METAPHORS' LIFE IN KNOWLEDGE COMBINATION

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TRACK: PROCESSES

This work deals with a process of continuous innovation, whereby actors with different skills need to find ways to combine and recombine their knowledge. Within a distributed way of organizing activities, we will show how metaphors inhabit and are central in a distributed process of innovation.

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ABSTRACT

Metaphors play a privileged role in a process of knowledge combination. While previous studies mainly focused on a specific metaphor and its impact in turning points of a scientific discovery, less is known on the dynamics of a collection of metaphors within an innovative project and how they act as dialogical tools. We show that when processes have a multidisciplinary nature, communication is populated by a multitude of metaphors that act and interact over time and with different roles. Through an historical reconstruction of a multidisciplinary scientific project, we analyse a collection of metaphors in the communication among scientists, study their different function and evolution in relation to the project advancements. We contribute to the research on metaphors in innovation by showing that (i) a process of knowledge combination is not based on just one metaphor, then (ii) by illuminating the dynamics of the ecology of metaphors: some persist; others are discarded after their use; while others remain in the rhetorical background.

METAPHORS’ USES AND LIFE

The metaphors is defined as “a figure of speech in which a word or phrase is applied to an object or action to which it is not literally applicable” (Oxford English Dictionary). After being relegated for long time to the peripheral domain of language artifacts and rhetoric, in the last decades metaphor has occupied the central stage of our understanding of human thought and action (Lakoff and Johnson 1979: 4): “our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature.”

Cognitively speaking, metaphors provide an understanding of things and events in terms of other things or events. Metaphors can structure much of our daily, ordinary experience (as in the conception of “time as space”), and they are also fundamental in dealing with previously unexperienced situations, by projecting what we already know about a domain onto the new domain and thus shaping our understanding of it.

First, metaphors in innovative processes act as generative tools. Metaphors are “generative” (Schön, 1993) when they structure relationships among elements according to the structure of the original domain of the metaphor. Metaphors’ generative power attracted scholars inside the management domain (e.g., Boxembaum & Releau 2011; Oswick et al. 2011; Cornelissen

2005) and outside of it (e.g., Lackoff 2008; Nersessian 2008; Dunbar, 1997; 1999; Thagard 2012). They are an effective mechanism to generate new knowledge within a given disciplinary group. Recent studies suggest that they are often used in laboratory meetings to discuss issues and results of research, and they provide hints and methodology to solve scientific problems, thus enhancing disciplinary knowledge (Dunbar, 1997; 1999).

Second, metaphors exceed the conceptual level and affect action (Biscaro et al. 2015). They provide systematic guidance to generate inferences and direct action in relatively unknown contexts. Moreover, we "live by" metaphors because the way we act and react is structured by the expectations and values carried by metaphors: conceiving a market competitor as "enemy" will favor aggressive marketing behavior (Rindova, Becerra, & Contardo, 2004).

Third, through metaphors we share concepts and coordinate with others (Warglien & Gärdenfors 2013). Metaphors are powerful vehicles to convey and translate to others meanings that could hardly be expressed literally (e.g., emotions), or that could be not understood if expressed literally (e.g., expert knowledge). For Nonaka and his affiliates (e.g., 1994), metaphors allow knowledge to overcome the boundaries of the group, transforming knowledge embedded in practices and local jargons into sharable knowledge.

Another key aspect is that metaphors help knowledge to emerge, not just by the comparison, but also by the combination of concepts (Cornelissen 2005; Tsoukas 2009; Black 1962; Fauconnier and Turner 1998). A mere union of conceptual sets would not sort the same effect of a metaphor.

What we know so far on metaphors comes from study that analyzed unique metaphors and their effect, leaving out the rich explanatory potential that a collection has in the organizing (Biscaro et al. 2015). Herein we want to follow up in this approach to understand the different roles and lives of a multitude of metaphors. We do that by studying a complex project of knowledge combination that requires the coordinated action of multiple actors: a context that provides a trove of opportunities for metaphors to emerge. When actors face unknown situations, metaphors may help illuminate a possible path for actions (Schon 1979; Hill & Levenhagen 1995). When meanings are not evenly shared, metaphors may help communicate the facets that are hidden (Morgan 1986). When there is a necessity to lead a team towards a goal, metaphors have the rhetoric power to recruit resources – among which stands attention – and align actors (Cornelissen & Clarke 2010).

