwards, relationships between innovation typology present in technological projects and the way they can be created are investigated.

Although the importance of innovation has already been recognized, the processes which contribute to an innovative performance and the factors which inhibit it are not totally explained (Salaman and Storey, 2002). The literature shows that the structure of knowledge related to innovation is fragmented and needs to be integrated (Adams et al., 2006).

Innovation can be analyzed at the level of either individuals or teamwork and even organizations. While investigating cases of product development projects focusing on developing the creative process of teams, the aim of this paper obviously draws attention to the second

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level. In spite of this approach, concepts presented in other papers which deal with individual creativity are used several times in this paper, attempting to establish a link between individuals and the collective features of NPD. During a critical literature review linked to innovation, Anderson et al. (2004) argue that there is a predominance of studies based on individual and organizational levels, highlighting a regrettable lack of investigations that deal with innovation using a teamwork approach.

CONCEPTUAL BASIS

The aim of this literature review is to present the basis to systematize an approach for knowledge creation linked to product innovation processes. Initially, studies which identify the nature and dynamics of knowledge creation are identified. Afterwards, attention is drawn to concepts related to integrating knowledge in organizations as this is a major challenge for new product development having a knowledge creation approach.

The nature and dynamics of knowledge creation in organizations

Even if the interaction of individuals, resources and organizational conditions in terms of creating innovative knowledge is not completely understood, important advances can be identified, which have taken place in recent years. It is recognized that knowledge creation is not a linear process using activities sequenced with formality, but it presents phases of search and selection, exploration and cycles of divergent thinking followed by convergence (Leonard and Sensiper, 1998).

Describing knowledge in its explicit and tacit forms is highly useful for studies in creative processes. Explicit knowledge can be easily codified, formalized and transferred. On the other hand, tacit knowledge does not allow its holder to manipulate it in a complete way, as it is an indissoluble mixture of skills, experience and technique (Nonaka and Takeuchi, 1995).

The Japanese theory of knowledge creation is grounded on a dynamic model which is based on the social interaction between tacit and explicit knowledge. This interaction consists of four change processes involving these two types of knowledge: Socialization, Externalization, Combination and Internalization - the SECI spiral (Nonaka and Takeuchi, 1995).

This spiral of knowledge creation begins with Socialization which means changing new tacit knowledge into shared experiences in daily social and technical interactions. The creation of tacit knowledge is clearly presented in the process of Externalization which forms the conceptual basis to produce new knowledge in the form of images and documents. The process of Combination consists of grouping and processing explicit knowledge in order to create more complex explicit knowledge, which can be widespread in organizations. Finally, Internalization takes place when explicit knowledge is applied to practical experiences, which forms the cognitive basis for new processes (Nonaka and Takeuchi, 1995).

Attempting to understand the process of innovation, Hansen and Birkinshaw (2007) propose the existence of an “innovation value chain”, three macro-phases (generation, conversion and diffusion of ideas) and six connective tasks (internal and external cooperation, cooperation among units, selecting and developing ideas, as well as promoting the chosen ideas).

Some studies attempt to identify organizational activities which effectively create knowledge at the level of individuals. Leonard and Sensiper (1998) propose that tacit knowledge can be dealt with in three ways in terms of creation: resolution of problems (use of experts’ tacit knowledge in order to find a solution to problems which are clearly presented); definition of problems (use of tacit knowledge to deal with less structured problematic situations and the ability to rethink the way of how to deal with a problem); and prediction and anticipation (being immersed in the phenomenon enables people to predict when problems could happen and consequently try to find the solutions).

During the effective process of convergence, the tacit knowledge assimilated by the members of a project team has to be coordinated and provided in a focused way. There are three types of tacit knowledge in this process. Firstly, superimposed knowledge is built up and shared by the interfaces among individuals and is fundamental in terms of integrating interdependent tasks. Secondly, collective knowledge is developed in an integrated way through interactions among team members. Finally, guiding knowledge is fundamental to orientate the knowledge process development and prevents the creation of an excessive number of guiding visions with a high level of abstraction (Leonard and Sensiper, 1998).

The relation between the innovative potential of a team and the creative attitude of its members is obvious. Therefore, some studies attempted to identify factors which stimulate the individual innovative behavior. Scott and Bruce (1994) found a significant correlation between factors, such as types of leadership and styles of solving problems, and the innovative behavior of individuals. While researching the influence of the social context in individual creativity, Amabile (1997) argues that it is formed by three fundamental factors: know-how, creative skills and intrinsic motivation.

Knowledge integration within organizations

Knowledge-intensive companies undergo an inevitable process of specialization which poses new challenges.

On one hand, the benefits from this high degree of specialization and focused action of individuals in niches of knowledge are undeniable. On the other hand, this context makes the coordination and integration of these experts' knowledge a fundamental task for this type of organization (Grant, 1996).

Grant (1996) states that coordinating and integrating complex knowledge involves two fundamental dimensions. The first one focuses on the rules, routines and policies which maximize the efficiency of the knowledge transference process. These mechanisms are highly appropriate for explicit knowledge change. The second includes processes which are more intensive in communication. Two processes are crucial for managing tacit knowledge widespread in organizations: decision-making and problem solving.

