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REGULAR ARTICLE

Theories and Theorizers: A Contextual Approach to Theories of Cognition

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Abstract An undisputable characteristic of cognitive science is its enormous diversity of theories. Not surprisingly, these often belong to different paradigms that focus on different processes and levels of analysis. A related problem is that researchers of cognition frequently seem to ascribe to incompatible approaches to research, creating a Tower of Babel of cognitive knowledge. This text presents a pragmatic model of meta-theoretical analysis, a theory conceived of to examine other theories, which allows cognitive theories to be described, integrated and compared. After a brief introduction to meta-theoretical analysis in cognitive science, the dynamic and structural components of a theory are described. The analysis of conceptual mappings between components and explanation strategies is also described, as well as the processes of intra-theory generalization and inter-theory comparison. The various components of the meta-theoretical model are

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presented with examples of different cognitive theories, mainly focusing on two current approaches to research: The dynamical approach to cognition and the computer metaphor of mind. Finally, two potential counter arguments to the model are presented and discussed.

Keywords Dynamical approaches to cognition · Computer metaphor, meta-theoretical analysis · Pragmatics · Contextualism, cognitive science · Conceptual mapping · Explanation strategies

Introduction

An undisputable characteristic of cognitive science is its enormous diversity of theories. Not surprisingly, these often belong to different paradigms and refer to different processes and levels of analysis. A unifying language does not exist for these sciences and the large quantity of disciplines involved makes a global vision of these manifold cognitive focuses difficult. A related problem is that researchers of cognition frequently seem to ascribe to incompatible approaches to research, creating a Tower of Babel of cognitive knowledge.

One useful way to understand the large number of cognitive theories is by means of meta-theoretical analysis. That is, to implement a limited number of simplified but useful tools taken from a theory conceived of to examine other theories. Such tools, borrowed from philosophy of science, allow the description, integration, comparison, and deepening of theories. This procedure, then, helps a researcher to be aware of the diversity and variability present in a certain scientific explanation and to better understand the relations between the components of a specific theory and between theories.

The aim of this paper is to present a meta-theoretical model for scientific theories, based on the synthesis and integration of various contemporary approaches in philosophy of science. While this subject may not be new for scholars well versed in philosophy of science, it constitutes a useful summary of developments in the philosophy of science in the last six decades. This summary is condensed into an analytical tool applied to the field of cognition. The application of the model presented in this article may allow researchers to better understand their theories. Additionally, this meta-theoretical model explicitly includes non-inferential relations between conceptual components of a theory, offering non-inferential meta-theoretical analysis routes relevant for the type of theories found in cognition.

Theories of cognition challenge the applicability of any meta-theoretical approach. Firstly, they deal with a multi-dimensional field of study that can be examined from the perspective of biology, neuroscience, psychology, philosophy or sociology (de Jong 2001; Ibáñez and Cosmelli 2008; Cosmelli and Ibanez 2008). Levels of description frequently overlap and many theories approach a phenomenon from different points of view simultaneously (i.e., a phenomenon that is understood as being simultaneously neurological and psychological). Cognition might be explained in many ways, including mechanical, reductionist, and physical methods, and even teleological and emergentist explanations (see for example, Barutta et al. 2010a). Finally, alternative approaches (Barutta et al. 2010b) to orthodox computationalism, such as connectionism (Leech et al. 2008), embodied, distributed and situated cognition (Anderson 2003; Smith and Collins 2009; Dufey et al. 2010), social neuroscience (Decety and Lamm 2006), the contextual approach to cognition (Aravena et al. 2010; Baker and Moya 1998; Cornejo et al. 2009; Hurtado et al. 2009; Guerra et al. 2009; Ibáñez et al. 2006; Ibáñez et al. 2009a, b; Ibánez et al. 2010a, b, c, d; Riveros et al. 2010; San Martín et al. 2010), ecological cognition (Turvey 2007), and dynamical approaches (Breakspear and Stam 2005), amongst others, are increasingly well known today in cognitive science (Cosmelli and Ibanez 2008). For these reasons, it is essential for meta-theoretical analysis to be sensitive both to the components of a theory that it is most possible to formalize and to the contextual framework of that theory. Therefore, the relevance of an at once formal and contextual model of analysis becomes evident.

