Journal of Engineering and Technology Management xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Journal of Engineering and Technology Management

journal homepage: www.elsevier.com/locate/jengtecman

The dynamics of collaborative practices for knowledge creation in joint R&D projects

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ARTICLE INFO

Keywords:
Collaborative practices
Knowledge creation
R&D
Innovation
Ambidexterity

ABSTRACT

Purpose: We aim to elucidate how the dynamics of collaborative practices in research and development (R&D) projects occur and to reveal the main practices adopted in developing an ambidextrous project. The dynamics of R&D practices in knowledge creation arise from complementary practices of exploration and exploitation undertaken over the lifespan of an interorganizational project that trigger an ambidextrous process of innovation.
Design/methodology/approach: This study involves interpretative guidance. We elaborate upon the history of the development of a collaborative R&D project in an intensive knowledge industry, the semiconductor industry, and use narrative as the methodological framework in a single case study with a processual approach. We conducted 65 interviews that were supported by secondary inventories of data that consisted of 167 files.
Findings: The type of collaborative practice adopted in a joint R&D project varies based on the stocks of knowledge required to make the concept a reality and also as a strategy of knowledge creation adopted in each project phase, ensuring a dynamic synthesis between tacit and explicit knowledge. We propose a three-dimensional model that accounts for the adoption of different practices throughout the life cycle of a collaborative ambidextrous R&D project.
Practical implications: We identified 19 collaborative practices of inter-organizational knowledge creation that ensure the dynamics of innovation using complementary exploration and exploitation approaches.
Originality/Value: This study makes important contributions to the relational view and the theory of knowledge creation, offering a contribution to understanding the origin of ambidextrous practices in knowledge creation throughout the life cycle of an R&D project.

1. Introduction

A primary factor of productivity and competitiveness in the current economic paradigm involves the capacity of individuals and organizations to generate, process and transform information and knowledge into economic assets (Nonaka et al., 2006). Given that an important asset of knowledge is innovation, several studies have attempted (and struggled) to identify the drivers of innovation and how innovation processes should be managed to increase innovative performance (Teece, 1986; Brown and Eisenhardt, 1997; Crossan and Apaydin, 2010).

Although a significant stream of research has highlighted the innovation performance implications of combining knowledge resources from different origins (Graetz and Smith, 2007; Nonaka et al., 2014), the origins of knowledge are but one of the determinants of innovation. In fact, the characteristics of the processes by which firms search for new knowledge also strongly influence

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https://doi.org/10.1016/j.jengtecman.2018.04.001
Received 21 December 2016; Received in revised form 14 February 2018; Accepted 4 April 2018
0923-4748/

Please cite this article as: Faccin, K., Journal of Engineering and Technology Management (2018), https://doi.org/10.1016/j.jengtecman.2018.04.001

innovation and can shape – or even subvert – the impact of the origins of knowledge on innovation outcomes (Fleming and Sorenson, 2001).

To capture this innovative behavior, Capaldo and Petruzzelli (2011) refer to the notion of search span, i.e., the extent to which firms search for new knowledge across different knowledge domains. Studies advancing a subject's knowledge frontiers have deepened the concept of ambidexterity, which postulates that the dimensions of exploration and exploitation are used simultaneously (Nonaka et al., 2014) and are enhanced by complementary knowledge internal and external to the organization.

The challenge is that knowledge increasingly extends beyond the boundaries of the firm, and the ability to build external alliances is an important source of new ideas and information that leads to technology and innovations that promote business performance (Dyer and Singh, 1998). In this sense, interorganizational cooperation allows companies to access new resources and complement existing resources, particularly in research and development (R&D) projects. In particular, R&D alliances have become widely adopted as an open innovation practice (e.g., Schilling, 2009) and are increasingly important units of analysis for understanding competitive advantage based on innovation (Capaldo and Petruzzelli, 2014).

Some authors (Dyer and Singh, 1998; Nonaka et al., 2014) who believe that the ability to create and use knowledge to generate innovation is an important source of sustainable competitive advantage to companies emphasize that this consideration still has gaps because does not identify with any precision which knowledge process is more likely to generate innovations, accelerate the implementation of an innovation or support organizational innovation (Quintane et al., 2011).

Reflecting upon these studies' main contributions, we see a theoretical gap, which is considered here as a "black box". The theory of knowledge creation and the relational view have thus far generated substantial knowledge. For example, we know that collaborative practices are essential to the process of knowledge creation, and we know that knowledge creation leads to the creative process of innovation. In addition, the Socialization, Externalization, Combination and Internalization (SECI) process and the conversion of tacit and explicit knowledge become important conditions for dialectic knowledge creation when applied to a "BA" and, in turn, act as mediators in this process. As highlighted in the literature review, many recent studies, such as Petruzzelli (2014), Nonaka et al. (2014) and Capaldo and Petruzzelli (2015), have demonstrated that exploration and exploitation strategies have been combined to improve an organization's innovative performance. However, these incipient studies have only begun to explain the collaborative practices that ensure effective knowledge creation for innovation, the best practices that generate tacit and explicit knowledge, and the ambidextrous R&D practices that lead to knowledge creation.

Even with scholarly advances in constructing a theoretical framework based on the theories and concepts of organizational knowledge, important gaps remain, such as the need to deepen the understanding of the knowledge creation process and, in particular, the practices employed by the actors involved in this process (Zboralski, 2009; Sun, 2010; Serenko, 2010). The dynamics of collaborative practices are not adequately explained by current theoretical perspectives, which present these practices as a "black box" in the study of inter-organizational relationships. Therefore, we ask the following questions to discover how the dynamics of collaborative practices of knowledge creation occur in collaborative R&D projects: Which types of collaborative practices of knowledge creation foster innovation? Do these practices change over the evolution of a collaborative project?

The study of collaborative practices in joint R&D projects is particularly relevant for project-intensive industries, as the survival of these industries often depends largely on their ability to accelerate innovation (Assudani, 2009). Moreover, the actors in these industries are increasingly using collaborative arrangements to meet this demand (Shih et al., 2008).

In seeking answers to our research problem, we collect evidence from collaborative projects in the semiconductor industry. Specifically, we examine the FD-SOI 28 nm transistor project, which is considered the most important collaborative microelectronics project in the French microelectronics cluster known as Minalogic, in Grenoble, France. This case provides a valuable example of how collaborative practices are implemented in joint R&D projects in the semiconductor industry. The collaborative FD-SOI collaborative project consisted of an ambidextrous innovation process using a combination of collaborative knowledge creation processes. We chose this unique case because it has an important place in the history and development of the transistor and because it overcame one of Europe's difficulties in innovating in knowledge-intensive industries, i.e., the difficulty of transforming academic knowledge into innovation (European Commission, 2011).

To solve the research problem, the article is structured in five parts. After the introduction, we present the theoretical framework that supports the development of this research, as well as the gap it is intended to fill as a theoretical contribution. The third section presents the methodological procedures. Then, we present the project's historical narrative and the data emerging from this process, before we present our final considerations.

2. Theoretical conversation

2.1. Collaborative practices in knowledge creation

Strategically, collaborative R&D projects open up innovation processes by means of collaboration with external actors, which leads to the combination, complementarity and creation of new knowledge across organizational boundaries (Davis and Eisenhardt, 2011). Technological alliances effectively help companies access additional resources and achieve competitive advantages (Krammer et al., 2016). In this regard, organizations have adopted innovation processes that are increasingly collaborative, open, and networked.

Today, organizations in many fields of human service are searching for and implementing best practices to increase their effectiveness in this context because they are under pressure to accomplish more with fewer resources and to meet increasingly higher performance expectations. Best practices may emerge from the innovative work of researchers and practitioners who are seeking novel solutions to emergent problems and challenging service delivery issues (Manela and Moxley, 2002). Manela and Moxley (2002) argue that best practices can be thought of as one of the principal products of organizational knowledge development. However, to fully understand best practices, we must also understand how organizational knowledge develops.

In their article titled *"The Relational View: Cooperative Strategy and Sources of Interorganizational Competitive Advantage",* Dyer and Singh (1998) present the relational view and define interfirm knowledge-sharing routines as institutionalized processes between companies that are purposely designed to facilitate knowledge exchange between alliance partners (Dyer and Singh, 1998). These processes are also known as collaborative practices in knowledge creation and involve regular patterns of interactions between businesses that enable the transfer, recombination and creation of specialized knowledge (Grant, 1996). Dyer and Singh (1998) argue that these types of interorganizational processes are particularly important because the transfer of knowledge typically involves an interactive process of exchange, and its success is reflected in direct, intimate and extensive interactions between the staffs of the two companies.

One of the hypotheses developed by Dyer and Singh (1998) is that the design of specific collaborative practices in knowledge creation facilitates exchanges between partners in an alliance and the creation of new knowledge. However, there are no solid contributions explaining the dynamics of these collaborative practices that also provide for the earning of supernormal profits. Regarding this dearth of research, Lounsbury and Crumley (2007) and Labatut et al. (2014) note that one of the most intriguing aspects of recent developments in organizational studies is that there have been increased efforts expended to deepen the understanding of "how" and "why" organizations change and to illuminate "what" the origin is of the new practices adopted.

Davis and Eisenhardt (2011) refer to the need for symbiotic relationships in collaborative high-tech projects. The authors begin by asking why some projects produce technological innovations and others do not. The researchers conclude that only projects that can establish symbiotic relationships survive. Although their research is important for theorists of interorganizational relations, they do not focus on the type of collaboration practices that are linked to the symbiotic relationship.

