Exploring over the Presumed Identity of Emerging Technology

Thomas Gillier[*], Grenoble Ecole de Management

Gerald Piat, EDF R&D

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ABSTRACT:

While scientists are stepping up their efforts to develop new technologies, the ability of firms to determine the value of their technologies by identifying potential applications has become a major challenge. This article focuses on a particular phase of technology development: the emergence phase. When a promising new technology first sees the light of day in a fundamental research laboratory, its target markets often seem plentiful but are ill-defined. The inability to produce prototypes or to identify potential users makes it difficult to explore potential commercial applications.

On the basis of four micro-nanotechnologies case-studies conducted within a multi-partner innovation project, this article aims to theoretically explain why the identification of applications from emerging technologies is not a trivial problem. That research analyses how technologists and non-experts interact during creative investigations on new applications. It shows that the technologists are victims of a form of cognitive fixation effect. Indeed, their beliefs and activities are guided by a stable cognitive representation of their technology: *the presumed identity of technology*. Based on a recent design framework, C-K Design Theory, the technological exploration process followed in our four case-studies is modeled and mechanisms to dismantle the presumed identity and to design an extended identity of technology are provided.

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[*] Address correspondence to: Thomas Gillier, Grenoble Ecole de Management, Centre pour l'Innovation Technologique et Entrepreneuriale, 12 rue Pierre Sémard, BP 127, 38003 GRENOBLE France. Tel : +33 (0)4 76 70 64 55. E-mail : thomas.gillier@grenoble-em.com

INTRODUCTION, OUTLINE AND RESEARCH QUESTION

Strategic management studies have shown that industries are shaped by technological trajectories, which structure the external environment and the value network of entire industries (Christensen & Rosenbloom, 1995; Dosi, 1988). Industrial contexts are frequently subject to dramatic technological shifts (Abernathy & Utterback, 1978). The effect can be radical, especially for firms trapped in a formerly dominant technological path [see the case of Kodak and the rise of digital photography (Christensen & Raynor, 2003)]. As noted by many authors, technology-based innovation has been argued to lead more often to “breakthrough” innovation than the firms that follow marketing-pull strategies (Newbert et al. 2007; Herstatt & Lettl 2004; Walsh et al. 2002). The development of emerging and enabling technologies, such as nanotechnologies, is frequently expected to impact almost every sectors of economy and to be the source of the next industrial revolution.

Economists acknowledge that a large majority of new products result from technological progress; efficiently managing the different stages of technology development by exploring valuable opportunities and alternatives is therefore a vital challenge for firms (Glaser & Miecznik 2009). This article deals with the design of new applications for science-driven emerging technologies. It refers thus to, the technological exploration stage, when research seems to indicate potential value but, unfortunately, the target markets are still unclear and the number of possibly unrelated applications is high.

During such upstream phase, information regarding customer needs, competitors and suppliers is often missing; the market uncertainty is high. However, given the massive R&D investments, the decision to pursue the development of the technology crucially depends on the sales potential of first applications. A quick and suitable identification of applications is always required.

From the initial presentation of emerging technology by technologists, that article aims to understand better how applications are created. Defining such first promising applications is still a difficult task and several pitfalls are reported by literature. These difficulties are often reported for general purpose technologies (Bresnahan & Trajtenberg 1995), for instance, (Shea, 2005) claim that nanotechnology “open up new opportunities rather than offering complete, final solutions” (p. 190). Burgelman and Sayles (2004) emphasize the danger in starting applications with what can be researched and evaluated easily, the risk of getting locked into one technical solution or the risk of addressing the needs of the atypical user. (Herstatt & Lettl 2004) point out that when new technologies are developed, the prospective points of entry into the market place are often limited to those that the organization currently serves. In other words, emerging technology is often viewed as a complementary or substitute solution and the opportunity to create entirely new business is neglected. According to the authors, detailed and all-encompassing examination of the technology's applicability would usually over-extend the intern team.

Therefore, our research question is: although emerging technology promises to revolutionize our way of life and economy, how can we theoretically explain the difficulties to design new creative applications? In order to investigate this research question, the article is organized as follows. First, in Section 2, a definition of the term "technology" is provided. Two main dimensions, Usage Dimension and Technical Dimension, and their interdependence are then discussed. Then, a quick overview of main creative design methodology is presented in accordance with our two dimensions-based framework. We briefly point out their limits when the *identity of the technology*, it means Usage Dimension and Technical Dimension, is ill-defined or not defined at all. Section 3 describes the research context, a multi-partner innovation project, the research methodology used and the four micro-nanotechnologies investigated. It also describes the research protocol, the D_4 method (Piat 2005), which permits to investigate the process of identifying emerging technology-based applications. In section 4, the empirical results of the case-studies are presented and these latter are then cognitively interpreted according to a recently-developed design framework, the C-K Design Theory (Hatchuel and Weil 2003; Hatchuel 2001; Hatchuel and Weil 2008; Elmquist and Segrestin 2009; Elmquist and Le Masson 2009; Gillier et al. 2010; Kazakçi and Tsoukias 2005; Reich et al. 2010). Then, a new theoretical notion, the *presumed identity of technology*, is introduced to explain why the process of finding emerging-technology applications is still hard. Methodological and theoretical guidelines to overpass this major cognitive trap are analyzed.

LITTERATURE REVIEW: EXPLORING EMERGING TECHNOLOGY

THE IDENTITY OF A TECHNOLOGY IN THE EMERGENCE STAGE: A DOUBLE UNSTABILITY

Some theoretical models already exist to give us an idea of what we should be focusing on when studying technology. For instance, (Faulkner & Runde 2009) maintain that the following two elements must be taken into consideration: the physical shape of the technology (i.e. its visible structure) and the functions of the technology (i.e. what it is used for).

In a more universal perspective, (Suh 1990) argues that every technical system, being tangible or intangible, can be depicted by the mapping between vectors that belong to four design domains: the customer needs, the functional domain, the physical domain and the process domain.