Firstly, we will develop a brief description of the classical distinction between *explanans* and *explanandum*; that is, the explanation used for the understanding of the phenomenon being explained, and that phenomenon itself, respectively. This distinction is redefined within a contextual and pragmatic approach to the philosophy of science. Subsequently, the meta-theoretical model is explained. This model summarizes the most important aspects of a scientific theory, according to post-empiricist views. Although these are rather heterogeneous ideas, they may also come together in a new meta-theoretical analysis that takes into account their most relevant contributions. Within this model, a theory is analyzed in terms of a set of non-falsifiable elements (the core of a theory and its respective frame) and a more dynamic set of properties. This dynamic part includes prototypes of application of the theory, and it accounts for the specific domain of knowledge to which such a theory applies. The explanation strategies and how they relate to the structural and dynamic components are also explored. Next, some of the consequences of the model are made explicit. Finally, two potential counter-arguments are presented and discussed.

The analysis of the components of our model will be illustrated by using examples from different theories in the field of cognition. Specifically, we will focus in two approaches: the computer of mind metaphor and the dynamical approach to cognition. Briefly speaking, the computer metaphor in cognitive sciences has integrated the research of multiple domains into a single image: Brain and mind implies a functional (computational) process based on the manipulation of discrete rules and representations of the world. The brain/mind modeling of this approach is based on central processor models. In contrast, dynamical systems theory proposes that the nervous system and the mind are a spatiotemporal dynamical system, constantly coupled with the body and the environment. Mathematical modeling of nonlinear tools has been proposed to describe cerebral dynamics, perception, meaning and intentionality. Both research programs will be used as examples of the metatheoretical analysis

Why a Pragmatic Approach to Theories of Cognition?

The metascientific method of analysis that we offer in this article conceives of scientific theories in their contexts, neither isolated from other theories nor from scientific work. As a result, our model will take into consideration the scientists and their research practices.

As expressed by C. Ulises Moulines in his *Plurality and recursion* (Moulines 1991), we must give up the normative/descriptive dichotomy, which has enjoyed a long life in the history of philosophy of science. According to Moulines, that which we can expect from a philosophical metascientific analysis is an interpretative model that speaks about science from a different view, which either allows us to see new things or to see the same thing as before but in a different way. Such interpretative models can be of very differing kinds (as can be seen in the history of the philosophy of science) and may be used to interpret different stages of scientific research under new light. This is where another well known dichotomy of philosophy of science might be revealed: the classical distinction between the context of discovery and the context of justification. Reichenbach was the first to suggest such a distinction in his *Experience and prediction* (Reichenbach 1938), within the framework of logical positivism, although the notion was already in use before Reichenbach's book was published. Since then, the most common approach for philosophers of science was to restrict their work to within the context of justification, leaving the context of discovery in the hands of historians, sociologists and psychologists. This was Rudolf Carnap's view, one of the greatest members of the Vienna Circle, expressed in his *The logical structure of the world* (Carnap 1967). Such a distinction drew much criticism, including from Thomas Kuhn, who warned about the difficulties of trying to draw a limit between the two contexts, in the introduction to his *Structure of scientific revolutions* (Kuhn 1962). Also, in chapter VI of his book, Kuhn writes about the artificiality in differentiating between discovery and invention. In this way, the historicist stream (T. Kuhn, I. Lakatos, P.K. Feyerabend, L. Laudan, etc.) showed that the context of discovery was actually a legitimate ground for philosophical reflection and, also, that the distinction between this and the context of justification was much more vague than it had been thought.