Furthermore, Defelix, Colle and Rapiau (2008) emphasize the need to engage in collaborative projects to achieve success, highlighting the study of the innovation process. Calamel et al. (2012) emphasize the need for coordination among multiple actors in innovation projects, calling this process the "construction of collaboration". However, neither of these studies shows how to build collaboration from the perspective of the actions or practices engaged in between the actors. Tranfield et al. (2006) mapped the different practices found in each of the phases of the innovation process (discovery, development and support) and constructed a hierarchical model of the process of knowledge management for innovation. In 2010, major studies in respected journals such as Sun (2010), which appeared in the *Journal of Knowledge Management*, note that organizational routines influence the processes of acquisition, creation, use and sharing of knowledge. Sun (2010) shows that different knowledge management processes (acquisition, creation and use) have specific organizational routines that influence this process.

According to Felin and Foss (2004, p.23), although notions about routines and capabilities abound in evolutionary economics and strategy, no study has clearly demonstrated how certain practices or routines are related to maintaining competitive advantages. Recently, at the Thirtieth Congress of the European Group of Organization Studies (2014) in the Netherlands, a subplenaria was held to discuss the dynamics and nature of routines. The imminent need to understand the dynamics of practices to improve critical areas such as creativity and innovation is broadly converging with the gaps identified by Felin and Foss (2004).

In the context of practices designed with one goal, researchers seem to agree that knowledge accumulates and is built and put into action through collective practices. Above all, the development of these practices can positively impact skills and organizational outcomes (Michaux, 2011). In addition to arguing that alliance partners can generate relational capital through knowledge-sharing routines (Dyer and Singh, 1998), it is important to understand which practices adopted by these partners result in competitive advantage and innovation.

2.2. Innovation as a result of the knowledge creation process

The theory of knowledge creation – founded by Nonaka and Takeuchi (1995) and followed by Nonaka and Toyama (2005, 2007), Nonaka et al. (2011) and Nonaka and Von Krogh (2009) to a greater or lesser degree – posits that knowledge comes from experience and is a "subjective process" of perception and interpretation of the environment and not a "substance" that can be materialized. In this theoretical perspective, the focus is on processes and working practices, which highlights a notion of knowledge that is socially constructed by the interaction.

In the best-known and earliest work supporting this theory, "*A Dynamic Theory of Organizational Knowledge Creation*", Nonaka (1994) argues that the key to understanding his theory is the knowledge conversion process – from tacit to explicit– through the SECI model. By 2000, Nonaka and his colleagues developed a model of dynamic knowledge creation. This dynamic model predicts the existence of three basic elements; in addition to the SECI model, they suggest the "BA" and the importance of leadership. The "BA" is the shared space in the process of knowledge creation. To support the SECI process, this shared space may present a level of greater detail, fitting specifically with each conversion mode of knowledge (Balestrin et al., 2008). After expounding upon the "BA", a phase ensued in which knowledge creation theory examined in detail questions related to the importance of context in terms of knowledge creation (Jakubik, 2011).

Recently, Nonaka et al. (2011) argued about the need for a new theory of the firm based on knowledge. The recent emphasis is on subjectivity in the process, practice and aesthetic aspects of knowledge creation. In addition, Nonaka et al. (2014) describe the "fractal organization," which is for them the way in which organizations must provide the dynamic synthesis of knowledge with no distinction between exploration and exploitation, as the two types of practice occur at different times. Nonaka et al. (2014) emphasize that exploration and exploitation, when performed simultaneously in an organization, help a company to become sustainably innovative. For Nonaka et al. (2014), the organization handles the concept of ambidexterity well in this more consolidated stage of innovation in which it both explores existing knowledge and advances in the search for new knowledge through its extensive relations with the external environment. How organizations can achieve ambidexterity has recently been the subject of increased attention in the innovation management literature (Lavie et al., 2010).

In this sense, Petruzelli (2014) found that innovations are positively influenced by companies' ability to find a trade-off between exploration and exploitation within and across technology domains. Capaldo and Petruzelli (2015) claim that innovative performance is influenced by the origins of existing knowledge and by the way in which the actors search for new knowledge. The authors emphasize that, although companies benefit from alliances with partners with different knowledge, they preserve relatively higher levels of absorbency, which are necessary for them to understand, internalize and use the knowledge of partners from different domains.

3. Research methodology

We use a single case study, taking a processual, qualitative and analytical approach, and relate a history of collaborative project development using narratives. This approach was chosen for theoretical reasons (Glaser and Strauss, 1967) because of the necessity to provide a detailed overview of the evolutionary process of knowledge creation over the lifespan of a collaborative project in a knowledge-intensive industry.

The narrative allows for recomposition of the history (Bizzi and Langley, 2012). In this study, we tell the story of the collaborative project developed over the last 15 years (1999–2014). However, instead of analyzing the data in search of properties and dimensions, we observed the action/interaction accompanying it to see 'how it changes and if it moves, or with allow to remain unchanged with changes in structural conditions' (Strauss and Corbin, 1998, p 161).

For purposes of data collection and analysis, we split the schedule into three distinct periods (as can be shown in the Fig.1), as suggested by the analysis conducted. The methodological stages of the research were defined by identifying important events that led to a change in the course of the project or the action patterns. Although it is important to note that the processes that accompanied the separation of the methodological phases' overlap of the formal and methodological limits of time, each period presents and explains its main dynamics over time, preserving the continuity of the different events.

Semi-structured interviews were conducted with those involved in different stages of the project (Corley and Gioia, 2004). From the definition of the methodological phases, the different sources of data for the methodological phase were separated, as shown in Table 1. Retrospective interviews and other data collection efforts began in August 2014 and lasted until the middle of 2015. The first contact of the researcher with the field was during the "Imaginons le Futur" ["Imagine the Future"] conference promoted by the Minalogic competitiveness center, whose objective was to showcase successful collaborative projects that became products. Most of the data collection took place in person from August to December 2014. Further data collection took place via e-mail or Skype, aiming at completing information or clarifying important elements for the continuity of the research.

In the first step, the choice of informants was "intentional" (Kumar, Stern, and Anderson, 1993; Corley and Gioia, 2004). Thus, the most agile and skilled informants were chosen to provide information on the dynamics of implementing knowledge creation practices during project development. From there, the snowball technique was used. Due to the focus and purpose of this research, the informants were engineers and others involved in interorganizational collaboration on the project and not those involved in company management processes or even in the internal processes of each of the organizations involved in the collaboration, that is, informants were those who clearly participated in the process of creating new knowledge. Thus, it is possible to say that the central actors of SOITEC, CEA and ST were specifically chosen and that the others were only confirmatory. As Langley and Abdallah (2011) note, the principle of data triangulation was used. Triangulation refers to the collection of data using different sources. Distinguishing subtypes of triangulation, Denzin (1978) proposes to study a phenomenon over time (dates – exploring temporal differences), space (in the form of comparative research) and with different individuals. For this research, data triangulation was used, since data was collected from different individuals in the development phase of the project in which they participated.

To maintain consistency, all the interviews were conducted by the same researcher between August 2014 and May 2015. First, all the interviews were recorded and transcribed. The interviews were conducted in French, and after analyzing the results, the author translated excerpts as required for inclusion in this thesis. As the interviews were conduced in French, they were therefore coded in the original language. However, in the presentation of the results, the main passages were translated, hewing as closely as possible to the original, as recommended by Strauss and Corbin (2008).

This approach resulted in an evolving sample of informants and increasingly focused on data relevant to the emerging theory until

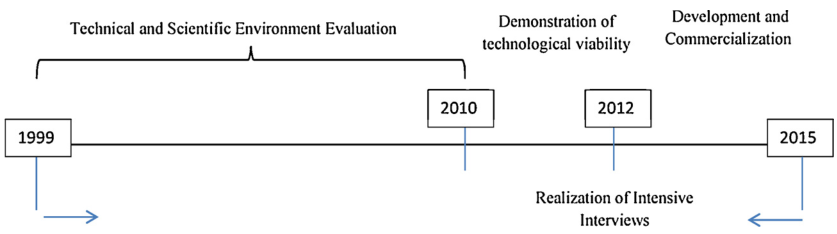

Fig. 1. Methodological phases.

Table 1
Data source.

	Data source for methodological phase			TOTAL
	I	II	III	
SOITEC	3	4	1	8
CEA – LETI	3	3	4	10
ST-MICROELETRONICS	2	6	6	14
INTEL MOBILE		1		1
SERMA TECHNOLOGIES		1		1
THALES COM		1		1
UNIV. STTUTGART		1		1
ACREO			1	1
INFINISCALE			1	1
DOLPHIN	1	1	1	3
ATRENTA-FRANCE			1	1
CAMECA		1		1
CEA-INAC		1		1
CNRS – LTM		1	1	2
ST-ERICSSON		1	1	2
FRAUNHOFER INSTITUTE		1		1
GLOBAL FOUNDRIES		1		1
IBS		1		1
CNRS/CEMES		1		1
INPG/IMEP		1	1	2
UCL		1	1	2
AMD Saxony	1	1		2
Siltronic	1	1		2
AIXTron AG	1	1		2
IBN-1 FZ-Juelich (FZJ)	1	1		2
MPI – HALLE	1	1		2
Total of Informants per period	14	33	19	65
Total of New Informants per period	14	19	9	42

the collection and analysis of new data yielded no further explanation of a particular category or theme, which Glaser and Strauss (1967) referred to as “theoretical saturation." The principle of ‘theoretical saturation’ (Glaser and Strauss, 1967) was used to indicate when data collection using the snowball technique would come to an end.