In the field of Science and Technology studies, (Bijker et al. 1989) propose the model of Social Construction of Technology to stress the fact that technology is shaped by human actions and usages. Contrary to Science, technology could not exist without the existence of applications (or usage), it is not strictly the production of technical knowledge, it also has to satisfy user requirements as utility, usability or safety. (Mitcham 1979), cited by (Custer 1995), provides a conceptual framework structured in four dimensions, a technology is composed of “(a) artefact (tools, manufactured objects, etc.), (b) knowledge (scientific, engineering, uniquely technological 'how to' knowledge, as well as insight from the social and physical sciences), (c) process (problem-solving, research & development, invention, innovation, etc.), and (d) volition (ethics, technology as a social construction, technology as a social force, etc.).” (ibid., p220). (Orlikowski 1992) conceptualizes the notion of technology and proposes the Structurational Model of Technology. This model posits technology as embodying structures (built in by designers during technology development), which are then appropriated by users during their use of the technology.

In common words, technology is defined as the involvement of technical knowledge to solve practical problems. According to (Geisler 2001), “Technology can be viewed as the outcomes from research that have found a use. So that, as soon as a use is identified, the term technology is introduced” (ibid., p135). (Arthur 2009) gives a basic definition by arguing that “Technology is a means to fulfill human purpose” (ibid., p7).

Although the existing definitions and models of technology incorporate some peculiarities, which will not be commented here, two interdependent dimensions are noticeable: thereafter they were referred to *(Technical Dimension, Usage Dimension) pair*. Technical Dimension (TD) refers to the phenomenological properties that give the technology its "shape", for example its physical and chemical properties (size, weight, volume, physical laws, energy consumption, style, etc.), the processes involved in manufacturing it, its environmental qualities (toxicity, biodegradability, etc.), technical functions and its economic characteristics (cost price, selling price, etc.). Usage Dimension (UD) covers how the technology will or may be used for, the users' needs and markets.

In respect to the well-known Axiomatic Design Theory (Suh 1990), Usage Dimension refers to Customer Domain (i.e. customer needs) and Function Domain (i.e. functional requirements and constraints), Technical Dimension is composed of Physical Domain (i.e. design parameters) and Process Domain (i.e. the process attributes) (cf. Table 1).

During its stage of emergence, by definition these two following dimensions are still not established: the boundary of the technical knowledge is still ill-defined and the targeted usages are not defined and not validated. As a consequence, finding applications consists in formulating the adequate *pair (Technical Dimension, Usage Dimension)* that leads to the definition of *the identity of the technology*.

In comparison to brand marketing literature, research on design makes few references to the notion of identity except two noteworthy research works. In the innovation intensive context, (Le Masson et al. 2010) pointed out the capacity of innovative firms to successfully change the identity of objects by exploring new functions, values, business model and so on. (Faulkner & Runde 2009) use the notion of identity to analyze the evolution of technical objects, for example, the authors studied the turntable's transformation into a musical instrument for DJ.

Our approach is quite different but complementary. First of all, it is interesting to notice that these authors carefully study the mutation of the identity of the objects. But, in order to study such phenomena, a first identity is supposed to exist. That article does not investigate the change from one identity to another one but, more particularly, on the creation of a first identity. How is an identity established and assigned? Secondly, at the stage of technological emergence, as the applications (i.e. objects) are not known in advance, research cannot focus on objects but on *the technology* itself. Furthermore, one object can be made of numerous technologies and thus, the study of the identity of the technology seems not to be derived from the study of the identity of the object.

		Identity of The Technology (TD, UD)	
		Technical Dimension	Usage Dimension
Axiomatic Design Theory (Suh 1990)	*Customer Needs*		*X*
	Functional Domain		*X*
	Physical Domain	*X*	
	Process Domain	*X*	

Table 1.The identity of the technology mapped with Axiomatic Design theory

FINDING APPLICATIONS FOR EMERGING TECHNOLOGY: A DILEMMA FOR THE CREATIVE DESIGN METHODOLOGIES

This section quickly reviews main creative design approaches in science-driven industry and gives the reasons why such methodologies seem to be limited to explore the applications of emerging technology. Indeed, classically, literature on technology management is frequently involved in two contrasted way. In the first approach, the TD is neither revised nor modified; only UD is investigated. The technology is directly applied to investigate new offers for customers. Conversely, in the second approach, the UD is poorly explored and firms focus only on TD. In this latter approach, technology is considered as a powerful means to address technical problems. Contrary to these two approaches, exploring emerging technology requires to explore both UD and TD.

TD stable – UD unstable: Integrating the customers' voice into technology-driven innovation

In this first approach, the performances of the technology are known, technical aspects are stable; prototypes may exist. A main objective is to find new usages in order to design creative products in accordance with the established technology.

In this perspective, several researchers emphasize the crucial role of "Lead-Users" in science-driven industry (Urban & Von Hippel, 1998; Kim & Garisson, 2010). Furthermore, several authors have stressed the value of experimentation with rapid prototyping in high-technology context to foster creativity, and to identify potential future users and competitive advantage (Thomke 1998). (Lynn et al. 1996) show through case studies that an iterative "Probe and Learn" process is best suited to the peculiarities of "technology push" projects. Such iterative process permits to integrate customers in the technological development process in order to successively gain market information while refining the prototypes.

In a different perspective, (Souder 1989) proposes a three-step method for technology-driven innovation. The potential applications are identified through the analysis of technology's attributes in terms of needs it could potentially fulfill. Second step is a creative session with interdisciplinary teams to integrate the demand-side aspects and third step is the evaluation of the ideas produced. In a similar perspective, (Henkel & Jung 2010) propose a more dynamic view of customer's needs by deducing the trends from the functions of the studied technology and then, to identify industries and market segments in which these trends are important.