At present, as Javier Echeverría (1995) states in his *Philosophy of science*, we find ourselves in a completely different scenario from that which was imagined by the proponents of logical positivism. We can now recognize not only two but four contexts in scientific research, which interact with each other in a mutually influential fashion, and all constitute legitimate ground for philosophical meta-science: context of education, context of innovation, context of evaluation and context of application. The context of education consists of the teaching, learning and spreading of scientific knowledge. The context of innovation replaces, and extends, the classical context of discovery, by adding inventions and novelties in general. The context of evaluation replaces, and extends, the classical context of justification, and receives this name in order to emphasize that not only methodological arguments are important but also a positive (or negative) evaluation of the novelties found in the context of innovation. Finally, the context of application points out that the results of scientific-technological research will eventually be applied to the environment in order to transform it, and that such application will coincidently change the results of scientific investigation according to the particular context in which it is applied. A particularly important feature implicitly present in our explanation of the four contexts is that all of them are, one way or another, socially mediated. As a result, the work of the philosopher of science is no longer exclusively restricted to the *results* of scientific research, the scientific theories, even though they undoubtedly play an essential role in metascience. Therefore, the sole task of “uncovering” the structure of knowledge (the scientific theories), that used to be the main aim of the Vienna Circle, though necessary, is insufficient. If we accept that the context of evaluation exerts its influences on the other three contexts and, conversely, that these also exert influences on the context of evaluation, then a more complete philosophical analysis of science requires not merely a structural and synchronic approach but also a pragmatic and diachronic one. This is exactly the aim of the meta-theoretical model we offer here: to provide an interpretative model of empirical scientific theories, particularly the cognitive ones, capable of shedding light on the structure of theories and their pragmatic features as well. We believe that in the case of cognitive research, where multiple theories and approaches can be found, an interpretative model that takes into consideration the pragmatic features of theories can help us to better understand such theories in a way that solely structural features do not do. We also believe that this is still an unresolved issue between cognitive researchers.

Finally, the meta-theoretical model we offer here does not preclude the relevance of other issues such as causation, it simply does not deal with it directly. Our model is a philosophical interpretative model of science interested in the structural and pragmatic features of theories, particularly cognitive ones.

Meta-Theoretical Analysis and the Global Properties of Theories

This perspective proposes a rational reconstruction of empirical cognitive theories through the analysis of its components. Such reconstruction recognizes that some global properties of theories cannot be completely formalized. This is why such components, termed the macro-logical components of a theory, are described as non-formal even though they allow partial formalization (e.g., by using set theory or category theory). This is part of the *non-statement view* of theories (Stegmüller 1976), i.e. it assumes the existence of macro-logical properties of theories, which cannot be exhaustively translated into formal propositions. Such macro-logical properties are a consequence of meaning holism, the impossibility of isolating a given empirical theory from its context (including other theories). Therefore, the non-statement view of theories, contrary to logical positivism, asserts that the best way to identify a theory is not through a set of statements or axioms but through a class of models. Models are conceived of here as systems constituted by entities that satisfy the laws of the theory. A theory, then, cannot be identified with a list of formalized statements. When this exercise is undertaken, its result is always partial and incomplete.

The objective of this section consists of presenting an analytical tool for rational reconstruction that allows the description, integration and comparison of theories. In this model, a theory is constituted of non-falsifiable elements upon which another more dynamic collection of properties is based. Explanatory strategies are sustained by mapping relations between the components of a theory. Figure 1 presents an outline of the proposed model, which will later be developed one part at a time.

One point of departure of the model is the pragmatic interpretation of the *explanans-explanandum* relationship. By ‘explanandum’ we understand that which a