The description of a process consists of the observation of events, stories and everyday events. Thus, all the respondents were asked to “tell the story of the collaborative project in detail, always emphasizing what was necessary and decisive in creating something innovative that could change the history of microelectronics worldwide and what perspectives they had on the possibility of achieving the possible result of its use by the market […]".

In the beginning, it was requested that the story always be told from the collective point of view of the working group and not based on the individual attributions of each of the companies that participated in it. Although the initial interviews lasted at least 60 min, the remaining interviews lasted from 30 to 90 min. These initial interviews contained questions about the company's experience, engagement at work, thoughts about the project's history, current or recentperceptions, and strategic and business context. Subsequent interviews, however, became progressively more structured as important issues (themes) emerged in the data. The progressiveness of the data collection during the interviews allowed the collection of targeted data in an attempt to identify patterns among all the informants, consistencies and inconsistencies, and hesitant relationships between concepts. Thus, most of the content of the second and third interviews with a particular informant focused on categories and themes represented in the emerging data structure. Some interesting statistics about the present research are notable. There were 2593 min of recorded interview minutes, totaling approximately 44 h. In addition, the transcripts yielded a compendium of 478 pages plus 40 pages of written text.

After each of the interviews, field notes and memoranda were prepared, which allowed the researcher to identify parts that needed further explanation. In addition, these tools facilitated further analysis, mainly because they contained thoughts, interpretations, questions and directions for future data collection or analysis.

In addition, during the interviews, many of the respondents used drawings to represent the evolution of the project and other important relationships, such as Fig. 2, drawn by Interviewee 1. Many of these figures were incorporated into the field notes prepared by the researcher. Below is one example of such a drawing.

In addition, in some of the interviews, we also opted for the use of photoelectricity to be able to aggregate more information about the development of the project.

Each of the respondents received a random number ranging from “E1 to E42;" in this way, it was possible to protect the confidentiality of all informants. The inventory of secondary data used for the analysis included 167 documents representing the three stages of the projects. We present the inventory of secondary data in Table 2.

In addition, sociograms of members who participated in each stage of the process were made using Ucinet ® software. We used social network analysis from a relational perspective (Mizruchi, 2006). This means that our analysis was based on the graphic technique, that is, we performed the analysis of social networks in order to map the connections between the participants of the

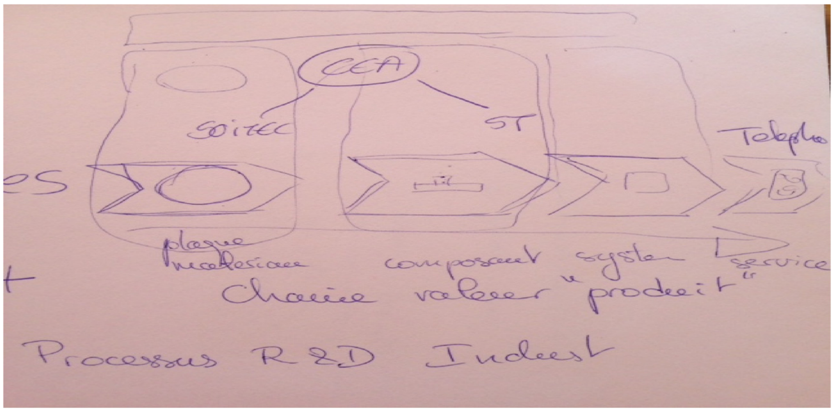

Fig. 2. Representation of the process.
Source: Interview

Table 2
Secondary data inventory.

Sources	Methodological periods			
	Step 1	Step 2	Step 3	Total
Internal documents	20	36	12	68
Books or chapters	1	2	–	3
Scientific articles	2	14	3	19
News on the internet	2	4	6	12
Financing projects	1	3	1	5
Project finance report	–	4	1	5
Theses	3	9	–	12
Slide presentations used at conferences	1	4	3	8
News in newspapers and magazines	1	4	12	17
Photos	15	3	–	18
TOTALS	46	83	38	167

collective (Knoke and Yang, 2008; Brass et al., 1998). In this sense, the positional analyses derived from the algebraic matrices that would allow the presentation of measures to describe the social network properties were not calculated.

To ensure the study's reliability (Lincoln and Guba, 1985), we used "Peer debriefing", which is defined as the engagement of other researchers who are not involved in the study to discuss data patterns and critical issues involving the collection and analysis of data and results. In this research, there were four sessions of peer debriefing. The first two took place in a French university. The other two took place in Brazil, with the research group to which the researchers belong.

Having described the methodology, we are able to present the main results.

4. Analysis and results

We will tell the story of the creation of the transistor FD-SOI. A transistor is the smallest and most basic building block for electronics (Turley, 2003) and is formed from a number of other transistors and other components that ensure the creation of a chip. Since the early 1970s, the semiconductor industry has used a new Complementary Metal Oxide Semiconductor (CMOS) technology approximately every two years. CMOS consists of the process of creating integrated circuits by combining thousands of transistors on a single chip.

4.1. Period I: from 1999 to 2010

The FD-SOI 28 nm transistor was an important innovation in the semiconductor industry because it enabled the process of chips' miniaturization and helped augment performativity. The first phase of the project, from 1999 to 2010, involved the collective realization that the contemporaneous technology, the bulk transistor, has some applicability failures. Highly pure, crystalline silicon mono is called "bulk". The electronics industry and microelectronics use silicon as the basic material. Around 1999, the semiconductor industry became convinced that it had to create something new to continue reducing the chips' size. With regard to this scenario, the respondents explain as follows, *"What is common to all these applications, before the development of 28 nm technology, is the use of bulk"* (E5) "*[…] but technology for obtaining bulk transistors became increasingly complex to able to meet the growing need for performance"* (E1). According to them, it was then that "*[…] the scientific and business community recognized that this technology should* *be abandoned because we had reached the limit dimensions of the transistor"* (E12).

The monocrystalline silicon, or bulk, is one of the most important technological materials of the past decades and is central to the birth and consolidation of the "silicon age" (Heywang and Zaininger, 2004). It is in this scientific context and − through the accelerated dynamics of Moore's law – that the history of the Silicon On Insulator (SOI) debuted in the 1970s in the Atomic Energy Centre (CEA) in Grenoble. Created in 1945, the CEA is a research laboratory recognized worldwide for its size and efficiency.

Thus, the SOI appeared at first as a modest possibility of change at the side of the bulk silicon, which was the most important material of microelectronics. The material, or SOI substrate, is a wafer (cylindrical wafer) created from CEA-LETI's research as a replacement for the bulk. The SOI wafer allows integrated circuits to be manufactured in the upper layer using the same methods as those used for bulk silicon wafers. This technique has been recognized as the "Smart Cut," and the CEA applied for a patent for the process in 1991 following initial development of the art. Already in 1992, the SOITEC start-up was created as early as 1992.

This initial story was told by all respondents with pride because it involves the birth of a material and subsequently of a company that would bring many other achievements to the city of Grenoble and make it among the world's most recognized sites in semiconductor production. With regard to the discovery of the material, Interviewee 5 notes: '*It (SOI) promised much but at the same time had a lot to prove. This was the beginning of a lot of opportunities for Grenoble and the region'*. In addition to this close relationship between the CEA-LETI and SOITEC, the research institute also was performing some joint work at this time with the Advanced Modules team of ST Microelectronics. A report from the Grenoble magazine *L'Express* (Constanti, 2012 p.83) from November 2012, entitled *"Grenoble: Le vrai pouvoir du CEA",* highlighted the partnership between the CEA and companies in the region, and stressed that "*[…] innovations thrived in the local economy. The best known example is that of ST Microelectronics, which from the capitalization provided by LETI, became a world leader in semiconductors"*. ST Microelectronics is one of the largest companies in the global semiconductor industry, with net revenues of US$ 7.40 billion in 2014. The company offers one of the broadest portfolios of semiconductor products in the industry, serving customers across the spectrum of electronics applications (ST, 2015).

The need for change in the system architecture level points to what Tidd et al. (2005) call the discontinuity condition. In 1999, this condition of discontinuity caused the union of the *"[…] three major companies of Grenoble: CEA, ST and SOITEC, to join efforts to continue to meet and exceed this limit, working more intensely collaboratively"* (Interviewee 5). One respondent notes that *"[…] what gave us the strength to create the first collaborative actions is that there were many people working in ST and made the thesis at the CEA, and the people who created the SOITEC were CEA, so you cannot forget this aspect"* (Interviewee 5). Thus, in a combination of research and industrial experience, SOITEC, ST and CEA-LETI began to work with greater determination to develop smaller and more efficient transistors, expecting difficulties in continuing the miniaturization process.

While they recognized that they were approaching technological limits, the project partners began to search for the best technological path they could follow. In the words of Interviewee 4, *"[…] it was necessary to make a smaller transistor out of a new material, this new type of material is important for us to have such electronic mobility. Ah! Yes! But we did not know how to do this, how do we do it? […]*". In addition, the project partners also had to worry about the possibility of using government resources for funding because *"[y] ou cannot do anything with success in this industry without being in line with the national strategy, with the government's plans"* (E22).

At the end of the first phase, the partners had broken through the knowledge frontier necessary to make the concept a marketable product, as highlighted by respondents 15 and 18, respectively: *"By integrating the knowledge of each participant in the project, it was possible to understand what was known and to disclose the limit approached in the articles, for example. So from then on, we create the future we want, at least in concept and run back to turn this into something concrete"*; and *"Realizing that you cannot continue is a difficult task if you do not have one set of activities to help you to [continue […] You have to attend trade shows, write articles, finance theses […]"*.