This issue has raised new debates about the role of middle management in companies. The importance of this hierarchical level, considering the focus of inefficiency by some administrative approaches over the last decade, is remarkably reinforced when an organization is analyzed in the subject of resource "knowledge" (Janczak, 1999; Nonaka and Takeuchi, 1995). This fact shows that these managers are crucial for the processes of integration and articulation of organizational knowledge.

The Japanese theory states that middle managers perform a central role in the new productive dynamics because they can connect two cognitive dimensions of organizations.

On a higher level, they are responsible for assimilating the strategic vision of top management in order to transform it into something more concrete, and make the knowledge, needed for its accomplishment, explicit. On a lower level, they obtain the tacit knowledge from the experts who work in the frontline of organizations (Nonaka and Takeuchi, 1995).

To better implement this flux of knowledge and stimulate the conversions of knowledge which form the spiral SECI, the authors propose a new managerial structure called *Middle-Up-Down* where knowledge creation is centralised on middle management. This structure is more prepared to accelerate the process of creation knowledge than where the innovation process starts from either top management (*Top-Down*) or frontline teams (*Bottom-Up*).

While studying the way middle managers integrate organizational knowledge, Janczak (1999) identifies three profiles in this hierarchical level. Problem solvers consider their achievements as problems which have been solved and tend to divide complex processes into smaller processes which can be solved by experts in these sub-processes. Entrepreneurs think their achievements are challenges focused on innovative solutions. Negotiators interpret their projects as jobs of intense articulation of the power and knowledge widespread in the whole organization.

KNOWLEDGE CREATION PROCESS IN PRODUCT INNOVATION

Based on previous analyses, the challenge of innovating products is analyzed considering two fundamental features: knowledge creation processes and new product development (NDP). Although the relationship between them is not recent, it is not completely known. Classical approaches of new product development process - NPD - have always recognized the importance of knowledge for its success. Clark and Wheelwright (1992) define NPD as a complex decision-making process that is responsible for transforming ideas into products. Smulders (2004) considers the process of product innovation as a learning process because the increase of knowledge related to a new product development requires not only individual, but also organizational learning.

If NPD is analyzed considering knowledge creation, other challenges can be identified. Grant (1996) states that classical mechanisms of transferring knowledge are completely ineffective at integrating the know-how of experts who deal with NPD. The importance of activities which stimulate the flow of tacit knowledge is evident, as corroborated by Silva and Rozenfeld (2003) while investigating the practice of the four types of knowledge conversion linked to the main dimensions of NPD. According to their findings, the Socialization process is considered as the most frequent conversion among all the dimensions of NPD.

It is very important to accept the influence of the product structure rather than the knowledge linked to its development process. Sanchez and Mahoney (1996) state that two main ways of knowledge creation in NPD can be identified: based on components and functions developed by them; and linked to the ways components interact and how they can be organized, which results in learning about the product architecture.

The approaches that investigate the knowledge creation process in organizations ratify that this process has to be understood in a much broader way than developing brilliant ideas. Not only is this a process which is highly influenced by individual cognitive abilities, but it is also undeniable that it has an inexorable collective character. Thus, it consists of human, environmental, contextual and structural aspects.

This fact makes the analysis of this process, which is the challenge proposed in this paper, more difficult. It is necessary to structure the various concepts linked to knowledge creation and product development in an organized way. As a consequence, the previous studies are included in an integrated model which identifies the main dimensions of this process. Table 1 describes all these dimensions.

To understand the innovation process in-depth, it is necessary to analyze the NPD and the knowledge creation process in an integrated way. If NPD can be thought of as a process which transforms market needs

Table 1. Dimensions of the analysis of the knowledge creation process.

Dimension of analysis	Description
1. Sources and types of knowledge	These explore the internal and external sources and types of knowledge which support the creation process.
2. Activities and knowledge conversions	These explore the conversions among the types of knowledge and the activities which contribute more to producing new knowledge.
3. Leadership and actors	These explore the role and profile of the leader and other formal or informal actors who are involved in the knowledge creation process in a significant way.
4. Context and environment	These explore the social environment and organizational conditions which support the knowledge creation process.

and new ideas into new products, the knowledge creation process has to be interpreted as being responsible for developing ideas and knowledge necessary to achieve an innovative product.

Projects for developing either new products or technologies include a wide range of knowledge creation processes. New knowledge is created in various activities inherent to innovative projects due to an intrinsic amount of uncertainty that these projects present. This feature orientates the theoretical synthesis of knowledge creation processes. Thus, it is not convenient to consider knowledge creation as a process parallel to NPD which starts in a project and finishes with a final product. On the contrary, the materialization of an innovative product has to be understood as a collection of a large quantity of small knowledge creation processes which take place, with more or less intensity in all the phases of NPD.

The relationships between these processes, which are considered as fundamental dimensions of innovation, are presented in Figure 1. This model uses the dimensions and a synthesis of the phases proposed by Rozenfeld et al. (2005) for NPD.

It is worth mentioning that developing different innovative products requires different levels of creative intensity widespread throughout the phases of NPD and the knowledge creation process. Issues like the environment and complexity of a product and its market, modularity and technological density influence the demand for novelty in the various phases of a project.

This model is favourable to be included in the culture and infra-structure that encourages creativity extension on the whole, and not only in its initial phases. Ideas developed in initial phases have clearly greater visibility in organizations and represent the essence of the product concept. However, a series of decisions have to be made and many technical problems have to be solved with a high degree of expertise throughout all the posterior phases of the product innovation process.