TD unstable – UD stable: Finding inventive solutions to technical problems

In the second case, conversely, the UD is stable and TD is unstable: an initial application already exists but it has to be optimized. In that case, new technologies are investigated in order to outperform the actual technologies, one of the major challenges here are to choose the appropriate technologies. In that perspective, in order to improve their capacity to recognize technological opportunities and to forecast new technology in terms of performance and maturity, firms resort to sophisticated tools like technology roadmaps or patent analysis systems (Lee et al., 2009). Besides, several creative methodologies are proposed to efficiently manage the technology portfolio of organizations. Generally, these methods have significant technological components, and hence require strong technical skills. The Delphi method (Linstone & Turoff 1975) aims to establish a consensus on the future role of a technology, using a specific protocol to obtain the informed opinions of a panel of experts. This method is usually combined with technical meetings, during which possible pre-existing applications are discussed. In a more open perspective, (Heiss & Jankowsky 2001) propose a technology management system allowing not only experts but all engineers to participate in the technology management systems. This method proves to be particularly powerful to identify what technology a future known product will require.

Furthermore, such strategy fits well with the implementation of creative design methodologies like, for example, TRIZ method of inventive problem solving (Altshuller et al., 1999). From the analysis of a technical system, TRIZ methodology proposes several interesting inventive principles, such as the use of laws of evolution or the concept of physical contradiction (Savransky 2000; Moehrle 2004; Cavallucci et al. 2009), to significantly improve or even create innovative products. In a recent publication, a TRIZ-based tool called "reverse inventing” for strategic market research has been developed and tested (Glaser & Miecznik 2009).

Still, such methodology requires the existence of an initial technical system in order to define contradictions and it has not been proved to be successful in creating radically new business markets.

TD unstable – UD unstable: the critical situation of emerging technologies

As argued previously, classical view in the literature seems to assume that either UD or TD is clearly known at the beginning of the design process. As explained above, during the stage of emergence, the usage and technical boundaries of a technology are unknown at the beginning of the design process. Indeed, the design process cannot be guided by the needs, problems or behavior of (lead) users (Ortt et al., 2007). The same limitation appears for the prototypes. The cost of developing emerging technology is sometimes so prohibitive that it is often impossible to produce limited series. Emerging technology-based applications need to be imagined without prototypes and users. Regarding TRIZ methodology, technology provides a means of solving technical problems: but, what “problems” does an emerging technology present? How can needs that do not even exist, be converted into contradictions?

EMPIRICAL MATERIALS AND RESEARCH METHODOLOGY

MINATEC IDEAS LABORATORY®: AN INNOVATION PLATFORM FOR EXPLORING EMERGING TECHNOLOGIES

This research project was conducted at MINATEC IDEAs Laboratory, a French multi-partner innovation platform located close to the micro-nanotechnology research campus MINATEC. MINATEC IDEAs Laboratory is a new type of organization, which brings together a group of partners with varying skills and knowledge around exploratory projects on emerging technologies (Ben Mahmoud-Jouini & Charue-duboc, 2008; Segrestin, 2005). In 2008, when this research project was carried out, MINATEC IDEAs Laboratory comprised six industrial partners from different market sectors (energy production, automotive industry, sport, optics, etc.) and two universities, and it focused essentially on new technologies developed by the French Atomic Energy Agency (CEA). As they operated in such diverse sectors, the partners were not interested in the same target markets. However, they agreed to pool some of their resources and to explore these new technologies together. Each reserved the right to independently develop its own applications later on. This type of collaboration is possible because the markets for micro-nanotechnologies have not yet been identified. Joint, multi-partner research is seen as an effective means of exploring the range of potential applications for micro-nanotechnologies and of identifying new market opportunities.

COLLABORATIVE RESEARCH METHODOLOGY

This research was part of a collaborative research program involving both academic researchers and experts from various sectors (Adler et al., 2003). In all, 35 different people were involved in the case-studies. The aim of this type of research is to collectively produce new knowledge, which is both scientifically valid and actionable (Argyris, 1993). Therefore, the contributors involved in the research project are committed to action; according to (Coughlan & Coghlan, 2002), this commitment is necessary to conduct "research in action, rather than about action". This research methodology enables researchers to work in close proximity with the experimental context and hence to access a wealth of data on the innovation process. This approach is particularly recommended for this type of qualitative research, as it allows researchers to refer effectively to both theoretical models and the experimental context, and to adjust the experiments accordingly.

MULTI-CASES STUDIES OF FOUR MICRO-NANOTECHNOLOGIES

The results obtained in this research are the outcome of an empirical inquiry based on four case-studies (Einsenhardt, 1989) which were conducted at MINATEC IDEAs Laboratory between 2007 and April 2008. Each of these four workshops involved technologists from the CEA and a group of industrialists who, it was assumed, had little (or no) knowledge of the above technologies. These one-day workshops involved a dozen people from different professions (engineers, sociologists, marketers, industrial designers, artists, etc.); each partner was represented by at least two people. All the workshops were recorded and filmed. These case-studies dealt with four emerging micro-nanotechnologies developed by CEA:

- ElectroWetting-On-Dielectric or EWOD (case-study #1): EWOD is a technology for manipulating small quantities of liquid (droplets measuring just a few microns) on an electrode coated with a hydrophobic dielectric film. The droplets on the electrode can be lifted and moved by applying an electric field (Pollack et al. 2002).
- Carbon Nanotubes (case-study #2): Carbon nanotubes are very small structures with high performance characteristics: from a mechanical point of view, they provide excellent rigidity and are extremely lightweight. In addition, they have remarkable optical, electrical, chemical and thermal properties.

- Managy (case-study #3): Managy is an energy-autonomous chip incorporating multiple sensors. The data thus captured can be transmitted remotely. Eventually, it should be possible to integrate Managy into existing products to provide new functionalities (information on tire adhesion, an aircraft wing supervision system, electronic shoes, etc.).
- ElectroMechanical Energy Harvesting or EMEH (case-study #4): EMEH is an energy harvesting system based on Lenz's law. It uses a coil, a moving magnet and a mechanical energy source (such as a push-button) to convert mechanical energy into electrical energy. The mechanical energy used to push the button is converted into electrical energy, which can then be stored and used to supply a low-consumption system.