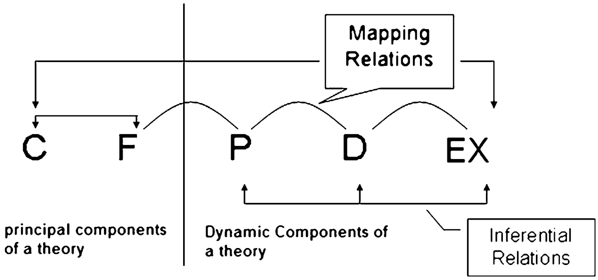

Fig. 1 Pragmatic model of a theory. This model shows the principal components of a theory (Core, Frame) as well as the additional components (Prototypes, Application domains, and Empirical extensions). Some of them are less dynamic (C, F); others are more subject to heuristic changes (P, D, EX). Explanatory strategies are sustained by mapping relations between the components of a theory. Global properties of a theory are analyzed by means of conceptual mappings between components and explanation strategies. C: *Core;* F: *Frame;* P: *Prototypes;* D: *Application domains;* EX: *Empirical extensions*

theory has to explain, while by 'explanans' we understand the conceptual resources used to explain the *explanandum*. The main difference from the empiricist use of these terms is that, in our understanding, the distinction between the two is contextualized and therefore pragmatic. A given *explanandum* can work as *explanans* in another context and vice versa. Also, the *explanans-explanandum* relationship is not upheld per se, but it is defined within a particular context, such that its understanding is sustained by unspecified tacit knowledge, facts and understandings that are mostly unsaid and undetermined (Polanyi 1969). No *explanans*, then, is micro-logically exhaustible given that the understanding of an *explanans* always requires subsidiary knowledge. The micro-logical analysis, contrary to the macro-logical one, takes into consideration isolated terms or statements.

Both that which is to be explained and that which works as explanation are contextualized within a specific situation with a certain knowledge background that usually remains implicit. So conceived, theories are tools to solve problems defined in a tacit knowledge background, whose specializations and domain applications may change as does the background from which they acquire meaning. As a consequence, a theory is not an artifact defined once and for all but is a—sometimes imperceptibly—changing one. Nonetheless, it is possible to distinguish some components that are less dynamic than others. These constitute the *structural part* of a theory, whereas the more dynamic components configure the *dynamic part* of the theory.

Structural Components

The structural components of a theory are not falsifiable in terms of logical inferences from empirical statements. They include the *core* and the *frame* of the theory. Both the core and the frame, following the tradition of Lakatos (1983) and Stegmüller (1976), are components that resist change. One can change a great number of hypotheses in a theory, establish restrictions on its areas of application and even throw out empirical facts. However, its structure has to be maintained. Despite this, the core and the frame are not completely static structures because the dynamic components of a theory influence, in a slow but pervasive way, its structural elements.

Certainly, the 'mind as a computer' metaphor is the best example of a very general and extended structural component of a theory: Cognition is computation based on abstract rules that mediate between the world and internal representations. Several hypotheses, predictions and theoretical restrictions are sustained by this metaphor, such as the preponderance of abstract computation over the passive action-perception cycle or the existence of discrete and specialized modules, among others. In contrast to that image, the dynamical approach describes a different scenario. This viewpoint proposes that mind is the result of an interaction between distributed self-organized neuronal groups coupled ongoingingly with the body and the environment. In the same line, several hypotheses and predictions arise form this approach: the intrinsic emergence of cognition from an active action-perception cycle, or the coupling between non-modular process in the brain which yields any emergent cognitive phenomenon.

The structural components adequately fit the notion of holism developed heterogeneously by Davidson (Davidson 1998; Cornejo 2004); Duhem (1905); Kuhn (1962); Quine (1951); and Feyerabend (1978). This implies that statements of a theory are not falsifiable in isolation, through certain empirical data, but that they accept or accommodate themselves to the whole theory. In Quine's words:

> The dogma of reductionism survives in the supposition that each statement, taken in isolation from its fellows, can admit confirmation or information at all: my counter suggestion … is that our statements about the external world face the tribunal of sense experience not individually but only as a corporate body (Quine 1951, p. 41) […] the English sentences of a theory have their meaning only together as a body (Quine 1969, p. 80).

This implies that for every expression of a given language, its meaning cannot be separated from the global epistemological context. However, it should be stressed that the term "holism" in this text refers more to *demythologized holism* (Stegmüller 1976). This implies that the structural components are not falsifiable themselves. And so it is not possible to assert that the structural components can be thrown out due to falsification. As Quine sustains, given the holistic nature of knowledge, a re-evaluation of some statements within a theory also entails a re-evaluation of the remaining statements of that theory. Therefore, any statement can be held true come what may (it may resist change) if we make drastic enough adjustments elsewhere in the system (Quine 1951).