In spite of their common features, innovative projects cannot be homogenously grouped. Considering the various criteria used for the existing types of classification, the technological innovation degree is the most relevant for the purpose of this paper. Garcia and Calantone (2002) show that there is vast literature which focuses on the taxonomy of the different innovation degrees. The aim of this paper is not to propose new types of classification. On the contrary, it uses the classical approach defined by Clark and Wheelwright (1992) to differentiate projects into four main types: incremental/platform/radical/advanced R and D ones.

RESEARCH METHODS

This paper uses the methodology of multiple case studies presented in Yin (1989) in order to plan the investigation of the researched phenomenon. The method consists of a systematic and detailed analysis of real manifestations of investigated social phenomena. Three projects having different innovation degrees are analyzed. The chosen projects were carried out in a Brazilian company which develops high technology systems for industrial automation.

Processes related to projects to develop high technology products are typically complex. To carry out an in-depth analysis of the cases, the proximity between one of the authors of this investigation to the company for more than two years was extremely important in interpreting the collected data.

As presented in Table 2, a wide range of investigation techniques was used. In all the studied projects, technical and project management documents could be accessed easily. In project A, one of the authors of this paper participated as a development engineer from the beginning of the project until the end. This daily presence in the project helped the author to understand subtle relevant details for this research, as proposed by Yin (1989).

In projects B and C, as this daily presence in the project management was not possible, semi-structured interviews were carried out with the respective coordinators. These interviews were based on an agenda of previously defined questions. However, there was flexibility to focus on particularly relevant aspects according to how the conversation developed. In the analysis of project B, a direct observation was possible because one of the authors worked together on this project team for a long time. Analyzing the information obtained from the cases was carried out in two phases. Firstly, the individual cases were studied. Secondly, the cases were compared in order to highlight the particularities of

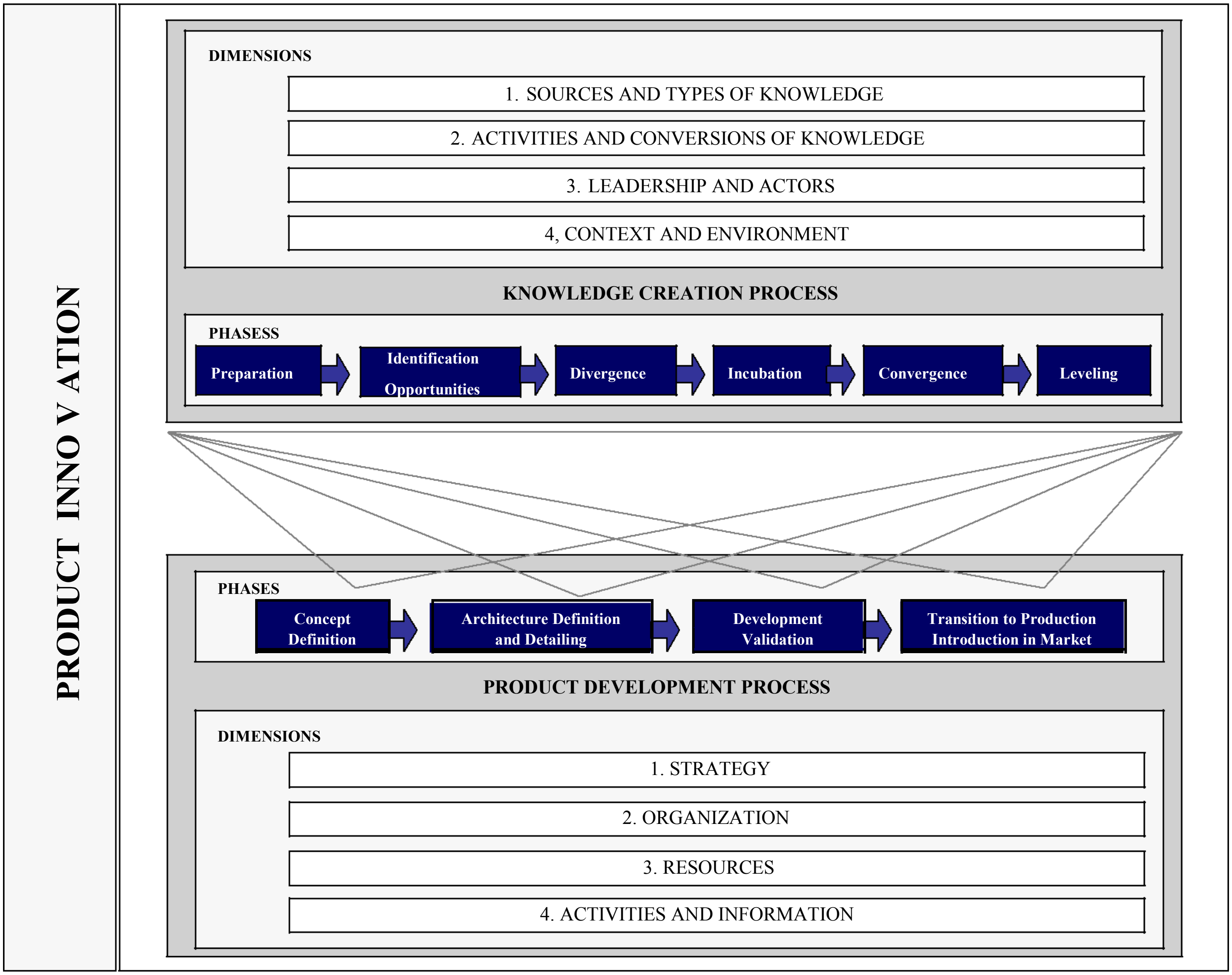

Figure 1. Model for the NPD and the knowledge creation process.