EXPERIMENTAL PROTOCOL

In order to deeply investigate the process under which the applications-based emerging technology are identified, the four case-studies were based on a specific method - the D_4 method (Piat, 2005) - which had been empirically tested a few times beforehand in internal EDF R&D projects. This method has been chosen because it permits to explore both TD and UD.

The D_4 method (Gillier & Piat, 2008; Piat, 2005) comprises four stages. In order to deepen the reader's understanding, an example derived from case-study #1 is given:

- Stage 1 / Deconstruction (expected duration: 1h30): Technologists play a central role in this stage, which aims to describe the phenomenology of the technology through its properties (physical, chemical, mechanical, electronic, etc.), and its main areas of application. The technologists are asked to describe, in the most exhaustive way, the Technical Domain of the technology. At the same time, the participants ask questions to the technologists about properties. The purpose of this stage is to provide as much details as possible on the technology. The technologists are free to choose their presentation tools (slideshow, documents, films, mock-ups, etc.).

  Example:

  TD_1: Enables the displacement and manipulation of droplets

  TD_2: Works within a large temperature range (0 < T< 100°c)

  TD_3: Can displace liquids on large surface

- Stage 2 / Declension (expected duration: 1h30): In this stage, technologists and participants identify some elements of Usage Dimension, i.e. for which functions the technology are (or might be) used. These possible uses are identified by combining the elements of TD described in the previous stage.

  Example:

  TD_1+ TD_2+ TD_3 = It is possible to spread droplets over a large surface within a large T° range

  TD_1+ TD_2+ TD_3 → UD_1 = Cool down or heat up a surface

- Stage 3 / Destination (expected duration: 1h30): This stage focuses on how the technology might be applied in one or more specific industrial sectors - sport, home automation, surveillance, protection, etc. - on the basis of the UD identified previously. This stage is equivalent to more conventional brainstorming sessions. The output of that stage is the definition of possible applications, that is to say the determination of several (TD, UD) pairs.

  Example:

  $(TD, UD)_1$ = A new frost-resistant windscreen for automotive industry

  $(TD, UD)_2$ = A new underfloor heating for building industry

- Stage 4 / Destination (expected duration: 1h): In this final stage, the technologists and the participants review the ideas of applications put forward in depth; the aim is to perform an initial assessment of the quality of the ideas, and to determine how compatible they are with the technology in question. In other words, this stage aims to select the best (UD, TD) pairs generated in the previous stage. The main purpose of this stage is to build on the ideas by considering how they differ from current applications of the technology, and who could make use of them and how. In regard to the robustness of the idea, two main questions are discussed: how would the technology have to be changed to make the idea feasible? Do more appropriate technologies already exist? Hence this final stage is also an opportunity to identify potential new avenues of research.

  Example:

  $(TD, UD)_1$ is negatively assessed by the technologist because the current technology is cheaper.

  $(TD, UD)_2$ is positively assessed by the technologist because it is thickener than existing products.

INTERPRETING THE RESULTS WITH A DESIGN FRAMEWORK: THE C-K DESIGN THEORY

In order to analyze the process under which new applications were found out from emerging technologies, we propose to investigate the results of our observation through a specific and recent design reasoning framework: C-K Design Theory (Hatchuel, 2001; Hatchuel and Weil, 2003; Hatchuel and Weil, 2008).

C-K Design Theory is a framework based on the interplay between two different spaces – a space C of concepts and a space K of knowledge (see Figure 1). The knowledge space models everything that is known by a designer (or a group of designers) : technical knowledge, user preferences, market studies, standards and regulations, etc. According to the theory, the knowledge space contains all the propositions that the designer can prove true or false.

The concept space, on the other hand, contains new ideas (concepts are relative to the knowledge space of a given designer). According to the theory, such undecidable propositions do not have a logical status at the start of the design process. The designer cannot say that they are possible, and neither can he say that they are not (e.g. “an eco-friendly-super-strong glue”).

Design starts with a disjunction process upon which a concept is formulated. It can be built progressively and detailed by partitioning (i.e. by adding or subtracting new properties). The resulting structure is a tree spanning from the initial concept .When a new and unprecedented property is introduced into the tree (by partitioning), a new definition is created and the identity of the object is changed – which may or may not lead to innovation. Such operations are called conceptual expansions or expansive partitioning (e.g. “an eco-friendly-super-strong glue” + “easy to remove if necessary”). New concepts that emerge as a result of this process should be investigated, built and validated in the knowledge space. This often requires the development of new knowledge - the expansion of the knowledge space. Hence the design process can be described as the interaction between two spaces: knowledge is used to elaborate on product descriptions in the concept space, while concepts are used to reorganize and expand the knowledge space. Design stops when a proposition that was previously undecidable becomes decidable in K.

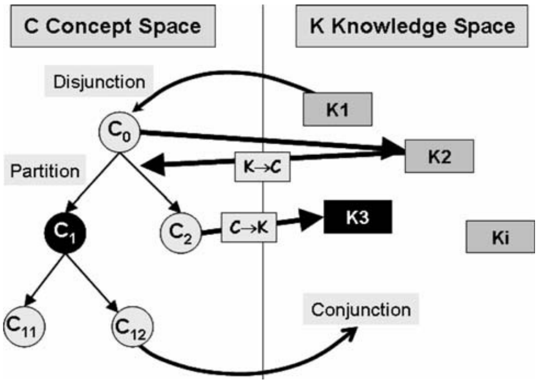

Figure 1. C-K design formalism (Hatchuel & Weil, 2008)

ANALYSIS AND INTERPRETATION OF RESULTS

ANALYSIS OF RESULTS

This section reports two main observations made during the four case-studies about the process that leads to the determination of new and unsuspected applications (1.). Then, C-K Design Theory is used as a “microscope” to analyze and model such process in details (2.). Details regarding the process by which the identity of technology is first deconstructed and then revised are provided. For reasons of clarity and convenience, these two major observations proposed in the next sections are only exemplified and modeled with examples coming from the EWOD case-study. However, the most significant data of the four case studies are merged and summarized in the appendices (see Table 2).