According to this model, there is no reason to accept radical incommensurability between theories, as has been argued (Kuhn 1962; Feyerabend 1978). Radical incommensurability is a consequence of *micrological* inconsistency. Trying to compare different theories by means of "term to term" or "statement to statement" relationships will come to a failure, given that different strategies of analysis prevent inferring sentences from one theory to another. However, inter-theoretical comparison can be done from a macro-logical perspective. This way, both theories are taken as a whole, and the comparisons are not made regarding the meaning of every term or statement, which, taken in isolation, may be incommensurable. Therefore, from micro-logical inconsistency at the object level between two theories—that is, from the fact that one cannot be *deduced* from the other—it does not follow that the two theories cannot be compared in their cores from a macro-logical point of view.

We will now describe in more detail both the Conceptual Core and the Frame.

The Conceptual Core

The core corresponds to a conceptual network of central importance to a theory. This conceptual network allows for a structure of order and meaning upon which the frame of a theory rests. The core is not specified in terms of deduction and induction. It is a quasi-pictorial structure,[1] a simple image that tolerates broad interpretative variability and can be set down in words with relatively different meanings. The same core can be updated in diverse ways with a common image, allowing inter-theory variability at this level of analysis.

The notion of the core is present in the work of Lakatos and Stegmüller. However, there are differences between the two presentations. Lakatos defines the core within the statement view, unlike the current proposal, which is based on an image that possesses interpretative variability (Lakatos 1983). On the other hand, Stegmüller defines the core of a theory as a conceptual mathematical structure, without the formulation of empirical content in linguistic terms (Stegmüller 1976). Despite these differences, both definitions have an aspect in common: the core as a conceptual relation that makes multiple interpretations possible (Longo 1999).

A good example by which to visualize the directional function of the core in the production and development of approaches to research is the use of quasi-pictorial images in the study of memory from the computationalist approach. For instance, the *spatial image* of memory, where remembered contents occupy space as physical objects, has largely inspired research on this issue: "Memory is, as it were, the storehouse of our ideas… a repository to lay up those ideas" (Locke 1975, Book II, p.10). Ideas in memory are "in themselves distinct; and therefore no two of them can be in the same space; they are actually different and separate one from another" (Hooke 1705, p. 142). James and Freud explicitly used spatiality as a metaphor for memory (James 1890; Freud 1924; Koriat and Goldsmith 1996; Roediger 1980). A large amount of cognitive research on long-term memory has been guided by this *spatial image*. There have been multiple criticisms of the spatial metaphor of memory: Bartlett (1932) was one of the first to make explicit this metaphor by establishing its limitations. It has also been assessed by Boon and Davies (1988), Bransford et al. (1977), Bahrick (1987), Gibson (1979), Koriat and Goldsmith (1996), Neisser (1984, 1988), Roediger (1980) and Winograd (1988).

Relevance and Argumentational Promise Closely related to the conceptual core of a theory, it is possible to identify its relevance and argumentational promise. A theory is

[1] The prefix 'quasi' is significant, given that unlike the common-sense notion of 'pictorial' the core is not considered a totally static component and it does not exclude language properties.

always an attempt to explain phenomena that have not been sufficiently explained. This attempt is based on the meta-theoretical criterion that progressive research will allow the explanation of new areas. It is also based on a particular argumentational relevance that refers to the relationship between the phenomenon to be explained and the explanation used for the phenomenon. The simpler the conceptual structure of the explanation and the greater the number of phenomena that are explained by it, the greater the argumentational relevance of the theory. A relevant theory tacitly offers an argumentational promise. This involves a mostly unarticulated and undetermined set of big questions whose answer the relevant theory *seems* to offer in the long run. This argumentational promise tacitly feeds the trust and persistency of relevant theories.