Yet, if there is abundant room for metaphors to inhabit a process of knowledge combination, what is their life cycle? How do they emerge, how are they selected? Are they discarded? Apart from a contribution of the French philosopher Ricoeur (2004), we do not much about the life of metaphors. Ricoeur states that a metaphor is *lively* when it contributes with new meaning to the understanding of a phenomenon, and it *worns out* when it becomes part of the vocabulary, it is no longer recognized, until it gets interchangeable with the concept that the metaphor is supposed to explain. Therefore have all *lively* metaphors a similar fate? Indeed the dynamics of metaphors is still under-investigated.

METHODS

For our exploratory aim to discover metaphors emergence and dynamics in a collaborative process of knowledge combination across distant disciplines, we adopted a theory-building qualitative research approach based on a historical reconstruction of a neuroscience research project that started in 2002 and still continues (Eisenhardt, 1989; Strauss and Corbin, 1990).

The key features of the setting were knowledge generation and a multidisciplinary context. The research setting was the NEUR scientific research project: a research project that included a variety of different partners located in 5 different countries. It was a very ambitious and successful project aimed at developing a new generation of implants to repair damaged central nervous systems (CNS). The project stands at the frontier of several scientific disciplines such as medicine, biology, engineering, chemistry and physics. Scientists succeeded in combining different research practices – in vivo, in vitro, and in silico – and epistemic cultures (Knorr Cetina 1991) without relying on large neither technical nor knowledge overlaps (Biscaro et al., 2015). Scientific research represent a special setting because any time goals are achieved, new ones must be imaged and pursued.

Data: Collection and Analysis

We gathered data on goals, processes and scientists' interpretations along the entire length of the NEUR project digging in their background and practical knowledge. Unlike most studies on metaphors that rely on textual and visual materials (cf. Gibbs, 2008), data collection comprised multiple sources (Eisenhard, 1989; Yin, 1984).

We gathered data from four sources: (1) interviews; (2) laboratories visits and direct observations; (3) archival data – scientific publications, images, presentations, sketches and other files; (4) press coverage, comprising written and audio interviews, see Table 1.

Table 1 - Data sources and analytical use

Data source	Type of data	Analytical use

Interviews (220 pages double-spaced)	*Semi-structured interviews* (10). The NPHt was interviewed two times, the CHt and ENGr once. We interviewed also six other scientists to discuss the origins of the project, of the research ideas, and the development of the joint project from each laboratory's perspective.	Reconstructing the history of the project. Investigating scientists' interpretation of facts, development of ideas and dynamics between the disciplinary and the cross-disciplinary activity. Triangulating evidence.
	Informal interviews (4) with the three key scientists and with a NPH post-doc to discuss our interpretations, to gain familiarity with their working materials and representations.	Gaining familiarity with each laboratory's materials, techniques, and representations. Supporting our interpretation and triangulate evidence.
Observations	*Laboratory visits* (3). One visit of the lab of each key scientist.	Understanding the dimension of the team and the endowment of tools and resources available to key scientists.
(90 pages double-spaced)	*Field notes and transcription of half-year meeting*. Verbatim transcription of the words of scientists explaining their laboratory scientific progress. Description of the misunderstanding and the strategies and tools adopted to solve them.	Controlling for the role of key scientists between them and the other partners. Understanding each laboratory's activity and drawing relations between them. Focusing on the visual cues to solve them.
	Primary sources (20 h 30'- 310 pages)	
Archival data	*Scientific articles* (34). Eight of them on the chemical manipulations of carbon structures, eight on the physiology of neurons, eight on computational models of neural behavior (24 in total) published by the key authors before joining the research group. 10 joint publications.	Reconstructing the history of the project. Content analysis to identify techniques, tools, methods in the 24 non-joint articles. The 10 joint articles were used to highlight the design of the experiment, the role of scientific partners and their relations, the necessary disciplinary advancements, limits of research, and the presence of metaphors (or cues to metaphors).
(252 single-spaced pages)	*Scientific theses* (2). A doctoral thesis in chemistry based on the activity within the lab focused on the preparation and functionalization of carbon nanotubes documenting some of the chemistry activities and results between 2006-2009. A Master thesis documenting the activity performed for the first successful experiment published in 2005.	Providing support to data and interpretation. Reconstructing the history of the project.
	Images (391). Visual material (pictures, plots, sketches, and PowerPoint drawings) produced and used for reasoning about and/or sharing ideas with the other research partners. 24 of them were part of the chemistry world, 15 of the neurophysiology, 132 of engineering.	Providing support to data and interpretations. Verifying of the presence of metaphoric reasoning in the sketches. Giving visual evidence to the reconstruction of the history of the project.
(171 slides)	*PowerPoint presentations* (7). 5 presentations of the engineering group, 1 of chemistry, 1 of neurophysiology of their research activity presented at conferences, summer schools and for internal meetings.	Providing support to data and interpretations. Verifying of the presence of metaphoric reasoning in the sketches.
(114 single-spaced pages)	*Institutional Report* (1) documenting all the activities and results of all scientific partners complying with the application for the grant.	Analyzing the activity of all partners and drawing relations between partners.
Press coverage (25 pages articles)	*Articles in the press* (19). 7 in the International press, 11 in the Italian press. Among these, two interviews to the key scientists were included in scientific journals.	Controlling the adoption of metaphors used in the dissemination.
(18 pages double spaces)	*Press interviews* (2). About the dissemination of the research results to a non-expert audience.	Controlling the adoption of metaphors used in the dissemination.