REVEALING UNEXPECTED FIXATIONS FROM THE TECHNOLOGISTS TALKS

Surprisingly, when presenting the technologies during the beginning of the first phase of our research protocol (i.e. D_1/Deconstruction), we systematically observed that the technologists present only some elements of TD. These well-mastered elements of TD were strongly and implicitly linked to some specific elements of UD. In this upstream stage, the technologists communicate their personal and restrictive representation of the identity of the technology: they deconstructed *the presumed identity of the technology* [1] (see Figure 2).

The term "Presumed Identity" was initially proposed by Prof. Armand Hatchuel (Mines ParisTech). The authors thank him for this insightful suggestion.

For instance, in the EWOD case-study, the technologist focused repeatedly on biomedical applications toward the case of "lab-on chip": "we are going to manipulate liquids [TD] to create lab-on-chip devices [UD]", "each droplet [TD] can be manipulated independently [TD] of the others like a micro-pump [UD]", "we carried out tests on biochips [UD] and it appears that any conducting liquid [TD] can be displaced", "so far, the droplet [TD] has been moved in a straight line [TD] because this is what our applications require (i.e. lab on chip [UD]), but they can also be made to move along a curved line [TD] "…

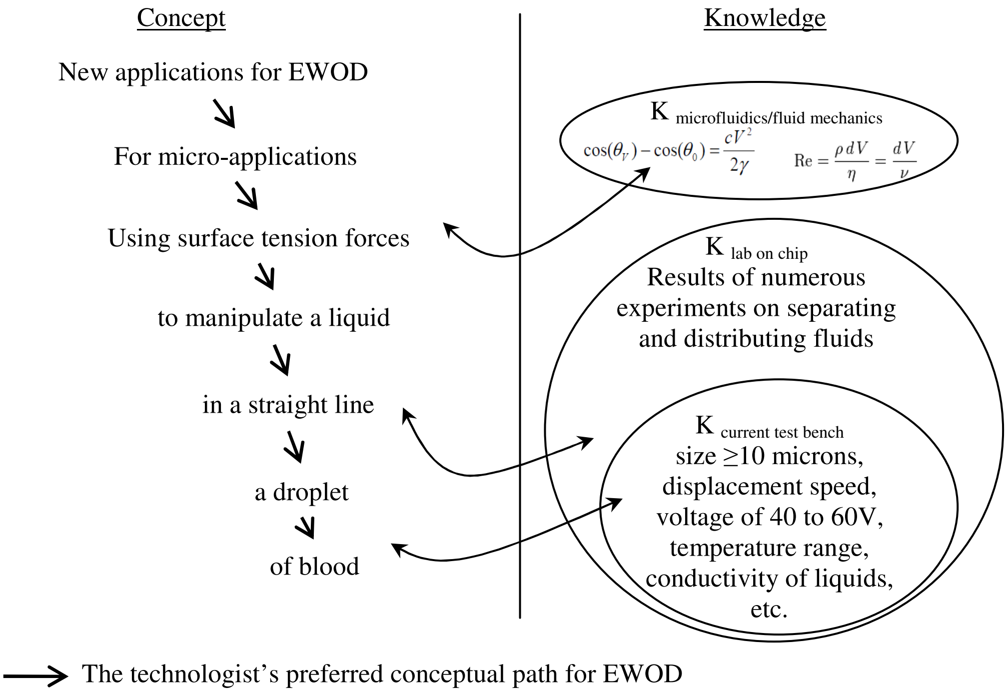

Figure 2. Deconstruction of the presumed identity of EWOD

OVER-PASSING THE UNEXPECTED FIXATION FROM THE DEBATES

Then, the debates between technologists and participants that took place from the end of the stage 1 to stage 4 was a fruitful opportunity to observe how the presumed identity of the technology is extended step by step to determine new and unsuspected applications (cf. figure 3).

Our observations revealed that some properties were implicit or had been completely overlooked by the technologist. When some of these properties were mentioned, the technologist was rather surprised: "displace soap bubbles? It should work. We could try moving bubbles through a liquid first and then bubbles on their own. We'll have to see, if they don't burst, why not"? or "displace a liquid as viscous as honey? It might work but very,

very slowly". Thanks to the participants' suggestions, properties that the technologist was aware of but didn't really use any more were revealed: "I've already seen that somewhere, I think it was at Alcatel-Lucent". In some cases, the technologist was hesitant and unable to confirm the validity of a proposition on the basis of his knowledge: "it has never been done, but displacing large pools of liquid should be possible. I'll need to check" or "developing slabs containing lots of electrodes would no doubt be very difficult, but it is feasible."

During the second and third stages of the D_4 method, we observe that the work group no longer focuses its attention on the presumed identity of technology but on some odd elements that had been poorly investigated by the technologists. These elements present technology from a different perspective and open up new avenues in terms of applications.

For example, a participant suggested using EWOD in glassmaking: "if I combine the fact that EWOD allows two immiscible phases to cohabit with the fact that the surface can be large, I obtain a function that consists in modifying optical properties (such as reflection). For instance, in glazing. Depending on the amount of sunlight, I can increase or decrease the amount of droplets to change the opacity of the glass and hence filter out the sun as required". The technologist, thinking out loud, decided that “Yes, that would involve manipulating thin films. I'm sure it's feasible". Another participant immediately coped with a new idea: “if we can displace two liquids, and bring them into contact to trigger a chemical reaction: for example, the development of air pockets in certain places or an explosion. It could be useful for generating minor detonations in hard-to-access places, for example airbags".