These conditions led to a variety of collaborative practices that allowed the project partners to create the concept that would be pursued: a smaller and more efficient transistor for use in portable devices and multimedia applications (low power applications).

Emerging practices in the first stage, which seeks knowledge to recognize a limit and choose a path, include those I) that allow companies to recognize existing research interests in the ecosystem, II) that motivate the discussion and recognition of the limitations of the available technological knowledge, III) for which potential sources of knowledge are investigated for items of interest, IV) that allow for the combination of heterogeneous knowledge, V) that articulate the knowledge created in the project, and VI) that are created for the potentiation of incremental resources. In Table 3, empirical evidence for each type of collaborative practice is presented, as well as the main type of knowledge that was added to the project and the potentialized BAs in this period. We called this Knowledge Assessment Creation Practices. We used roman numbers to indentify each type of practice that we discovered in the sequence of the article.

Ten companies were involved in this first stage of the collaborative project. The partners already knew one another and had similar technological capabilities. Between late 2009 and early 2010, the project partners acquired knowledge of a new substrate, FD-SOI, that could replace bulk (the conventional material), but they had no idea how to overcome this barrier. *'Even though the very thin SOI (option to use the bulk) was the smarter alternative to minimize the transistor, I could not do it alone, and this is the most important, so that if this innovation was possible, it was necessary to explore all knowledge in the value chain' (E1)*. Then, after identifying the concept, a search to overcome this limit was launched, which involved the widespread need to formulate an explanation for the problems through collective discussion. One respondent noted that *"this opportunity to reflect collectively is the most effective practice. So, we did that in scientific programs in packages and even when we were writing the crowdfunding proposals"* (E5). This is the beginning of the second stage of the project.

4.2. Period II: from 2010 to 2012

This problematization period allowed the collaborators to ensure the technological and market feasibility of continuing the

Table 3
Collaborative practices from 1999 to 2010.

Practices in Knowledge Creation	Empirical Evidence	Potentialized BAs	Aggregate Knowledge
I	*Workshops*, tradeshows, *brainstorming*, informal conversations, formal and informal meetings and R&D consortium	Systematization BA triggered by combining different bodies of explicit knowledge.	Explicit
II	Following the sectoral roadmap; helping construct the roadmap; establishing scientific programs; formal meetings; and R&D consortium.	Systematization BA triggered by combining different bodies of explicit knowledge.	Explicit
III	Writing scientific papers. Reading articles. Thesis funding.	Systematization BA triggered by combining different bodies of explicit knowledge.	Explicit
IV	Establishing scientific programs and work packages.	Externalization BA triggered by collective reflection.	Tacit
V	Benchmarking results; systematic meetings; teleconferences; computer simulations; work packages; and material exchanges.	Externalization BA triggered by collective reflection.	Tacit and Explicit
VI	Proposals for funding of collaborative projects; use of government research infrastructure, and involvement in developing sector strategies.	Systematization BA triggered by combining different bodies of explicit knowledge.	Explicit

knowledge creation process. About this period, the interviewees said that *"we tested and we used the results to write a scientific publication, listen to criticism, questions […] in this period, we wrote a lot because we found a lot of new things, we moved fast forward from here on […]*" (E 8). This is one of the most critical stages, as it is here that the concept of technology is expanded and becomes feasible. One of the interviewees emphasizes that sometimes *'the discussion can be difficult. That is, I can do it, but I do not do it because it costs […]. Here comes someone and says, "Oh, but I need this". This is where we have to discuss […] Okay? Sometimes we even have a solution, but it is so expensive that it is not worth it, and what is acceptable for it to work must be at the right cost and the right price. So here there is a great discussion' (E3).*

During this period, an industrializable product is imminent but only in a laboratory environment. Interviewee 13 summarizes this period by saying that *"in research labs, it is like that, you test things in very small areas because the principle is: does it work or not? The technique is demonstrated on this small surface, but making a transistor is one thing, making a million is more challenging and requires other collaborative practices […]*" (E 13).

During this period, they adopted practices seeking to mobilize tacit knowledge possessed by partners with whom they collaborated infrequently and to combine it with the stock of knowledge acquired in the first phase of the project. They expand the stock of existing knowledge on the transistor FD-SOI, searching for technological synthesis. To complete the process of technological synthesis, *"we used what we knew and with work, we created what we did not know, and the more we progressed, the more distinct knowledge was necessary, and we would work and create it […]"* (Interviewee 1).

The search for technological synthesis generates practices that this study calls fractalization practices of knowledge creation. Fractalization practices intend to VII) assist with the perception of reality, VIII) articulate a future scenario, XIX) combine knowledge through action, X) allow direct interaction among project participants, XI) combine different knowledge, and XII) confirm inventions. Table 4 summarizes the main collaborative practices in this collaborative project development stage.

The extensive discussion necessary at this stage of the project involved the participation of 18 companies. These partners are less familiar to one another, and their fields of knowledge are diverse, as there is an opening for the value chain. Each member's tacit knowledge thus becomes more important in the collaboration.

Table 4
Collaborative practices from 2010 to 2012.

Practices in Knowledge Creation	Empirical evidence	Potentialized BAs	Aggregate Knowledge
VII	*Brainstorming*, informal conversations, formal meetings and scientific programs.	Socialization BA triggered by sharing experiences.	Tacit
VIII	Write scientific articles	Externalization BA triggered by collective reflection.	Explicit
IX	Work packages and formal meetings.	Socialization BA triggered by sharing experiences.	Tacit
X	Joint writing projects to expand knowledge	Externalization BA triggered by collective reflection.	Tacit
XI	Mixed team.	Socialization BA triggered by sharing experiences.	Tacit
XII	Prototyping; simulation; tests, and work packages.	Socialization BA triggered by sharing experiences.	Tacit

4.3. Period III: from 2012 to 2014

From 2012 to 2014, project members sought to crystallize the knowledge created, which thus began the third phase of the project, which is the transformation process of a prototype in a product or service. At this stage, the technology is disclosed to the market, and it is ascertained that the technology works when applied to a final product. *"It was the first time we did a test. We publicly demonstrated a telephone FD-SOI 28 nm, and the phone with the FD-SOI chip showed a different speed than that of a normal phone. This demonstration involved the indescribable experience of implementing the work of a decade" (*E12). This demonstration unleashed a broad reflection on the existential conditions of the project that ensured its success and the possibility of disseminating the project as a success story for the entire community. In Grenoble, it is said that no one "*gets to participate in events such as technological barbecues and collective brainstorming as we imagine the future […] because it allows us to present our case to the community and at the same time reflect on our next actions […]*" (E1). "*We want to inspire others […]"* (E42). At this step, the collaborative nature of the knowledge creation practices is modified and called a crystallization practice.

Knowledge crystallization practices focus primarily on practices that XIII) develop the technology to market, XIV) demonstrate the uses of technology, XV) boost the process of technological innovation, XVI) continue the innovation process, VII) provide technological improvements to customers who acquire the technology, XVIII) are associated with the debate regarding the main difficulties encountered, and XIX) promote innovation (as shown in Table 5).

Table 5
Collaborative practices from 2012 to 2014.

Practices of Knowledge Creation	Empirical evidence	Potentialized BAs	Aggregate Knowledge
XIII	Participation in internationally recognized tradeshows.	Internalization BA triggered by reflection on what has been learned.	Explicit
XIV	Project for expansion of knowledge; focused work packages.	Externalization BA triggered by articulation of tacit knowledge.	Tacit
XV	Participation in internationally recognized tradeshows.	Internalization BA triggered by reflection on what has been learned.	Tacit and Explicit
XVI	Mixed teams	Socialization BA triggered by sharing experiences.	Tacit
XVII	Scientific programs	Systematization BA triggered by editing and application of explicit knowledge.	Explicit and Tacit
XVIII	Technological barbeques; collaborative brainstorming.	Internalization BA triggered by reflection on what has been learned.	Tacit
XIX	Presentation of technological innovation as a success story.	Internalization BA triggered by reflection on what has been learned.	Tacit

In this last stage, the inter-organizational work is carried out by eight companies together. The partners gather to collaborate less and less frequently, and there is still some heterogeneity of knowledge. The exchange of information is now no longer reciprocal as it had been. In this period, the creation of knowledge has become more concentrated because it is now the beginning of the industrialization process, which has led one of the companies to become more of a central actor in the demand and supply of information to improve the technology. The result of the crystallization of knowledge is the innovation, the product of the knowledge creation process.

4.4. Analysis of data

As shown in the historical narrative, knowledge creation practices have different natures in each phase of a collaborative project. These natures are linked with the growing knowledge needs of the product (in this case, the transistor) being developed. In other words, as knowledge of the new product increases, new collaborative practices become necessary to enable continuous expansion of knowledge. For this reason, the various collaborative practices adopted are differentiated throughout the life cycle of an R&D project. Depending on the type of practice created, there are different types of action standards; as the collaborative project evolves, collaborative practices of knowledge creation are also transformed. To discover the source of the new practices adopted, the first research proposition that emerges is as follows:

(P1) Collaborative practices vary with the increase of the knowledge stock needed to make the concept of reality.