Table 2. Analyzed projects and techniques of data collection.

Project	Innovation degree	Data collection
A	Incremental	Analysis of documents; participant observation.
B	Platform	Analysis of documents; direct observation; interview with the coordinator.
C	Radical	Analysis of documents; interview with the coordinator.

the processes of the knowledge creation for each case.

Case studies

The company which was studied has been operating in the industrial automation market for more than 30 years. It was set up having a close link to sugar and alcohol producers. There were approximately 1,200 employees in 2008. It has a strong position in its market niche and its presence in the global market is strengthened by representations and branches widespread in 10 countries.

The company operates in a remarkably innovative market. Results from the Industrial Survey on Technological Innovation (IBGE, 2000) show that the sector of industrial automation equipment presents one of the highest rates of technological

Table 3. Description of the main phases of project A.

Phase	Description	Integration and application of knowledge	Creative intensity
Concept definition	Concept is previously defined by the customer's order.	Knowledge transference from the customer's operations to the team.	Null.
Architecture definition and detailing	Development of functional solutions which made the controller capable of meeting the required actions.	Explicit knowledge integration, linked to both the norms of the oil and gas industry and customer's operations.	High and centralised on the coordinator.
Development and validation	Implementation of algorithms to calculate the quantity of petrol in the *software* of the controller.	Tacit knowledge of engineers linked to programming which is used to implement algorithms.	Low and widespread in the developers.

innovation in Brazil. To compete in this field, the company has distinctive competitive features in terms of developing new technologies and flexibility to innovate. Not only has the company already been awarded prizes for technological innovation, such as the FINEP prize for technological innovation, but it has already established international partnerships for technology transference and registered patents (20). Another 23 patents were registered (23) in the United States of America in 2008.

The break into external markets is a consequence of its success in the Brazilian market just after the *Pró-Álcool* program. This encouraged the production of alcohol in the country, as well as the Brazilian regulation to replace imports which ended in the 1980's. Taking this into account, efforts have been intensified by developing new products.

As a distinctive feature, products of the industrial automation market have to incorporate a wide range of technologies: electronics, software, telemetry and mechatronics. A complete system of automation basically includes three main structures. The lowest level is related to field equipment, responsible for the physical action in devices of a plant and by measuring various processes. The highest level is made up of software that configures and supervises operations. An intermediate level integrates these two environments. It consists of controllers who can exchange information with both field equipment and management applications.

The investigated projects are individually described as follows. After the initial analysis, a comparative analysis including all of them is presented in section 5.2.

Description of the cases

Project A - incremental innovation: Project A started with an Order of a solution to automate the gauging of the petrol level in tanks of a large company of the oil and gas sector. The challenge was to use existing internal technologies to develop a system which could meet the needs of the oil industry, which is marked by the demand of high precision, safety and tracking operations.

The innovation degree of this project can be described as incremental because it did not present either the market or technological lack of continuity at a macro level. There were already similar systems in the international market. Thus, the development should only complement some new functions to support petrol gauging. In technological terms, the company was able to use platforms of embedded hardware and software which were previously developed. Thus, the efforts to develop this system were focused on both in terms of including algorithms and creating some new modules in the controller software and supervisory software which is specific for the oil and gas industry. The development team was made up of a coordinator, three development engineers and a test engineer. The phases of this project are described in Table 3.

The creative process in the Architecture Definition and Detailing system phase could be clearly observed. In this phase, it was necessary to structure the way the calculating algorithms would be incorporated into the structure of functional blocks of the existing technology. To meet this demand, three types of knowledge had to be integrated: dynamics of the customer's plant operation; national and international norms which regulate the operations of petrol gauges; and the architecture of the technology used.

This process of creative synthesis was highly focused on the coordinator of the project. The conversion between the types of knowledge, which was most important in this phase, was the combination. After an intense process of integrating the knowledge presented in norms, linked to customer's demands and from handbooks of competitors' similar products, extensive documents were drawn up. A 300 page document was put together to be used by the development engineers when implementing new algorithms in the software. The use of explicit channels in knowledge changes among the members of the project team was noticed.

The project coordinator worked as a catalyst of a wide range of knowledge, and the process of a divergence of ideas and concepts happened in a rather individualized way. With regards to the gradual convergence of the solution phase, analyzing the documents drawn up by the leader shows that he performed a fundamental role: teams of the company responsible for contacting the customer foresaw inconsistencies related to adapting the system to the plan operation; development and test engineers found technical inconsistencies during the implementation of the solution.

A strict adherence to the model *Middle-Up-Down* (Nonaka and Takeuchi, 1995) could clearly be seen. The project coordinator, manager of the Applications Group of the R and D Division of the company, used his broad experience in developing projects, the large input of information concerning customers and competitors (provided by the commercial sectors of the company) and the technical results obtained by the development engineers when implementing the software for the final product.