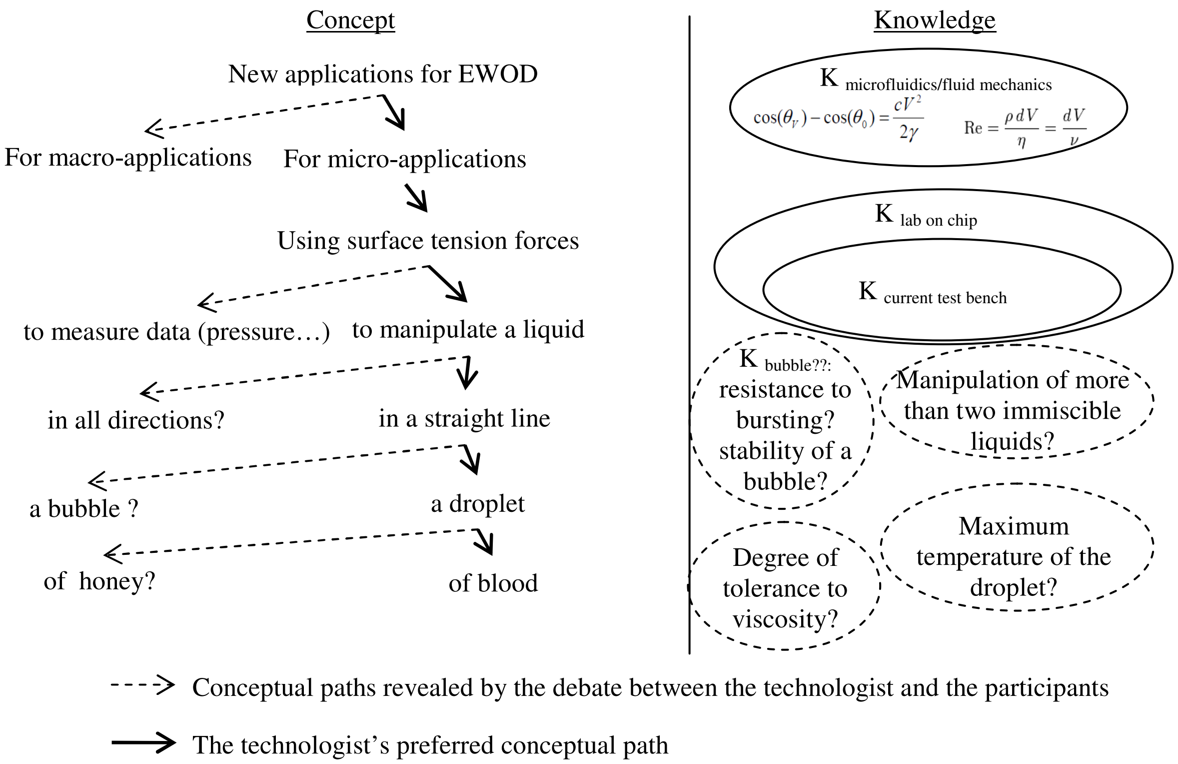

Figure 3. Challenging the presumed identity of EWOD

INTERPRETATION OF RESULTS

INTERPRETING THE "PRESUMED IDENTITY" OF AN EMERGING TECHNOLOGY WITH C-K DESIGN THEORY

During the beginning of the first stage of the case-studies – the deconstruction phase – the technologists presented the properties which, in their view, were fundamental. We observe that the technologists did not provide all-inclusive pockets of knowledge, but based their presentations on implicit usages. To summarize, we observe that technologists limited their presentation only to few known (UD,TD) pairs. Although the four technologies were in the emergence phase and had not been clearly defined, the technologists assigned an initial identity to them: the *presumed identity*. Indeed, the technologists did not present the technologies in a neutral way but, to demonstrate their potential interests and advantages, they often highlighted technologies within specific situations where it seemed easier to reveal and show their interesting properties. In order to describe technology, the technologists selected some elements of TD in accordance with known UD.

According to our framework, we interpret our observations as the fact that the technologists present their technology as a *design solution* (Simon 1969). They presented a sequence of actions – i.e. a series of attributes – in the C space, and each attribute related to specific knowledge pockets! For the technologists, the technology is the result of the technologists' efforts to address the challenges and satisfy the constraints of an implicit problem. For instance, the technologist stated that the design of accurate bio-medicals applications with EWOD (i.e. the problem) would be performed by applying an electrical field (property 1 of the design solution). This allows the displacement of droplets (property 2 of the design solution) over a distance of *x* mm (property 3 of the design solution), in order to trigger chemical reactions (property 4 of the design solution) and so on. The technology's presumed identity is, in fact, a design solution, i.e. a series of properties that are used to validate specific concepts.

The above events can be interpreted as follows: technologists present their technologies via specific concept spaces and knowledge spaces; technologists seem to develop a *fixation effect* on certain knowledge (cf. Figure 4).

(Smith et al. 2010) broadly define fixation effect as "a persistent and implicit use of knowledge that is inappropriate and counterproductive". Cognitive psychologists have extensively studied fixation effects (German & Barrett, 2005; Jansson & Smith, 1991; Purcell & Gero, 1996). For instance, in the scope of idea generation, when an example of ideas is previously given, the participants often incorporated some features of the example in the ideas produced (Landau & Lehr 2004; Smith et al. 1993).

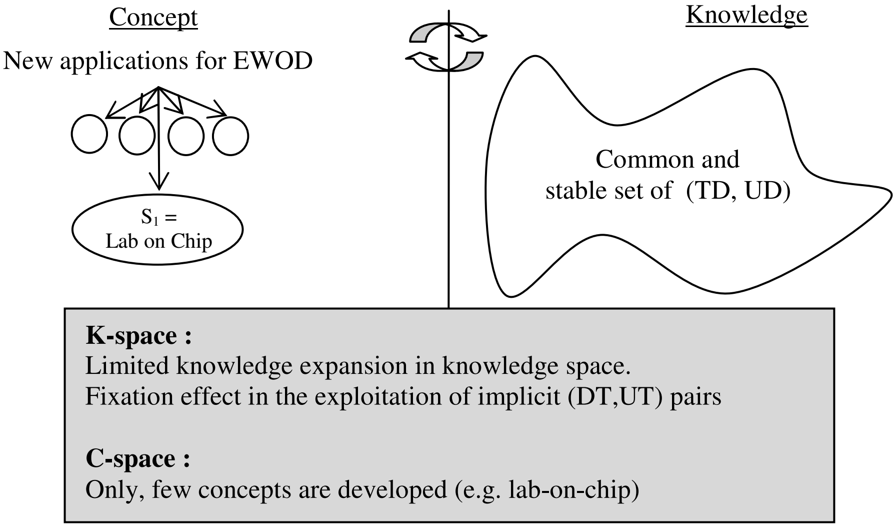

Figure 4. The Presumed Identity of Technology: a Fixation Effect modeled with C-K Design Theory

The analysis from the end of the stage 1 to the stage 4 clearly shows how the presumed identity is revised by the social interactions between the technologists and the participants. Our research protocol is therefore of primary importance in the sense that it reveals the technologists' preferred conceptual paths, restores knowledge originally concealed by these paths (reactivation of existing knowledge) and identifies new properties.