For Nonaka and Von Krogh (2009), there is a controversy in current studies on social practices of knowledge conversion – particularly with regard to the lack of explanation of the relationship between social practices and knowledge creation –because the literature's evidence regarding the characteristics of knowledge creation has attacked the practices of the actors facilitating the process of synthesizing knowledge. In addition to this theoretical gap, in 2014, Nonaka et al. for the first time spoke of "fractal organizations", i.e., organizations that can maintain the proper balance between exploration and exploitation strategies. Since that time, few studies on this subject have been conducted. Indeed, maintaining an appropriate balance between exploration and exploitation (Ahn et al., 2006; Kodama, 2003) and promoting synergies between exploration and exploitation (He and Wong, 2004) can help improve performance.

However, coexisting and simultaneous application of two different archetypes (exploration and exploitation) in a company

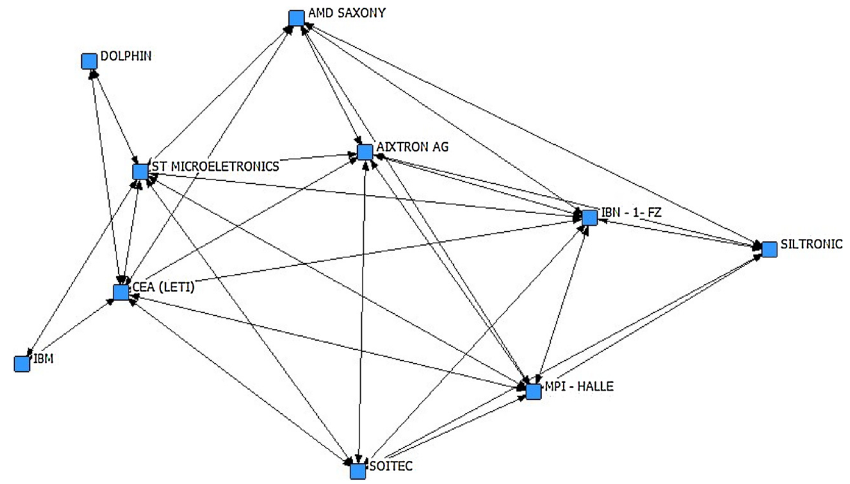

Fig. 3. Sociogram from 1999 to 2010.

requires skilled management – or "strategic contradiction", "creative friction" and "productive conflict" – to make use of potential synergies (Nonaka et al., 2014). In this sense, it is believed that collaborative practices function as important tools for managing these conflicts. In the theory of knowledge creation, organizations are understood as networks with multiple mutually interwoven layers of a diverse "BA" (Nonaka and Konno, 1998). "BA" means a shared context in motion, interactions of circumstances, structures and actors in a "relationship", "here and now" i.e., in time and space. The "BA" emerges and develops through interaction between actors and between actors and the environment. Therefore, the actions in the "BA" or relations between members of a "BA" also form actors' environments, structures and actions.

Several case studies, such as the study of Kumon strategy, are available in Nonaka et al. (2011), in the study of NTTDoCoMo company evaluated by Kodama (2011) and Wilhelm and Kohlbacher (2011). The Toyota Case evaluated by Nonaka et al. (2014) reported the development of the Prius and identified the existence of networks with multiple layers of "BA". The existence of multi-layered "BAs" was also found in the FD-SOI 28 nm design. To evaluate the formation of "BAs", a sociogram of each step of the collaborative project was created. After evaluating the sociograms' transformation, it was possible to confirm what Nonaka et al. (2014) emphasized about the relationship between the organizations.

For Nonaka et al. (2014), relations between organizations, environments, structures, individuals and different types of actors are dialectical relationships that change constantly as the "BA" reforms and remodels when several "BAs" connect and relate to one another. As observed in the narrative, in the first stage of the collaborative FD-SOI 28 nm project, the partners already knew one another and had similar technological capabilities, indicating more focused knowledge flows that resulted in more of a "closed" sociogram (see Fig. 3).

In the second stage, there was greater openness in the network, and the partners were less well known to one another. These partners' fields of knowledge were different, as there was an opening in the value chain, and the tacit knowledge possessed by each member gained in importance (see Fig. 4).

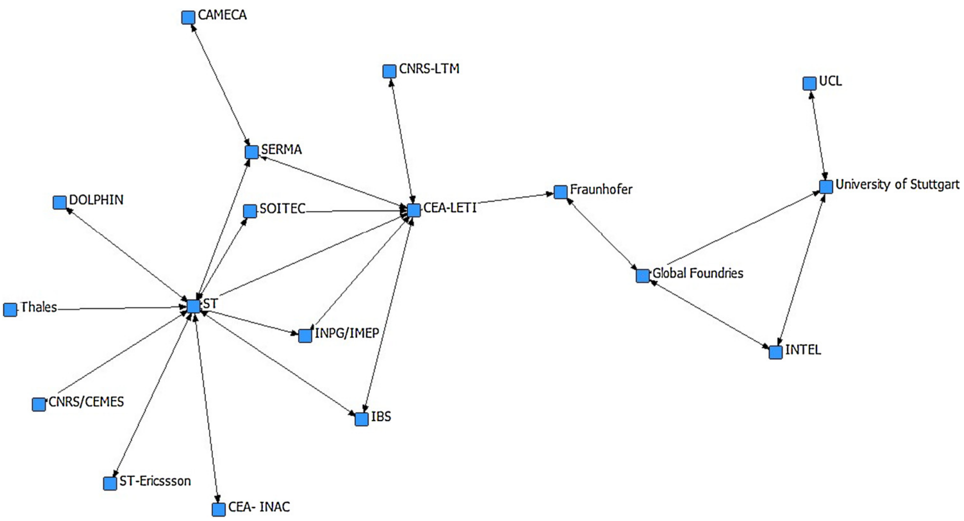

Fig. 4. Sociogram from 2010 to 2012.

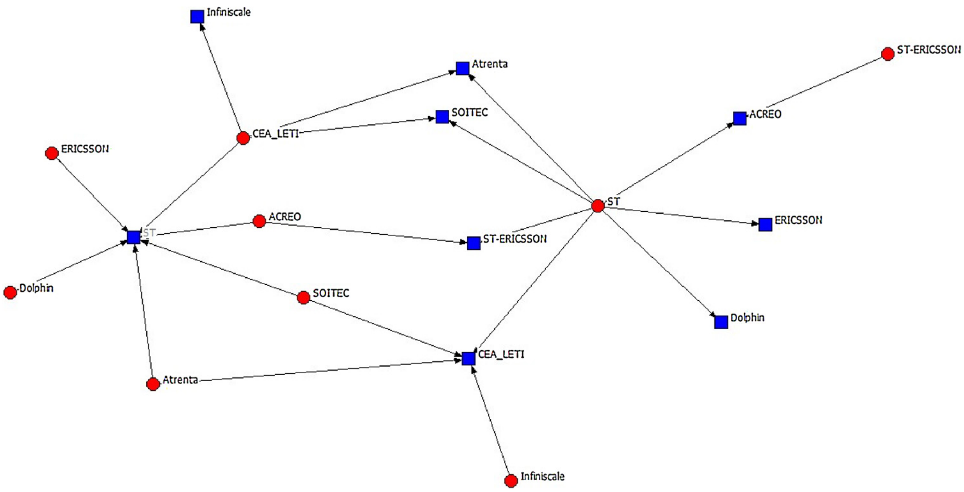

Fig.5. Sociogram from 2012 to 2014.

Finally, in the third stage of the collaborative project, while the partners collaborated less frequently, the heterogeneity of knowledge continues. At this stage of the project, graphs, unlike other periods, are indirect, i.e., "[…] indirect graphs show relationships in which direction does not make sense or is not always logically reciprocal, as of affection between friends or relatives" (Borgatti et al., 2013 p.48). Because the creation of knowledge becomes much more concentrated in this period with the commercialization of the technology process, we might emphasize that one company, ST, has become a more central actor in the demand and supply of information to improve the technology. Unlike the other stages of the project in which information circulated among all participating partners, at this juncture, it is ST that determines the direction of knowledge creation, as the project is in the industrialization phase (in which most of the development activity takes place within the ST factory) (see Fig. 5).

Thus, from evaluating the changes in the sociograms at different stages of the project, a new proposition for research could be revealed:

(P2) Collaborative practices vary according to the strategy of knowledge creation adopted in each project phase.

It was demonstrated that the dynamics of collaborative practices produce a dynamic synthesis between exploration and exploitation by using a group's tacit and explicit knowledge, providing connections between multilayered "BA" networks, which lead to the creation of inter-organizational knowledge.

The FD-SOI 28 nm project reproduced a dynamic fractal organizational model in which there is no dichotomy between exploration and exploitation in strategic activity. Instead, strategies must be implemented in their respective relationships and distributed in a robust balance and then must involve mutual supplementary relationships in the different project stages. Collaborative R&D projects can also be fractals, or they can combine more exploration stages and more exploitation stages in accordance with what is necessary to expand the stock of knowledge about what is being developed. From this finding, the following new research proposition is suggested:

(P3) Adopted collaborative practices vary based on the type of knowledge needed to continue the collaborative project.

When uniting the set of emerging proposals after analyzing the experience of FD-SOI design, which revealed a perspective of knowledge creation that is both relational and theoretical, it was possible to create a theoretical and conceptual framework of the findings of this experience that assists in explaining the adoption of different collaborative practices in innovation. We mentioned earlier those incipient studies explaining the collaborative practices that ensure effective knowledge creation for innovation and how they change during the evolution of a collaborative R&D project; these matters have remained in a black box, hidden from view, until now. Fig. 6 shows the theoretical contribution of this study, which was to open the black box of the knowledge creation process related to the dynamics of practices and to identify the factors that influence the adoption of collaborative practices, i.e., the stock of knowledge needed for knowledge creation, the type of knowledge needed to advance a collaborative project and the strategy used during each stage.