The environment was predominantly described by the individual action of the team members. In spite of the great concern with coordination and sequencing of the activities of each member, few brainstorming and problem solving activities were noticed. This happened because technological challenges did not include the need to explore little known problems. Even in phases where the subject was new, such as understanding the operation mechanisms to gauge the level of petrol in tanks, the available documents helped them understand most of the difficulties.

Table 4. Description of the main phases of project B.

Phase	Description	Integration and application of knowledge	Creative intensity
Concept definition	Definition of technical requisites for the new family.	Definitions based on the coordinator's knowledge about the trends of the sector.	Intermediate, centralised on the coordinator.
Architecture definition and detailing	Architecture proposed by the coordinator is redefined by the experts. Important choices of technological platforms.	A gradual integration of expert's tacit knowledge with the architecture proposed by the coordinator. Intensive processes of decision-making and documentation.	High, centralised on the coordinator, but with the participation of the whole team.
Development and validation	Development of new components and interfaces. Intensive process of problem solving within the team. Adaptation of software modules to the new hardware platform.	Process of knowledge socialization in search for solutions. Intensive meetings with great commitment from the team members.	High, widespread in the whole team.

Analyzing this case shows a creative process which is strongly centralised on the convergence phase. Thus, a range of consolidated explicit knowledge, originating from various sources, was integrated into a design of a structure of functional blocks, systematized and appropriate for the industrial application required by the customer. The freedom for creative action was restricted by previous definitions of the system's functioning which were done by the customer and industrial norms, and by the use of an existing technological platform (which had limitations) as well.

Project B - innovation platform: Project B included developing a new family of controllers which overcame the previous family because the innovations were mainly focused on increasing the performance and incorporating new communication protocols, which made new six products possible. The company's motivation for this project is a result from the demand for a new generation of controllers with greater interconnectivity and processing speed.

The innovation introduced by this family is the hardware platform that was totally developed for this project and based on a combination of technologies not found in competitors' products. With regards to the software, some modules of the previous family were adapted to the new hardware and others were completely developed. The hardware platform and most of the software form the common basis for all the products of this family. The difference among them is caused by their communication protocols supported by each one.

According to the coordinator, it is worth mentioning two sources of knowledge in the project. Firstly, he points out the fundamental importance of his participation in a conference on technological trends in embedded software which took place in London, a short time before project B. According to him, unlike traditional exhibitions, where companies showed the products of the present, events linked to trends may encourage developers to imagine the products tomorrow. This event had a decisive contribution to the insight of a new technological platform for the family of controllers. Secondly, he highlights the importance of the commercial teams of the company and its customers. As a manager of the group of interfaces of the R and D Division, the coordinator of project B is considered a reference because of his knowledge about technological architectures of automation systems. This made him always question the feasibility of developing systems in order to sell them either to private or public companies. This interaction was fundamental in identifying market trends and customers' needs.

The coordinator also emphasized the importance of other external interactions to obtain knowledge used in the project, such as technological standardization organizations and vanguard movements in research that is the free software. The team was initially made up of the coordinator and eight development engineers. Sometimes, there were 20 members in this team. The phases of this project are presented in Table 4.

As the development of this product line was based on a common platform, the definition of its architecture was a fundamentally important process. The challenge consisted of defining a structure coherent with the concept proposed by the coordinator and compatible with the technological restrictions of all its components. During this process, the documentation performed the important role of externalizing the coordinator's proposal, as well as submitting it to the experts' analysis to incorporate their tacit knowledge into each component. Concurrently to this iterative progress of the architecture, important decisions related to choices of hardware platforms could be made.

The development phase presented a high level of uncertainty linked to the incorporation of one communication protocol which was totally new for the company. The choice of not hiring an expert in this subject posed great challenges for the team: the domain of a new technology and integrating it into the product line. Most of the team members were dedicated to this job, which included processes of trial and error. According to the coordinator, this phase was the most challenging and the high degree of commitment and dedication were crucial for the success. According to him, "the team members were pleased to develop and integrate the component. Many of them continued working together at their home even during a strike, which the company had to cope with".

The high uncertainty level of the development phase required a great amount of collective work. At weekly meetings, the team established goals defining problems and understanding technology. Tacit knowledge changes were intense. The coordinator stated that creative insights often came from people who had more theoretical knowledge than others who had practical experience in product development processes.

The coordinator highlights two main roles of his leadership in this project. Firstly, as a knowledge integrator, he applied his tacit knowledge in product development and his knowledge on system architecture in order to integrate the experts' tacit knowledge. Secondly, he points out the importance of his participation in anticipating and solving problems. His experience with typical

Table 5. Description of the main phases of project C.

Phase	Description	Integration and application of knowledge	Creative Intensity
Concept definition	International movement towards the standardization of a digital protocol	Approximation among companies from the whole world interested in participating in normalization	Low
Architecture definition and detailing	The architecture was proposed by some team members, assessed by the others, documented and analyzed	Integration of various companies' knowledge. Socialization in meetings and externalization in worldwide extensive documentation	High, widespread
Protocol development and validation	Development of the protocol (software) in accordance with the defined norms	Intense consolidation and application of knowledge about the layers which make up the protocol	Very high, centralised on the coordinator
Development and validation	Integration of the protocol with other components: new product line	Intense socialization of knowledge and teamwork; idealism and high personal commitment	Very high, widespread in the whole team

development processes, in particular those whose main challenge is to define the problem, increased his intuition power to choose the best way forward.