Thanks to C-K Design Theory, we could analyze the major cognitive processes (see Figure 5). First, the technologists' concept space is gradually rebuilt by a *process of departitioning*. In order to understand well the technology and its validity perimeter, the participants ask the technologists about elements of TD or UD that were implicitly known by the technologists. The emergence of these new elements gives the technology an extended identity and reveals the limitations of the technologists in terms of concepts and knowledge.

Then, from the end of stage 1, because participants tried to find undecidable (ex. EWOD technologist: "it depends. I don't want to say no, but I'm not sure") or overlooked elements of TD and UD, the technologists are challenged and their *knowledge and concept spaces are expansioned.* In the phase 2 and 3, we observed *expansions of TD*. Conversely, we observed that new applications were derived from *expansions of UD*. These expansions can be done due to the fact that participants come from different market sectors (energy production, automotive industry, sport, optics, etc.) and they challenge the technology with usage and needs that belong to their specific business.

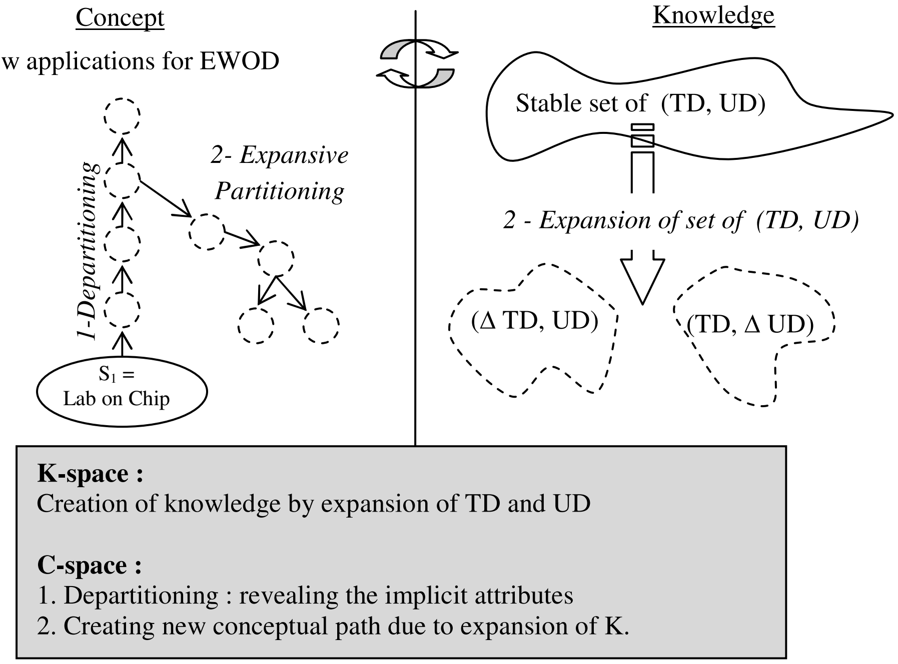

Figure 5. Exploring over the Presumed Identity of Technology

CONCLUSION AND DISCUSSION

MANAGERIAL AND THEORETICAL CONTRIBUTION

Given the rising cost of R&D, research policies now require that the production of scientific knowledge be strongly linked to sales potential from the earliest stages of the technology development process. This article aimed to better understand the difficulties to manage emerging technology like nanotechnology (Shea 2005; Adner & Levinthal 2002; Bucher et al. 2003; Linton & Walsh 2008). This article specifically focuses on the technological emergence phase, when the identity of the technology is not yet established and further development work is required. In that phase, albeit the emerging technologies are promising, managers and scholars frequently mentioned the difficulty to identify valuable commercial targets. How can one theoretically explain this trap? How can one overpass it?

One of the most important results of our research consists in clarifying the process of exploring new technological applications from both a theoretical and an empirical point of view. Indeed, we argue that exploring a technology fundamentally consists in knowing simultaneously what the technology is (i.e. Technical Dimension) and what it can do (i.e. Usage Dimension). In other term, finding applications of a technology corresponds to designing the identity of the technology. That quite simple definition permits us to understand deeper the reasons why it is so difficult to find new applications from emerging technology. We identify two main reasons.

A first reason concerns the foundation of classic design creative methodologies. Practitioners have extensively used many of them and their implementation has led to develop several successful and innovative products. Their diversity of scope enables to cope with usage and technical oriented issues. However, according to us, it is often hard to use the existing creative methodologies for designing emerging technology-based applications. We explain such difficulties by the fact that they have not been conceptualized for the simultaneous exploration of UD and TD. In fact, according to us, classical view in the literature seems to assume that either UD or TD is stable at the beginning of the design process. Indeed, based on a given technology, it is possible to design new uses. Conversely, based on known uses, new Technical Dimension can be imagined. The inability to identify potential users or to create prototypes makes it difficult to explore emerging technologies. So what is the solution? How do we explore markets that don't exist with technologies that only just exist? How can we proceed if usage and technical boundaries are unknown at the beginning?