The framework also provides an objective set of practices that are important to the process of knowledge creation for innovation, which are adopted based on the combination of the factors described above to generate innovation.

Using this framework, a three-dimensional model emerges that can theoretically explain the dynamics of the collaborative practices involved in knowledge creation that ensure that a collaborative project becomes ambidextrous. In this model (see Fig. 7), there are three major continuums: a) the type of knowledge, ranging from tacit to explicit, b) the stock of knowledge in the project that extends from concept to reality and c) the strategy adopted based on each phase of the project, ranging from exploration to exploitation. We emphasize that each vertex of the three-dimensional model is a continuum because we do not believe in binary relations in the relationship of the proposed variables. The three-dimensional models resemble cubes that allow a multitude of possible combinations. Thus, from the best combination of different points of the three continuums, different collaborative practices can be created and/or identified. In this high-complexity collaborative R&D project, we found 19 practices. Simpler projects, more

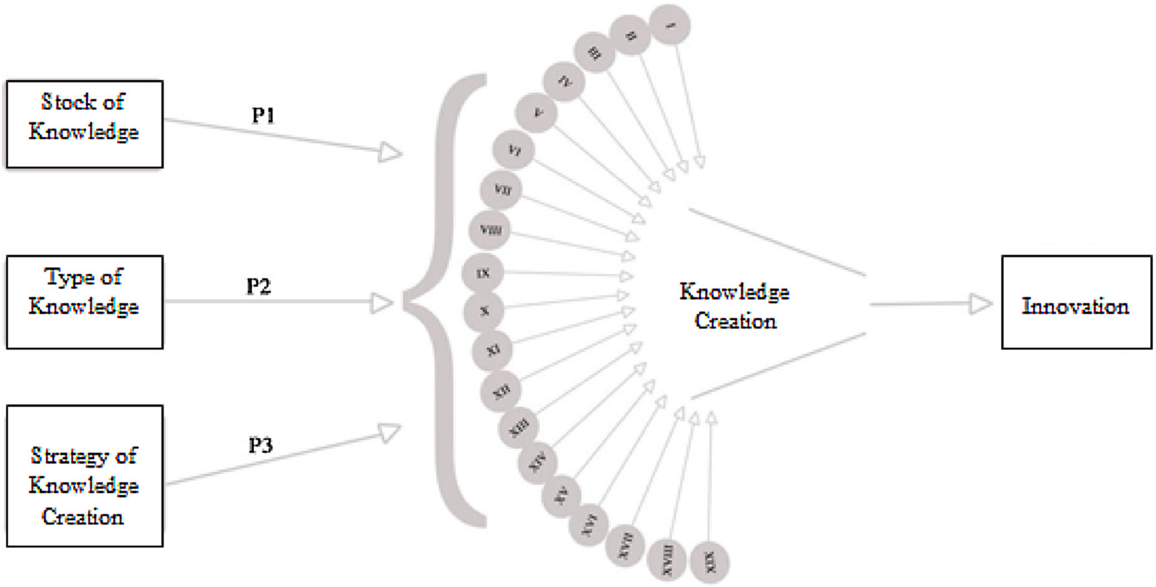

Fig. 6. The factors that explain the dynamics of ambidextrous practices of knowledge creation.

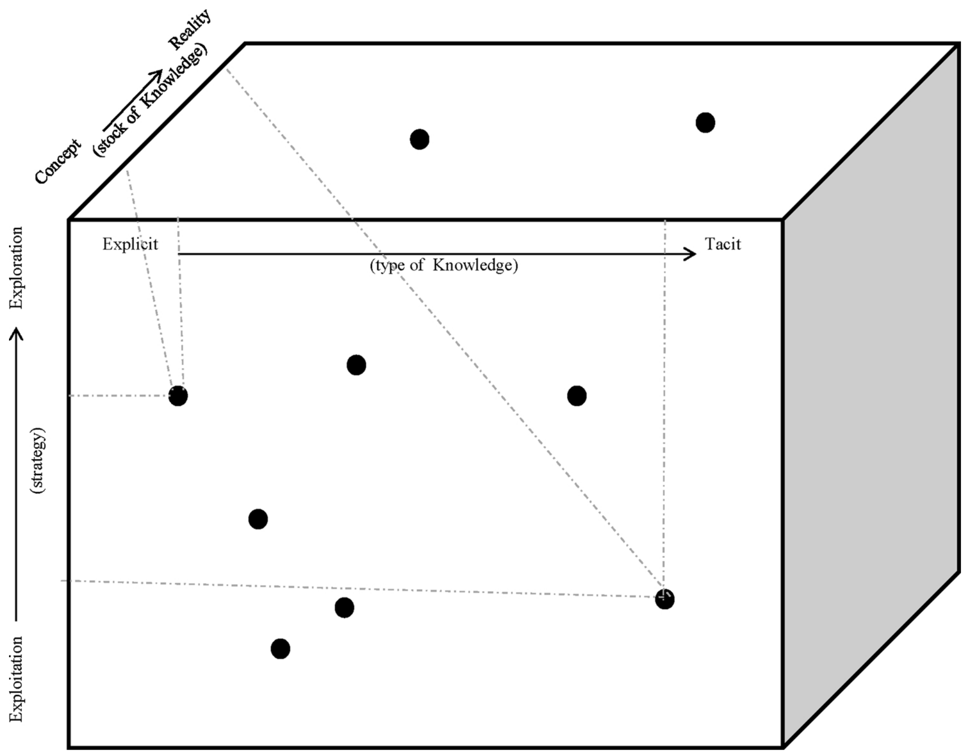

Fig. 7. Model of the dynamics of collaborative practices in ambidexterity.

incremental in nature, may have other practices based on new combinations among the three factors on the continuum, as suggested in the figure below.

In the following section, we present the relation between derived propositions and previous studies and after our final remarks.

4.5. Relation between derived propositions and previous studies

This study makes important contributions to the relational view and the theory of knowledge creation, offering a contribution to understanding the origin of ambidextrous practices in knowledge creation throughout the life cycle of an R&D project. The discussion of relational vision arises from the questioning of how firms achieve above-average returns. One of the hypotheses developed by Dyer and Singh (1998) is that the design of specific collaborative practices in knowledge creation facilitates exchanges between alliance partners as well as the creation of new knowledge.

The studies developed by Dyer and Singh (1998) and relational viewers such as Möller and Rajala (2007); Nobeoka et al., 2002, and Inemeka and Matthyssens (2013) emphasize the importance of collaborative practices; however, they do not pay attention to the dynamic and temporal aspects associated with them. Thus, in this study, we have contributed by demonstrating that ***collaborative practices vary with the increase in the knowledge stock needed to make the concept a reality***, as highlighted in the first proposition in this study. This finding also helps extend upon studies such as Hatchuel and Weil (2003) and Le Masson et al., 2006 on innovative design (Hatchuel et al., 2005). Innovative design in the concept-knowledge studies reflects the assumption that design can be modeled as the interplay between two interdependent spaces with different structures and logics: the space of concepts (C) and the space of knowledge (K). The first proposition that emerged in this study posits the need to consider the different collaborative practices that help link these different spaces, since the tools, practices or elements required to connect knowledge to concepts were little explored by the authors of this school.

Some studies, such as those of Boumgarden et al., 2012 and Blank (2013), allow exploration and exploitation through temporal separation based on the idea that firms can focus their exploitation during periods of exploration and during periods of time; in other words, at the project level each firm can choose the type of project they pursue. Studies such as these did not consider that "collaborative practices can vary according to the strategy of knowledge creation adopted in each project phase," as we assumed in our proposition 2.

In addition, by assuming that a project can be divided into different stages and that each of these stages can adopt a differentiated strategy, we are considering that the type of knowledge needed to continue the collaborative project also changes, and with it the adoption of differentiated collaborative practices, as we assumed in proposition 3. This proposition extends the conception of the forms of mobilization of tacit knowledge in projects. In addition to these contributions, our study further builds on the contributions of a set of recent studies, including Nonaka et al. (2014), Lavikka et al. (2015) and Chen (2017), who emphasize the importance of the existence of specific practices in the creation of knowledge through the processes of exploration and exploitation.

Nonaka et al. (2014), as we have already noted, based on the study of the Prius project emphasizes that it is possible to obtain a balance between exploration and exploitation practices in the creation of knowledge in collaborative projects. Chen (2017, p. 385) examines the 'logics of exploration and exploitation, evaluates the difficulties of accommodating both logics, and identifies dynamic ambidexterity as a new way to overcome these difficulties." The author emphasizes that the notion of dynamic ambidexterity and its managerial practices can help firms manage exploration and exploitation and ensure long-term survival and prosperity. Lavikka et al. (2015) seek to explain the process of ambidexterity building in interorganizational projects. Among the main findings, the authors note that co-developing coordination mechanisms and/or collaborative practices is essential for the continuous exploration and exploitation of new ideas in future collaborative service processes. These studies, as well as others that preceded them, consider that "dynamic ambidexterity' (Chen, 2017) utilizes sequential ambidexterity at the project level, or rather they manage exploratory and exploitative projects by different processes and highlight that, to achieve sequential ambidexterity, projects should be managed at the exploration stage through search-oriented processes and projects at the exploitation stages through execution oriented processes, but they do not explain how and why these dynamics arise.