Project C - innovation radical: Project C includes developing a digital and open protocol called Fieldbus, concerning communication among automation pieces of equipment in a pioneering way in the world. In the mid 1980's, there was an initial movement towards standardizing the way data were exchanged within a system. In spite of the resistance of leading producers who controlled the market with proprietary protocols, the movement strengthened at the beginning of the 1990's when international committees were formed to manage this standardization process.

The definition of the concept of new technology was gradually incorporated by various companies participating around the world. Instead of an isolated decision, there was a process of converging towards developing an interoperating protocol which could perform distributed processing, an advanced diagnosis and redundancy in all the parts of the systems which are in the field. The main phases of this technology development and its pioneering incorporation in a product line are presented in Table 5. The first two phases involved other companies and the last two took place in the studied company.

The company which was studied had a staff of 300 employees at the time, and saw this as a unique opportunity to achieve a technological vanguard position in inter-cross digital-operability. Thus, an engineer was chosen to participate in the meetings of the committees which defined the technology architecture. These events were divided into various concurrent sessions and the new protocol was discussed. While the leading companies sent an expert to each session, the interviewed engineer stated he had to go from one session to another, going through them all, analyzing all their written registers throughout the night. What seemed to be a disadvantage turned into a distinctive competitive advantage because the knowledge about the digital protocol was integrated by only one person who could develop it.

Concurrently to the protocol architecture definition, companies competed to develop this new digital technology, which was normalized first. The leaders would certainly be references in this new emerging automation market. The project was followed by countless international meetings, sending edited texts of the documentation and participating in exhibitions where companies showed what they had already developed.

Leading companies stated that the progress would be slow because it was impossible to implement the complex protocol in hardware platforms existing at that time. The R and D director of the studied company thought this was possible. Thus, he gave significant autonomy to the development team. The initial effort was highly centralised on the coordinator and consisted of creating solutions to implement embedded software which met the international norms. The second phase consisted of integrating this protocol with other software and hardware components in the first Fieldbus products in the world.

In both initial phases, the coordinator highlights that people were really committed to this project. When preparing for the international exhibitions and validation tests, engineers usually programmed codes overnight. The coordinator stated that there was a unique feeling that we were doing something really new and that we would be pioneers in the world to develop some technology which would result in a distinctive breakthrough in the automation market.

Comparative analysis of the cases

Based on the three case studies, a comparative analysis was made, which is summarized in Table 6. This analysis suggests that there is a greater concentration of the divergent phase of more radical projects, which influences all the dimensions proposed in this paper. Firstly, a link between the innovation degree and the types of knowledge sources which supply the development process can be observed.

In Project A, the sources of explicit knowledge were predominant, mainly through extensive documents. The respective tacit knowledge was much more linked to transforming obtained knowledge into new product components than to the essential technological trends of this area. In Project C, the opposite situation is noticed. There is little consolidated explicit knowledge to be obtained from the external environment. As the coordinator states, there was not a way to learn either from customers or competitors because the type of technology needed was neither available on the market or was being developed. Thus, while participating in international organizations brought an understanding of industrial sector trends, the other types of knowledge were completely developed within the team from both the previous individuals' experience and new

Table 6. Comparative analysis of the three projects.

Project	A – Incremental	B – Platform	C – Radical
Knowledge creation	Integration of explicit knowledge obtained from various sources.	Creation of architecture knowledge and integration of experts' tacit knowledge.	Assimilation of new technological standard and creation of knowledge which makes it possible to include it in new products.
Type of knowledge	Components (low)	Components (low) Architecture (high)	Components (high) Architecture (high)
Conversions of knowledge	Focus on Combination	Focus on externalization and socialization	Focus on internalization, externalization and socialization
Roles of leadership in the creative process	Catalyst and translator of a wide range of external knowledge.	Leader of the decision-making processes. Facilitator of problem solving processes	Assimilation of knowledge. Development of creative solutions Inspiration of the team towards an ideal objective
External sources (explicit knowledge)	Customers (demands) Competitors (handbooks) Organization for Technological Standardization (norms)	International organization for technological standardization (norms) Providers (specifications)	International organization meetings for technological standardization (norms)
External sources (tacit knowledge)		Technological exhibitions and customers (trends)	Technological exhibitions and international organization meetings for technological standardization (trends).

in-house solutions. Project B had an intermediate innovation degree and presented a mixture of knowledge sources. The learning based on the market is complimented by a range of more tacit knowledge created within the team.

Secondly, a clear difference between the leadership roles of the three projects was observed. In the gradual development, the leader acted as a catalyst and translator of knowledge obtained from various sources. This fact has a significant adherence to the managerial model *Middle-Up-Down* proposed by Nonaka and Takeuchi (1995). The leader acted as a linking element between the different cognitive spheres.

With regards to the most radical project, the leader had more inspiring attitudes and encouraged the search for breakthroughs. To stimulate the creation of new technology and obtain tacit knowledge present in the team, a higher level of personal commitment to the project was required. This profile is very similar to the middle manager with an entrepreneurial type proposed by Jankzac (1999). Thus, the importance of this more entrepreneurial character as a catalyst element for the extraction process of tacit knowledge from engineers is worth mentioning.