To strengthen the internal validity, we triangulated interpretation (Yin 1984), relied only on not disconfirmed information overlaps (Miller, Cardinal, & Glick, 1997), combined retrospective accounts with real-time secondary sources (Leonard-Barton, 1990), used multiple coders and verified inter-rater reliability for metaphors' identification and codification (Biscaro et al., 2015), and validated our interpretations and reconstruction with the key scientists multiple times. A preliminary part of our findings was included in the final report of NEUR to the granting body.

In the reconstruction of the events, we select a theoretical sample (Eisenhardt 1989) of metaphors that emerged from discussions among scientists throughout the project.

FINDINGS

The research activity of the scientists involved in the NEUR project implied a continuous interaction between disciplinary backgrounds grappling with the difficulty of understanding each other domain requirements and materials. During the project, scientists made use of microscopy images, reading materials and gave joint lectures with the intent to reach common understanding and develop a joint research path. They used several metaphors that allowed them to facilitate the design of joint experiments and guide their research activity.

In these accounts there will be three scientists: a chemist (CHt) expert of nanotubes, a neurophysiologist (NPHt) expert of neurons, and an engineer (ENGr) expert of artificial neural networks.

Context of metaphors

In the accounts of scientists we identified a multitude of metaphors among which we present only a selection and discard many others (nanotubes as *sea*, or as *needles* for instance). We contextualise each metaphor in Table 2.

The *electric wire* metaphor served to a neurophysiologist to make sense of carbon nanotubes at the beginning of the research project. The metaphor was triggered by vision of microscopy images of carbon nanotubes and generated the first experiment that exploits the two-dimensional layout and the conductivity of the electric wire (Biscaro et al. 2015). The metaphor of the *scaffolding* is a second imagery of nanotubes and help scientists establishing nanotubes' third dimension that will be exploited in a second experiment. *Percolation* draws on the percolation theories in the scientific domains of physics and electrical engineering and brings theoretical models to reason of the interaction between neurons and nanotubes. *Shortcuts* draws also on everyday knowledge and serves to model the conductive effect of nanotubes on neurons: nanotubes accelerate the electrical current thus being an analog of a shorter neuronal path. It gives rise to a theoretical model and a new electrical recording technique. *Carpet* is used to describe the nanotubes layer that is rough, irregular and made by many different short filaments; it is adopted for both formal and informal communication. *Electric wire* (neuron) *sitting over other electric wires* (nanotubes) nests the first metaphor into a more complex one that establishes the third dimension by 'sitting over' and identifies that the interaction be thought as an electric network. *Body with small arms* is the description used by a neurophysiologist to describe the neuron to an engineer who – thanks to this description – can perform microscopy imaging on the correct cells amidst an array of similar ones that dwell on the sample glass. *The finger* and *the blind man* metaphors are used to describe the functioning of a particular microscopy that feels the resistance of the material by 'touch': it generates an experiment where the elasticity and stiffness are measured in populations of neurons grown inside nanotubes. *Transistor* is the metaphor that draws on electrical engineering concepts to describe mathematically neurons: such a description does not lead to a single experiment, but it will be commonly used by the engineer in his modeling.