The dynamical systems approach offers an appropriate example of argumentational relevance. The promise of dynamical approaches to cognition is the proposal that neurophysiological, cognitive and social phenomena can be studied within a single theoretical framework. This perspective promotes a self-organization model of cognitive events, which can explain brain dynamics, intentionality, subjective consciousness or meaning (Ibáñez 2007a, b)

Additionally, taking into account a broader area, current Darwinism offers anther good example of argumentational relevance. Since the foundation of HBES (the Human Behavior & Evolution Society) in 1988, Darwinism has not ceased to attract the attention of psychologists, anthropologists, economists and historians. For some, the Darwinian Theory can serve as the perfect context for psychology, anthropology and other sciences that might be going through a moment of confusion after more than half a century adrift (Barkow et al. 1992). This emphasis on Darwinian Theory can be partially understood thanks to its powerful argumentational relevance: by using a reduced *explanans* (natural selection and struggle for life) it attempts to explain diverse complex phenomena such as life and humanity. In Dennett's words, Darwin's dangerous idea is that which "unified the realm of life, meaning, and purpose with the realm of space and time, cause and effect, mechanism and physical law" (1995, p. 21). In this way, the Darwinian idea promises the reconciliation between the mechanic, deterministic world and the intentional, apparently unpredictable human world. It tacitly promises to overcome the schism between the natural sciences and the humanities. Because of this argumentational relevance and promise, "it attracts not only religious fundamentalists, but also very capable scientists" (Horgan 2001, p. 276).

Argumentational relevance and promise have an aesthetic dimension, habitually defined within a context of acceptance. This context provides the framework for what is expected as normal practice for scientists.

The Frame

The frame (F) of a theory defines its micro-context. Unlike dynamic components, it should be understood as an extension of the core. The main function of the frame consists of anchoring the core to a series of assumptions and in extending the structural content of a theory.

The frame describes: (a) the ontological premises of a theory, that is, questions *regarding what there is* according to a particular theory (entities, processes); (b) the specifications and restrictions of the core, i.e., the frame implies the creation of additional components not explicit in the core, as well as the type of relationship between theoretical concepts and (c) the types of explanatory strategies that the given theory allows. The type of explanatory strategy depends largely on the collection of ontologies and processes that are assumed, as these partially determine certain methods of explanation.

The frame of a theory determines the kind of explanation, as for example, emergent, homuncular, teleological explanation strategies, or strategies exclusively based on laws. In the case of the computer metaphor, the frame involves discrete entities with independent properties; consequently a homuncular analysis (e.g., decomposition and localization, see below) will be possible (Bechtel 1998). At the same time this frame establishes that reality can be known via general laws that can be formalized in isolated representations; then strategies of the covering law type will be used. In contrast to computationalism, the frame of the dynamical approach establishes the existence of different levels of reality, each with specific properties. Consequently it will tend to accept emergent explanatory strategies.

The properties of the core, extended by its theoretical frame, can be mapped onto the properties of the dynamic elements of theories (properties of phenomena described by the areas of application and theory prototypes, as well as experimentation).

Dynamic Components

This section describes those components that change with greater frequency. They include the prototypes (P) of the theory, the domains of application (D) and the empirical extensions (E). Prototypes are specific applications of the theory to particular areas where its operation can be visualized in a concrete and parsimonious way. The domains of application and empirical extensions include terms that can be subject to quantification, known as non-T-theoretical terms (or theoretical terms dependent on measurement) (Sneed 1971; Stegmüller 1976), which do not belong to the theory itself and allow the use of quantifications and falsifiable relationships. Non-T-theoretical terms do not refer to something epistemologically observable. They are the conceptual elements of a theory upon which quantification values are defined.