Then, a second reason to explain the difficulties to extend the alternative of new commercial applications has been found by analyzing our empirical observations with a design framework. After observing the technologists's opinions and statements, it was concluded that they reason like designers: they present technologies as providing a specific solution. During the first stage of our research protocol, technologists describe technology as a way to reach a goal, a means of "changing an existing situation into a preferred one" (Simon 1969), which is the definition itself of design work. Therefore it can be argued that the *reasoning processes of technologists are identical to design reasoning processes.*

The knowledge expressed by the technologists was permanently linked to their conceptual perception of the technologies. The technologists were fixed in their approach: their search for ideas and their research were strongly influenced by the concepts they used. Although the technical and commercial possibilities of emerging technologies are not clearly defined, technologists attribute an initial identity to them: a presumed identity.

It is important to point out here that there is a fundamental difference between the work of scientists and that of technologists. Unlike scientists, technologists do not only present knowledge structures, but they continually link their knowledge to one or more concept space models symbolized by applications (Dunbar 2001). Technologists do not discuss the state of the world, they do not present only structured knowledge, but they discuss a means of transforming the world through the links between concepts and knowledge.

Face to the presentation of technologists, the reactions of the participants resulted in the deconstruction of these identities and the identification of the concept paths preferred by the technologists. The next stages in the research protocol were to start reconstructing the identity of the technologies by exploring new and unsuspected properties and functions. Not only did this new identity encourage the technologists to reconsider their existing knowledge and to explore new areas of knowledge, but it also pushed them to reassess the range of validity of technology and identify new applications.

In one respect, this research shows that technology exploration involves a series of design processes, the aim of which is to successively manage several knowledge and concept spaces. We believe that finding applications should not simply consists in screening markets according to a technology's presumed identity, but also in extending this presumed identity and hence reveal previously unsuspected areas of application.

LIMITATIONS AND FURTHER RESEARCH

Although this article is based on a multi-case study, it is still far from a generic model of technological exploration of the nature of cognition in science (Dunbar 2001) and of design (Simon 1969). Two main directions of research can already be highlighted: the importance of design fixation effect (Jansson & Smith 1991; Purcell & Gero 1996), not only regarding creative topics, but in the global management of the R&D activities and the implementation of new creative methodologies in upstream process of science-based industry.

First of all, the nature of the presumed identity of technology needs to be further studied. Still questions remain: can one measure the intensity of these psychological barriers? Does the presumed identity vary according to the technologies? More generally, our results invite us to rethink about the notion of fixation effect. Previous research works have highly criticized the negative impact of fixation effect in creativity. But is the fixation effect ever so "counterproductive" (Smith et al. 2010)? Although our case-studies revealed that the presumed identity prevents covering a wide-ranging scope of applications, the results of our case-studies also pointed out that the presumed identity enables technologists to systematically stock and exploit their rich knowledge. From this new angle, presumed identity of technology also seems a powerful vehicle of learning, which enables technologists to organize large volumes of complex knowledge. So, who should be in charge of over-passing it? Would it be the responsibility of technologists or of the innovation managers?

Then, this article suggests more research in the field of creative design methodology in science-driven innovation. Effective methods for finding technology applications are extremely important in the early stage of innovation process (Brem & Voigt, 2009, Khurana & Rosenthal, 1998, Reid & de Brentani, 2004). According to our research, D_4 method is useful for finding technology-based applications with cross-functional teams (Griffin & Hauser 1996; Troy et al. 2008). However, a more careful comparison of D_4 method with other existing methods is required (see (Henkel & Jung, 2010)). More particularly, D_4 method seems to have similarities with Souder's methods (1989): they both start with an examination of technology's attribute. Our research shows that a technology is composed of many attributes and the selection of the most promising properties is not obvious. In order to select and to assess the possible applications, linking D_4 method with technology roadmapping methods such proposed, for instance, by (Oliveira & Rozenfeld 2010; Caetano & Amaral 2011) may be beneficial.

In this research, we use C-K Design Theory to theoretically analyze the exploration process. It has been still poorly implemented in organizations (Elmquist & Segrestin 2009; Gillier et al. 2010) and more researches are required. According to us, it could be interesting to use simultaneously the main principles of C-K Design Theory and D_4 method. C-K Design Theory would be useful to formally represent the evolution of the identity of technology, to drive the design process, while D_4 method would be used to create and develop the surprising and emerging properties and functions. In addition to this, further research should more precisely focus on the UD and TD expansion. How do we know what expansions to do? Regarding C-K Theory, operators that give directions to the exploration process seem missing: what is the rationale behind the choices of exploring one partition rather than another one?

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APPENDICES: SUMMARY OF SIGNIFICANT DATA

Case-Studies	The presumed identity expressed by the technologists		Toward a new identity
	Short description of the design solution	Examples of stable (TD ; UD)	Properties revealed by the debates → Unexpected ideas of applications
#1	*The problem:* Accurate bio-medicals applications with EWOD *Properties of the solution:* applying an electrical field, displacement of droplets, over a distance of *x* mm…	• (to manipulate liquids ; lab-on chip) • (blood droplets, lab-on chip)	• co-existence of two immiscible phases → glass that filter out the sun as required • to displace and mix two different chemical liquids → generating minor detonations in hard-to-access place
#2	*The problem:* High performance materials with carbon nanotubes (CN) *Properties of the solution:* doping process, depends on the quantity of CN, depends on the distribution of CN in the material…	• (mechanical resistance ; CN doping for high performance material) • (thermal conductance ; heat evacuation)	• carbon nanotube absorb luminosity → black ink forever • photon recovery→ camera and imagery
#3	*The problem:* Monitoring products with Managy *Properties of the solution:* integrates a variety of sensors, energy autonomous, …	• (energy harvesting ; active RFID tag) • (low energy ; autonomous sensors)	• Large temperature range (–20°C - 80°C) → hard conditions captors • small RF devices → mobile sensors mesh network
#4	*The problem:* Battery-free products with EMEH *Properties of the solution:* conversion of mechanical energy into electrical energy, with a coil, with a moving magnet…	• (portable device ; TV remote control) • (low energy supplying LED lightings)	• large-sized button → energy havesting of pedestrian crossing • Accurate tuning of energy production → Accurate dosing of medical syringe.

Table 2. Summary of the presumed and new identity of the four case-studies