Table 2. Table of metaphors and their use.

Quote	**Metaphor's source**	**Source domain**	**Led to experiments**	**In a NEUR article**
I think that it was easier for them to understand, because of the assumption that nanotubes are like tiny electric wires connecting two neurons.	Electric wires	electricity	Yes	No
CNTs represent a scaffold composed of small fibers or tubes that have diameters similar to those of neural processes such as dendrites	Scaffolding	construction, tissue engineering, chemistry	Yes	Yes
Probably only the word percolation allowed me to see the same electron microscopy images in a different way. Those nanotubes touch each other; thereby I can imagine there is an electric path between any two points in the network.'	Percolation	physics, material science	Yes	Yes
A sort of short-cut, I simplified that much… I put here a resistance, here another mega resistance, and I asked 'what are the conditions such that these points are closer if these resistances occur?' … the more the neuron is long, the more these short-cuts (are efficient), and this effect should take place.	Shortcuts	electrical engineering	Yes	Yes
In this meshwork of nanotubes, the idea of the electric wire is a simplification of a bi-dimensional geometry. Assuming the symmetries of the profile, a neuron that sits over nanotubes becomes an electric wire that sits over other electric wires.	Wire sitting over wires	electrical engineering	No	No
under this neuron, there is no carbon nanotubes, and it is one of the drawbacks, instead here there is a neuron that is laying on a carbon nanotube carpet	Carpet	handcraft	No	Yes
It was really funny, because the description was that of a ball, a small ball, something, like a body, with small arms. I remember it pretty clearly; this was the first description of the neuron. Because we knew very well nanotubes, but regarding cells we were a bit ignorant, and this first description of the neuron as a small ball from which some processes stemmed, that now I identify as dendrites and axons, immediately gave us the idea of what we would have seen in the first image. And that was it	Body with small arms	anatomy	No	No

I imagined like a finger, very very very small (the tip of microscopy), with which you touch the surface (the material in the experimental glass), and with eyes shut, like a blind man, you try to infer the shape, the morphology of the surface, simply perceiving it by contact.	Finger, blind man	anatomy, mechanics	Yes	No
Nanotubes can behave like a transistor, therefore it can be necessary an external electric field to allow a(n electric) path. Thus a non-linear behavior.	Transistor	quantum mechanics, electrical engineering	No	Yes

The dynamics of each metaphor profoundly differs. Some take the project too far and are discarded, as not coherent with the project's direction; others serve to accomplish a task and then disappear; others are re-used and nested in more complex metaphors. Some are used in the scientific communications, others not. Some have a generative power, others only a communication function. A metaphor's life interacts with and depends on other metaphors and the process in which they are grounded, see Figure 1. It is such a cognitive and practical process of knowledge combination that determines a metaphor's fate. With an image of our research setting, studying a metaphor in-vitro (in isolation) or in-vivo (in context) generates different results.