As has already been stated, dynamic elements are related to structural elements in a specific way, through the mapping of relations when developing explanatory strategies, and in a general way, during the evolution of a theory. That is why the mapping of relations is essential to sustain the proposed model. This notion is derived from current developments in the cognitive sciences, particularly research into conceptual metaphor (Johnson 1987; Sweetser 1990; Amstrong et al. 1994; Lakoff and Johnson 1980, 1998; McNeill 1992, 2000; Wilcox 1993, 1996), studies of conceptual blending (Fauconnier and Turner 1996, 1998, 2002) and some approaches of embodied cognition (Anderson 2003; Dourish 2001; Iverson 1999; Rohrer 2001, 2002), which have theoretically and empirically reassessed the iconic and metaphoric processes, including in the areas of abstract and mathematical language (Goldin-Meadow et al. 2001; Lakoff and Núñez 2000; Núñez 2004).

A mapping implies at least two conceptual domains, in which one domain (target) is understood in terms of the other (source). The *source domain* represents the conceptual framework that will be mapped onto the *target domain*, normally the conceptual framework that is more difficult to understand. For example, it is normal to understand temporal concepts (*target domain*) in terms of spatial relationships (*source domain*). Although viewpoints based on the conceptual metaphor mapping of two unidirectional domains predominate, those based on *blending* perform mapping between multiple domains in a multi-directional fashion. A mapping is carried out on the basis of conceptual frameworks. The framework can be conceived of as the abstract structure of an image (Johnson 1991). Therefore, a mapping is a set of projections from one or more conceptual domains to another one, whose improved understanding is intended. In the context of the current proposal, the domains correspond to the components of a theory.

For example, computational models of cognition are based on two basic explanatory strategies: decomposition, under the premise that activity is the result of the execution of components, and localization, under the premise that those components exist *within* the system (Bechtel and Richardson 1993). These strategies have also been called *homuncular analysis* and *mechanistic explanation* (Clark 1997; Bechtel 1998). These heuristics are sustained upon premises specific to computationalism: all processes are computable and able to be formalized; every problem can be decomposed into sub-problems; the system in its totality is explained by the parts (Edmonds 1996). The view of dynamical approach presents an alternative to a mechanistic explanation (Clark 1997; Bechtel 1998). This explanatory model is based on the description of regularities in an organism and its environment where there are emergent properties. It is based on two premises: the existence of emergent processes and the coupling between organism and environment. Depending on a theory's level of global coherence, explanatory strategies should be mapped by ontological premises and the prescriptions of the theory's frame and knowledge domain components. For instance, in both previous examples, the mapping between the structural and dynamic components of the theory can be focused on in order to analyze the relevance of a theory.

Prototypes

Prototypes (P) are *bona fide* cases of an empirical application of the theory, illustrating the adjustments made between structural components and explanatory strategies. Using prototypes, a theory is applied to an object area in a clear and concise way, making the theoretical concepts concrete and allowing an integrated view of the way in which a theory works. Prototypes have a powerful heuristic value because they allow us to put the theoretical focus into practice and, above all, promote extrapolation to other domains through the use of analogy.

During the birth of the cognitive revolution and based on the metaphor of the mind as a computer, Newell and Simon (1961) developed a computer system capable of resolving theorems and problems. The *General Problem Solver* (GPS) represented an extraordinary achievement in artificial intelligence with its attempt to model the human mind. The authors stated:

> Given that GPS behaves like a human (in an admittedly limited domain), and given that GPS is a computer program, it follows that GPS constitutes

> irrefutable evidence that…the free behavior of a reasonably intelligent human can be understood as the product of a series of complex, but finite and determined laws (p. 291).

This model was cited as emblematic of cognitivism and produced great expectations. This brought the authors to propose this prototype (GPS) as a model of physical symbol systems theory. They affirmed that the prototype was applicable to many domains of intelligence beyond the resolution of theorems and other problems where it had been successful, to the point that they asserted: "A physical symbol system has the *necessary and sufficient* means for *general intelligent action"* (p. 41, italics added). The study of the olfactory bulb (Skarda and Freeman 1987) and its simulation (K-set model) can be considered a prototype of the chaotic dynamic theory of cognition (Ibáñez 2007a, b). Skarda and Freeman (1987) discovered that the pattern of cortical responses in animals during learning experiments was that of global changes. Consequently, they modeled this process and proposed chaotic dynamics as the basic form of collective neural activity for all perceptual processes. The k-set model led Freeman to surmise that the brain does not behave like a passive receptor of perceptual activity based on information, but that the brain constructs the meaning of the events based on its on-going activity and its own history. The K-set model (and its modifications) was then extended to almost all cognitive process (see for example Freeman 2003).