Finally, the hypothesis is presented by analyzing the conversions among the most important types of knowledge in the creative process of the three projects. In Project A, the creation focused on combining explicit knowledge, creating more complex explicit knowledge. With regards to other projects, socialization performed an important role by using tacit knowledge in intense activities of decision-making, creating alternatives and solutions, identifying and anticipating problems.

Conclusion

This research reinforces the idea that it is important to analyze the dynamics of knowledge creation and integration to increase the understanding of the innovation process. While suggesting that projects with different types of innovation make use of different types of intensive knowledge processes, this study shows the need of approximating concepts from NPD to the knowledge-based organizational theories. In spite of the obvious limitation inherent to this investigation, that is, the impossibility of generalizing results obtained from only three cases, some important aspects of these case studies suggest some reflections.

Alternatives are indispensable to increase the ability to foresee future restrictions. The more radical projects are, the greater the creative intensity in the divergent phase is, because they require continuous rethinking of frontiers between what exists and what is possible to be developed. Furthermore, throughout all the phases of the development process, teams deal directly with unknown and unpredictable situations which require new ways of solving problems and making decisions.

As suggested in the comparative analysis of the cases, this feature of the creation process influences the types of leadership, sources of knowledge and processes of knowledge conversion presented in projects with different innovation degrees in a substantial way. The results found in each dimension are analyzed as follows by linking the conclusions from the case studies and the literature review.

Dimension 1: Sources and types of knowledge

It is evident that both incremental and radical projects use a wide range of explicit and tacit knowledge. However, the results of the case studies show that more radical projects require a more intense use of tacit knowledge. The reasons for this fact are found in the nature of the challenges that teams responsible for different types of projects have to cope with.

More radical projects require a greater change from the current situation to a planned future. Thus, people have to be provided with non-consolidated, non-disseminated and non-explicit knowledge. These projects do not only combine different information in the process of materializing a product, but they are also guided by abstract trends in new technological paradigm creation, as well as technological and market references. Thus, the higher the level of uncertainty is, the more individuals need to use their accumulated experience, creative insights and critical analysis of the phenomenon.

It is possible to make comments on the type of knowledge created according to the product structure. Incremental projects are usually followed by changes and improvements in some parts of a product, requiring typically only incremental or modular learning about components, as stated by Sanchez and Mahoney (1996). On the other hand, the intensity of changes in radical and platform projects do not only change the product components, but also the way they are organized and interact. Thus, as observed in the cases, these types of projects require architectural learning.

With regards to the sources of knowledge, it is suggested that the radical projects require an assimilation of information linked to the trends of technologies which are used in products, more than the particular needs of the current market. More important than the ability to understand the present in details is the need for breakthrough demands that the project team is able to predict in the future. Incremental projects, on the contrary, may be provided with the current knowledge about current customers' needs. As shown in the cases, customers and competitors are sources of vital knowledge to help teams manage the technological increment in order to meet current market requirements with precision.

Dimension 2: Activities and conversions of knowledge

The greater requirement for the use of tacit knowledge in more radical projects presents strong implications in the typology of the activities inherent to the product development process of these projects. This fact is justified by the impossibility of dissociating the nature of the knowledge which flows in their teams from the nature of the processes, which are conducted and disseminated.

Incremental projects, characterized by the intensive use of explicit and consolidated knowledge, use document-tation as a fundamental tool to conduct the acquired and created knowledge. The abundance of explicit knowledge for these projects motivates the use of documents to make knowledge flow within the team. Knowledge usually comes from the documents created in previous projects which form a platform for the increment to be introduced in a new project. Thus, it is remarkable that these projects have Combination as the fundamental conversion of the knowledge included in projects.

With regards to more radical projects, this study suggests the predominance of other mechanisms for knowledge of integration and transformation, such as the more intense use of brainstorming, decision-making and shared problem solving. The Socialization process presents and strengthens the tacit way of knowledge exchange among individuals.

This evidence is supported by Grant (1996), who identifies documents as the basis of integrating explicit knowledge and the processes of problem solving as the basis of integrating tacit knowledge. Furthermore, this analysis corroborates the approach of Leonard and Sensiper (1998) who highlight that a strong social component is required by the divergence phase. According to the authors, this need for multiple divergences enhances the importance of dialogue and brainstorming.

This situation suggests some comments about the efficacy of information systems to manage knowledge related to radical projects. There is a difficulty of using these systems because most of the know-how which flows cannot be easily formalized and made explicit. The instability and the non-structured character are obstacles for storing and moving this knowledge through systems.

Dimension 3: Leadership and actors

In the literature review, the profile of leadership linked to projects with different innovation degrees was discussed. The managerial model *Middle-Up-Down* (Nonaka and Takeuchi, 1995) considers the leader mainly as a knowledge integrator who is more appropriate for incremental projects. As this model depends on a combination of knowledge from different sources, it is highly compatible with the challenges that less radical projects have to deal with.

As suggested in the case studies, more radical projects require considerable encouragement in an entrepreneurial posture. Uncertainty and the need for breakthroughs make extracting tacit knowledge from individuals a fundamental task of leadership. This task requires an energized environment which inspires and challenges individuals to overcome current paradigms and have a more proactive and visionary posture.