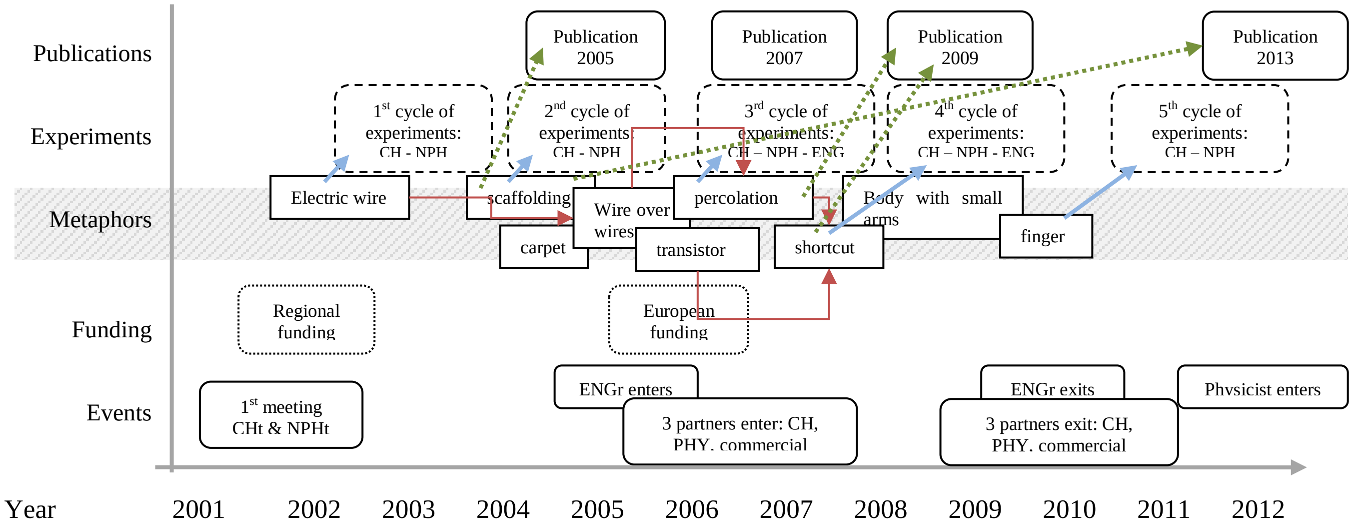

Figure 1. Metaphors in the NEUR research project. Red arrows connote evolutions of metaphors into other metaphors. Blue arrows denote the metaphors that led to experiments. Green arrows show metaphors that appear in NEUR scientific articles.

CONCLUSIONS

Our research shows that metaphors are not just decorative tropes, but play different productive roles in shaping the way problems are structured and solved, guiding important decisions and framing action in cooperative tasks.

Our findings show that metaphors are not just used for translation, but also for knowledge combination. Generative metaphors (Schön 1979), the "metaphors we think with"

(Thiboldeau & Boroditsky 2011) help structuring the problem setup (e.g.: Nonaka and Takeuchi, 1995; Knorr-Cetina 1981; Schön 1979; Dunbar 1997; 1999), they are used to make individual knowledge understood by others as well as to understand how to combine other knowledge that we do not fully comprehend, to identify goals and guide activities.

According to the role they play, metaphors emerge differently and have different fate along a process of knowledge combination. The metaphors that translate knowledge without combining it emerge within a knowledge domain. Those that combine pieces of knowledge held by different individuals, however, emerge in knowledge overlaps created through conversations, co-teaching, and temporary co-location of collaborators. Such overlaps are limited with respect to the depth of a whole discipline, but sufficient for metaphors to emerge.

Metaphors facilitate the coordination of the activities of groups and are successful only when they operate in or create knowledge overlaps and this makes metaphors similar to boundary objects (Star 1989). For example, the scaffolding concept resonated in the mind of two different scientists, as well as the ball of small arms resonates immediately in the mind of the recipient. However, unlike boundary objects that are effective when goals are defined and the division of tasks is clear (Star 1989; Carlile 2002; 2004; Bechky 2003), metaphors help setting the cross-domain goal that, in turn, suggests group-specific goals.

Metaphors do not have just a "cognitive" evolution. Their dynamics interacts with the social practices within which metaphors live; furthermore such dynamics cannot be separated from the life cycle of other – competing or complementary – metaphors. So, for example once it helps generating the first experiment, the limits of the *electric wire* make it impossible to successfully guide the scientific work further. As a result, such metaphor apparently leaves the scene in favor of a more structural and “3-dimensions” one, the *scaffolding*, enabling to structure the experimental materials and procedures in ways that will avoid the shortcomings of the initial layout. Yet, as we shall see, the first metaphor remains latent rather than disappearing. The scaffolding metaphor in turn subsequently temporarily decays not because it is unsuccessful (the experiment it generates is a major success!), but because of the puzzling observations it produced: the anomalies in the electrical behavior of the neurons require a new guiding metaphor to orient the joint work of the scientists. The continuous reliance of specialized groups on metaphors to anchor their distant knowledge domains, to generate knowledge, along with the fact that metaphors emerge from recognized similarities increases individuals’ dependence on those practices that make overlaps visible. Images, measures, and experimental actions continuously modify the cognition of domains and span the possibilities for new associations.

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