In setting forth three propositions to explain the variation in collaborative practices that guarantee dynamic ambidexterity, our study contributes to explaining how to achieve this dynamism through the management of collaborative practices in knowledge creation. We did not identify previous studies that sought to explain the change in collaborative practices that ensure ambidexterity in an interorganizational project. This lack of explanation about the origin of collaborative practices is in line with remarks by Lounsbury and Crumley (2007) and Labatut et al., 2014. These authors, although at different times, noted that one of the most intriguing aspects of the recent developments in organizational studies is increased efforts to broaden the understanding of 'how' and "why" organizations change and "what" is the origin of the new practices.

5. Final remarks

The discussion of the relational view is born from questions regarding how firms achieve average returns. According to the relational view, this is only possible because of existing idiosyncratic connections between businesses that earn relational rents, i.e., a supernormal profit that is generated in an exchange and that cannot be earned by a single firm – instead it can only be created through alliances with specific partners. One of the hypotheses developed by Dyer and Singh (1998) is that the design of specific collaborative practices in knowledge creation would facilitate exchanges between alliance partners and the creation of new knowledge. However, as already shown in the theoretical framework, no solid contributions explain the dynamics of these collaborative practices that lead to supernormal profits. This lack of explanation of the origin of collaborative practices meets with notes by Lounsbury and Crumley (2007) and Labatut et al. (2014), who emphasized at different times that one of the most intriguing aspects of recent developments in organizational studies consists of the concentrated efforts to expand the understanding of "how" and "why" organizations change and "what" the origin is of these newly adopted practices.

Thus, we seek to identify the main factors that guarantee the dynamics of collaborative practices in an ambidextrous innovation process during the lifespan of the FD-SOI 28 nm collaborative project. Three main types of collaborative practices were found: assessment (1 st phase), fractalization (2nd phase) and crystallization (3rd phase). In the first phase, collaborative assessment practices of knowledge emerge to interpret reality as it occurs and the different forms in which it appears. This characteristic has also been described by Nonaka and Toyama (2007) and follows practical wisdom. Recognizing limits occurs during the period in which the group chooses practices that help them to recognize the existing stock of explicit knowledge. This means the technological limit in a sector such as the semiconductor industry, which is knowledge-intensive. This step attempts to define the best technological path that the project partners should follow. Kapoor and Macgrath (2014) show that during the various stages of the emergence of a technology, the environment is characterized by high technological uncertainty, and R&D efforts are mainly undertaken to accumulate knowledge. This accumulation of knowledge seems to be closely linked to the concept developed by Teece (2007), which supports the notion that reality must be interpreted by feeling what is occurring in the ecosystem using the existing knowledge stock.

This step also has some affinity with the concept of "extraordinary technological efforts", which was developed by Dosi (1984) to explain technical change and industrial transformation based on a study in the semiconductor industry. To Dosi (1984), extraordinary technological efforts are related to the search for new technological directions and arise when it becomes increasingly difficult to move forward in a particular direction, as in the FD-SOI 28 nm design. The choice of a path requires the articulation of tacit knowledge and substantial collective reflection to construct the new concept, and both involve collaborative practices to grow the space needed for the creation of knowledge.

The knowledge creation practices designed in the first phase of an R&D project in the semiconductor industry are called assessment practices of knowledge, as they are adopted during the stage in which the limits of technology are recognized and a new path is sought based on the national strategy; this stage is considered a trial period in the technical and scientific environment. In other words, as boundaries become clearer and the existing body of knowledge better assessed, a new path can be chosen that involves crossing these boundaries. The emergence of collectively identified technology results in a change in the context of the group work of the companies participating in the project, shifting from system evaluations to demonstrations of technological viability. In other words, the existing stock of knowledge is not sufficient to make the concept a reality; therefore, at this stage, collaborative practices are required to expand the stock of knowledge. These practices are closely related to the concepts of "modeling" and "examination" suggested by Engestrom (1999) to analyze the cycles of knowledge creation in practice.

According to Engestrom (1999), modeling offers a solution to a problematic situation, whereas "examination" relates directly to the operation, with the potential of identifying the limitations of what was created. These conditions are similar to those emerging in the study of the FD-SOI 28 nm collaborative project. This reflects a broad need for dialogue among project partners based on trial, error and choices, which corroborates the findings of Kim and King (2004). These authors also conducted an interpretive study in the semiconductor industry using the method of grounded theory. As in this study, the "problematization" was representative of the process of knowledge creation experienced in the industry.

This change of context, which is provided in the development of course work, implies synthesizing the group's knowledge. In this sense, the search for synthesis generates practices called fractalization practices of knowledge in this knowledge. This new condition for changing the group's working context provides a new environment for members, signals the transition to the industrial scale, and leads to marketing the development activities. In other words, as the stock of knowledge on the transistor increases, new conditions arise, and new collaborative practices are necessary. Emerging from the industrialization period, the results confirm a trend in the use of new market research methods because conventional methods have been shown to be inefficient, as pointed out by IDEO (2015), a consulting firm for global projects and development. The foregoing shows that market surveys allow for the acquisition of important knowledge for further commercialization of the product.

This is the step knowledge gained during the project lifespan is internalized. Collaborative practices of knowledge creation used in this step are designed to crystallize or to make knowledge more substantial, such as in the form of a product that can be presented to the community. In turn, the collaborative nature of the practice is modified to become crystallization practices.

This research makes similar advances as Dyer and Singh (1998) made, as it uses the relational view to show what factors influence the adoption of certain collaborative practices of knowledge creation. It also extends the findings made by Tranfield et al. (2006) that indicate a set of collaborative practices in the creation of interorganizational knowledge for innovation. We identified types of knowledge and potentiated spaces for each of the 19 collaborative practices. It has been shown that companies that participate in collaborative R&D projects must configure multilayer "BA" networks proactively, which demands collaborative practices to synthesize tacit and explicit knowledge and to reap successful knowledge creation. The different practices throughout the life cycle of the collaborative project are responsible for the connection between tacit and explicit knowledge of the actors involved in the project. The dynamics of collaborative practices guarantee reproduction of the ambidextrous organization model, in which there is no dichotomy between the practices of exploration and exploitation; instead, the practices lead to a robust balance and a mutually complementary relationship in different phases of the project.

This study also provides a theoretical and conceptual framework that shows that the dynamics of collaborative practices in a project depend on the existing knowledge stock in the project, the type of knowledge to enhance and the strategy used at a particular project development stage. In other words, we propose a scheme that reveals 19 collaborative R&D practices of knowledge creation that trigger an ambidextrous process of innovation. The semiconductor industry has strategic importance for developing countries. Nonetheless, developing innovations at the speed required by this sector would be nearly impossible without collaboration agreements. The most common collaborative arrangements are collaborative R&D projects. Understanding the dynamics of collaborative practices in this type of inter-relationship can ensure effective project management in this specific sector.

In developing this research, we used intensive interviews with people who have relevant experience (Charmaz, 1995), which allowed us to closely examine a particular topic. However, the evident limitation in this technique is that the interviewee undergoes many other experiences between the time of the experience and the date of the interview, which means that they have been subject to learning opportunities and contexts that modify their point of view and interpretation of what occurred in the past.

Future studies may focus on assessing the impact of the characteristics of each collaborative practice (such as complexity, interdependence, uncertainty, frequency and duration) as well as on seeking to validate the proposed three-dimensional model of the many different types of practices that can emerge from such practice.