This analysis characterizes the leader of an incremental project as a manager of more explicit knowledge. On the other hand, the leadership of more radical projects contemplates not only the coordination of formalized and consolidated knowledge, but mainly activities and processes which integrate and create tacit knowledge.

Thus, two levels of leadership roles in more radical projects can be identified. The conduct of typical activities linked to integrating tacit knowledge, such as decision-making processes and problem solving in a teamwork environment, exists at a first level (Leonard and Sensiper, 1998). At a higher level of extracting tacit knowledge from team members, activities are linked to inspiring and mobilizing individuals towards the objectives of a project and encouraging entrepreneurial attitudes.

It is suggested that this entrepreneurial dimension required by more radical projects is needed to make decisions in markets with a high level of uncertainty and complexity. Furthermore, this proactive posture is a requisite to dealing with organizational pressures for short-term results in projects with a high degree of market uncertainty.

With regards to the formation of teams, radical projects require more internal diversity among the individual profiles. To deal with less predictable situations and the need for developing alternatives, teams need to use many experiences to increase the ability to cope with challenges. Thus, the importance of people with different styles of solving problems and contacts of different external sources of knowledge is higher for this type of project. Obviously, this diversity may also be enriching in incremental projects. However, the previous restrictions and the focus on convergence decrease the possibility of a more personal contribution.

Dimension 4: Context and environment

Some factors, observed in the other dimensions, contribute to a greater amount of personal commitment and teamwork in radical projects: an inexistence of consolidating sources of the required knowledge, high uncertainty and the need for successive discoveries either to a larger or smaller degree. This situation makes extracting knowledge internalized in individuals a fundamental challenge in these projects.

A greater requirement for autonomy, flexibility and informality in more radical projects can be observed. Autonomy and flexibility are vital for individuals who deal with less structured challenges in an adaptable and tolerant way to the particularities of processes of trial and error. Informality prevents behaviours and solutions from becoming rigid and standardized. It encourages more authentic and original contributions fundamental for the demanded divergence. Nemeth (1997) states that uniformity and coherence are appropriate for implementing ideas which have been created and dissidence and flexibility are fundamental for creative activity which can break paradigms.

FINAL REMARKS

The results obtained in each dimension of the proposed model are presented in Figure 2. The aim of the figure is to represent the main trends found in these types of projects, but not to build up an exclusively bipolar vision of these results and activities which are included in the creative process of these projects.

Both incremental and radical projects use a wide range of practices and processes to create knowledge. However, the case study and literature review suggest the aforementioned trends and the predominance of some features according to the innovation degree of a project.

The analysis suggests that the way that a higher degree of uncertainty of more radical innovation projects influences the dynamics and features of the creative process. The results show that these projects are related to contexts of less in-depth knowledge and are susceptible to internal environments with more autonomy and less prediction and determinism. Furthermore, they show that creative processes need to be collective, provided with a greater internal diversity and managed by a leader with a strong entrepreneurial and inspiring component.

This description of the team and nature of an innovative and radical project is not new. Various elements quoted here and compared with those of incremental projects are mentioned, with more or less emphasis and clarity in previous studies. Clark and Wheelwright (1992) emphasize the autonomy conferred to Tiger Team, for radical innovations. Veryzer (1998) highlights the low level of formalization and the eventual chaotic dynamics of projects with a higher degree of breakthrough.

The contribution of this paper to analyze projects with different innovation degrees, by presenting features correspondent to these degrees, is to carry out this investigation of knowledge creation processes. Thus, not only does it structure this characterization comprehensively and systemically, but it also suggests that different features linked to projects are strongly connected to the typology of their creative process. The differences which were found show the need to vary the way of managing people according to the innovation degree of the project.

Although a model for the creative process according to the innovation degree of the project was identified and used in this paper, the dynamics of a project are highly influenced by the particularities of an industrial sector, organization and type of products. This statement was made by Hansen and Birkinshaw (2007) and can be seen by analyzing the relevance of the particular details of progress in the projects studied here, such as the inter-organizational context of the technological standardization.

DIMENSION		INCREMENTAL ↔ (INNOVATION DEGREE)		RADICAL
1: Sources and types of knowledge		Explicit	↔	Tacit
		Related to current needs	↔	Related to trends and future scenarios
		Stable, consolidated	↔	Instable, changing
		Related to product components	↔	Related to product concept/architecture
2: Activities and conversions of knowledge	Main knowledge conversions	Combination	↔	Socialization
	Main knowledge-creating activities	Explicit knowledge integration	↔	Tacit knowledge integration
		Documentation Document analysis	↔	*Brainstorming* Problem solving Prototyping
3: Leadership and actors	Main leadership roles in creative process	Explicit knowledge integration	↔ Lead decision making and problem solving processes ↔	Stimulate entrepreneur attitude Team inspiration
	Diversity relevance	Low	↔	High
4: Context and environment		Integration of individual creations	↔	Collective creation
		Intense flow of documents	↔	Insights exchange and face-to-face contact
		Technical and market constraints	↔	Autonomy to create
		Predictability	↔	"Creative chaos", "Trial and error"

Figure 2. Description of the creative process according to the innovation degree.

The results presented here should be seen as an effort towards integrating approaches which investigate the dynamics of innovative projects. In this perspective, the aim of this paper is to contribute to the organization of concepts, which are often discussed in an isolated way, in a systemic evaluation model including the multiple dimensions of the product innovation process.

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