References

Ahn, J.H., Lee, D.J., Lee, S.Y., 2006. Balancing business performance and knowledge performance of new product development. Lessons from ITS industry. Long Range Plann. 39 (6), 525–542.
Assudani, R.H., 2009. Dispersed knowledge work –implications for knowledge intensive firms. J. Knowl. Manag. 13 (6), 521–532.
Balestrin, A., Vargas, L.M., Fayard, P., 2008. Knowledge creation in small-firm network. J. Knowl. Manag. 12 (2), 94–106.
Bizzi, L., Langley, A., 2012. Studying processes in and around networks. Ind. Market. Manag. 41, 224–234.
Blank, S., 2013. Why the lean start-up changes everything. Harv. Bus. Rev. 91 (5), 63–72.
Borgatti, S.P., Everett, M.G., Johnson, J.C., 2013. Analyzing Social Networks. Sage Publications, London, UK.
Boumgarden, P., Nickerson, J., Zenger, T.R., 2012. Sailing into the wind: exploring the relationships among ambidexterity, vacillation, and organizational performance. Strateg. Manag. J. 33 (6), 587–610.
Brown, S.L., Eisenhardt, K.M., 1997. The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations. Adm. Sci. Q. 42, 1–34.
Chen, Y., 2017. Dynamic ambidexterity: how innovators manage exploration and exploitation. Bus. Horiz. 60, 385–394.
Calamel, L., Defélix, C., Picq, T., Retour, D., 2012. Inter-organisational projects in French innovation clusters: the construction of collaboration. Int. J. Project Manag. 30 (1), 48–59.
Capaldo, A., Petruzzelli, A.M., 2011. In search of alliance-level relational capabilities: balancing innovation value creation and appropriability in R&D alliances. Scand. J. Manag. 27 (3), 273–286.
Capaldo, A., Petruzzelli, A.M., 2014. Partner geographic and organizational proximity and the innovative performance of knowledge-creating alliances. Eur. Manag. Rev. 11, 63–84.
Capaldo, A., Petruzzelli, A.M., 2015. Origins of knowledge and innovation in R&D alliances: a contingency approach. Technol. Anal. Strateg. Manag. 27 (4), 461–483.
Charmaz, K., 1995. Grounded theory. In: Smith, J.A., Arré, R.H., Van Langenhove, L. (Eds.), Rethinking Methods in Psychology. Sage Publications, pp. 27–49.
H. Constanti, 2012, Grenoble: Le vrai pouvoirdu CEA. L'Express. Revista de Grenoble, 80-83.
Corley, K.G., Gioia, D.A., 2004. Identity ambiguity and change in the wake of a corporate spin-off. Adm. Sci. Q. 49, 173–208.
Crossan, M.M., Apaydin, M., 2010. A multi-Dimensional framework of organizational innovation: a systematic review of the literature. J. Manag. Stud. 47 (6), 1154–1191.
Davis, J., Eisenhardt, K., 2011. Rotating leadership and collaborative innovation: recombination processes in symbiotic relationships. Adm. Sci. Q. 56 (2) 159–120.
Denzin, N.K., 1978. The Research Act: A Theoretical Introduction to Sociological Methods. McGraw-Hill, New York.
Dosi, G., 1984. Technical Change and Industrial Transformation – The Theory and an Application to the Semiconductor Industry. Macmillan, London, UK.
Dyer, J.H., Singh, H., 1998. The relational view: cooperative strategy and sources of interorganizational. Acad. Manag. Rev. 23 (4), 660–679.
Engestrom, Y., 1999. Innovative learning in work teams. Analysing cycles of knowledge creation in practice. In: Engestrom, Y., Miettinem, R., Punamaki, R. (Eds.), Prespectives on Activity Theory. Cambridge University Press, Cambridge, UK.
European Comission, 2011. Key Enabling Technology Ome. Disponível em: http://ec.europa.eu/programmes/horizon2020/en/area/key-enabling-technologies. Acesso em: 29 mar. 2015.
Felin, T., Foss, N.J., 2004. Organizational Routines: A Sceptical Look. Druid ? Danish Research Unit for Industrial Dynamics, Working Paper. Danish Research Unit for Industrial Dynamics, Denmark.
Fleming, F., Sorenson, O., 2001. Technology as a complex adaptive system: evidence from patent data. Res. Policy 30 (7), 1019–1039.
Glaser, B., Strauss, A.L., 1967. The Discovery of Grounded Theory. Aldine, Chigado, IL.
Grant, R.M., 1996. Toward a Knowledge-based Theory of the firm. Strateg. Manag. J. 7, 375–387.
Hatchuel, A., Weil, B., 2003. A new approach of innovative design: an introduction to C-K theory. In: Proceedings of the International Conference on Engineering Design (ICED'03). Stockholm, Sweden. pp. 109–124.
Hatchuel, A., Le Masson, P., Weil, B., 2005. The development of science-based products: managing by design spaces. J. Creat. Innov. Manag. 14 (4), 345–354.
He, Z., Wong, P., 2004. Exploration vs. exploitation: an empirical test of the ambidexterityhy pothesis. Organ. Sci. 15 (4), 481–494.
Heywang, W., Zaininger, K.H., 2004. Silicon: the semiconductor material. In: Siffert, P., Krimmel, E.F. (Eds.), Silicon: Evolution and Future of a Technology. Springer Verlag, Heidelberg, DE.
IDEO, 2015. Our Approach Design Thinking. Available at: https://www.ideo.com/ Acessed in 15 November 2015.
Inemeka, Aydin, Matthyssens, Paul, 2013. The impact of buyer–supplier relationships on supplier innovativeness: an empirical study in cross-border supply networks. Ind. Market. Manag. 42 (May(4)), 580–594.
Jakubik, M., 2011. Becoming to know. Shifting the knowledge creation paradigm. J. Knowl. Manag. 15 (3), 374–402.
Kapoor, R., Macgrath, P., 2014. Unmasking the interplay between technology evolution and R&D collaboration: evidence from the global semiconductor manufacturing industry, 1990–2010. Res. Policy 43, 555–569.
Kim, J., King, John., 2004. Managing knowledge work: specialization and collaboration of engineering problem-solving. J. Knowl. Manag. 8 (2), 53–63.
Kodama, M., 2003. Strategicinnovation in traditional big business. Organ. Stud. 24 (2), 235–268.
Kodama, M., 2011. Knowledge Integration Dynamics –developing Strategic Innovation Capability. World Scientific Publishing, Singapore.
Labatut, J., Aggeri, F., Girard, N., 2014. Discipline and change: how technologies and organizational routines interact new practice creation. Organ. Stud. Jan. 33 (1), 39–69.
Langley, A., Abdallah, C., 2011. Templates and turns in qualitative studies of strategy and management. Res. Method. Strat. Manage. 6, 201–235.
Lavie, D., Stettner, U., Tushman, M.L., 2010. Exploration and exploitation within and across organizations. Acad. Manag. Ann. 4 (1), 109–155.
Lavikka, Rita, Smeds, Riitta, Jaatinen, Miia, 2015. A process for building inter-organizational contextual ambidexterity. Bus. Process Manag. J. 21 (5), 1140–1161.
P. Le Masson, B. Weil, A. Hatchuel, 2006, Les processus d'innovation. Conception innovante et croissance des entreprises. Herme's, Paris; forthcoming English translation (2009) Strategy and management of innovative design.
Lounsbury, M., Crumley, E., 2007. New practice creation: an institutional perspective on innovation. Organ. Stud. 28 (7), 993–1012.
Möller, K., Rajala, A., 2007. Rise of Strategic Nets – New Modes of Value Creation Industrial Marketing Management 36. pp. 895–908.
Michaux, V., 2011. Articular as Competências Individual, Coletiva, Organizacional e Estratégica: esclarecendo a teoria dos recursos e do capital social. In: Retour, D. et al. Competências Coletivas: no limiar da estratégia. Bookman, Porto Alegre, BR.
Nobeoka, K., Dyer, J.H., Madhok, A., 2002. The influence of customer scope on supplier learning and performance in the Japanese automobile industry. J. Int. Bus. Stud. 33 (4), 717–736.
Nonaka, I., Konno, N., 1998. The conceptof BA bulilding a foundation for knowledge creation. Calif. Manag. Rev. 40 (3), 40–54.
Nonaka, I., Takeuchi, H., 1995. The Knowledge Creating Company. Oxford University Press, Oxford, England.
Nonaka, I., Toyama, R., 2005. The theory of the knowledgecreating firm: subjectivity, objectivity and synthesis. Ind. Corp. Change 14 (3), 419–436.
Nonaka, I., Toyama, R., 2007. Strategic management as distributed practical wisdom (phronesis). Ind. Corp. Change 16 (3), 371–394.
Nonaka, I., Von Krogh, G., 2009. Perspective-tacit knowledge and knowledge conversion: controversy and advancement in organizational Knowledge creation theory. Organ. Sci. 20 (3), 635–652.
Nonaka, I., von Krogh, G., Voelpel, S., 2006. Organizational Knowledge Creation Theory: evolutionary paths and future advances. Organ. Stud. 27 (8), 1179–1208.
Nonaka, I., Toyama, R., Hirata, T., 2011. Teoria e casos de empresas baseadas no conhecimento: Managing Flow. Bookman, Porto Alegre, BR.

Nonaka, I., Kodama, M., Hirose, A., 2014. Dynamic fractal organizations for promoting knowledge-based transformation –a new paradigm for organizational theory. Eur. Manag. J. 32, 137–146.
Petruzelli, A.M., 2014. Balancing knowledge exploration and exploitation within and across technological and geographical domains. Knowl. Manag. Res. Pract. 12 (2), 123–132.
Quintane, E., Casselman, R.M., Reiche, S.B., Nylund, A.P., 2011. Innovation as a knowledge-based outcome. J. Knowl. Manag. 15 (6), 928–947.
Schilling, M.A., 2009. Protecting of diffusing a technology platform: tradeoffs in appropriability, network externalities, and architectural control. In: Gawer, A. (Ed.), Platforms, Markets and Innovation. Edward Elgar Cheltenham, ENG.
Serenko, A., 2010. A scientometric analysis of knowledge management and intellectual capital academic literature (1994–2008). J. Knowl. Manage. 14 (1), 3–23.
Shih, W., Pisano, G., King, A., 2008. Radical collaboration: IBM microelectronics joint development alliances. Harvard Business Review.
Strauss, A., Corbin, J., 1998. Basics of Qualitative Research. Sage Publications, New York, NY.
Sun, P.Y.T., 2010. Five critical knowledge management themes. J. Knowl. Manag. 14 (4), 507–523.
Teece, D.J., 2007. Explicating dynamic capabilities: the nature and micro fundations of (sustainable) enterprise performance. Strat. Manage. J. 13 (28), 1319–1350.
Tidd, J., Bessant, J., Pavitt, K., 2005. Managing Innovation: Integrating Technological, Market and Organizational Change. Wiley Publications, New Jersey,EUA.
Tranfield, D., et al., 2006. Knowledge management routines for innovation projects: developing a hierarchical process model. In: Tidd, J. (Ed.), Knowledge Management to Strategic Competence. Imperial College Press, London, UK.
Turley, J., 2003. The Essencial Guide to Semiconductors. Pearson Education, New Jersey EUA.
Wilhelm, M., Kohlbacher, F., 2011. Co-opetition and knowledge co-creation in Japanese supplier-networks: the case of Toyota. Asian Bus. Manag. 10 (1), 66–86.
Zboralski, K., 2009. Antecedents of knowledge sharing in communities of practice. J. Knowl. Manage. 13 (3), 90–101.