The main importance of prototypes stems not from their aesthetic contribution to elegance and concreteness, but more from their heuristic role in validating and extrapolating from the theory. Prototypes allow a theory to be validated as they represent a concrete case of its successful application in which the theoretical concepts have been clearly exemplified and the theoretical predictions corroborated. At the same time, prototypes favor theoretical extrapolation by being mapped onto domains where the theory has not been consolidated. Nevertheless, promissory prototypes can facilitate the excessive extrapolation of a single model extracted from a specific fact to several other domains of complex phenomena (as in both of the examples from computationalism and dynamical approaches described above). This extrapolation can be explanatorily successful or, conversely, inadequate.

Application Domain

In the application domain (D) there is accumulated knowledge that is not derived from the core and frame of a theory. This knowledge comes from the expertise developed in a specific area of research and it partially becomes part of the theory. The application domain includes factors that have not been considered by the structure of a theory, but which redefine its global properties. Since by definition the application domain is restricted to that domain in which it has already been applied, the applicability of a theory is always limited. For example, the *General Problem Solver* (GPS) cited above was successful within the mainstream of artificial intelligence, such as expert systems. When the GPS was applied to other application domains, such as decisions under uncertainly, the power of the prototype as well as that of the whole theory was reconsidered (Dreyfus and Dreyfus 1990). A theory can never be a universal tool for application in all domains. On the contrary, the properties of the core or the frame will only be sustained by an application domain when they are compatible with this domain. Subsequently, these domain properties are mapped to the frame and the core, establishing an explicit relationship through analogies. The importance of the application domain stems not only from the fact that it provides specification and restriction to a theory, but also from the fact that it supports the mapping relations between the application domain and the structural components. Finally, the expansion of research programs allows generalizations and constraints between domains, which can result in greater theoretical refinement, empowering the predictive capacity of the theory. This implies enrichment through *cross-connections* (Stegmüller 1976) between the domains of a theory, which can be extensive or restrictive.

Empirical Extensions

The role of empirical extensions in the construction of theories is not just part of a theory from the perspective of falsification and corroboration but due to the fact that scientific comprehension is a mixture of theory, experimentation, mathematics, common sense and technology. Empirical extensions are those empirical components involved in the theory, outwith the application domain, such as technology. This implies both the specific tools as well as their conceptual use (Gigerenzer 1991). The relationship between theory and technology is bidirectional. There is a relationship reaching from theory to technology when the latter is used to empirically validate the former. There is also a relationship in the direction of technology to theory when progress and technological achievements are used metaphorically to build new theories. In this way, tools provide metaphors that can be re-conceived within a theory's core and frame.

The conceptual use of technology is well explained in the thesis "*From the tools to the theory*" (Gigerenzer 1991). The application of the computational metaphor to comprehend the mind, although it was implicitly present in certain developments in classical philosophy (Frege, 1884/1968; Hobbes, 1651/1994; Lebniz, 1887/1997), only acquired scientific status with the advent of computer technology. As the computational procedures were specified, these were inversely used as explanatory models for comprehending mental processes (Gigerenzer 1992). In the same way, the consideration of biological and mental phenomena in terms of their temporal dynamics was only possible once computers allowed the graphic representation of the global dynamics of a system of differential equations.

Technology also refers to the mediation of knowledge through mainly computational tools, of which contemporary science makes unavoidable use (Agazzi and Lenk 1998). Technology then becomes an essential scaffolding in the construction of research programs, favoring new forms of comprehension that mutually favor the sophistication of experimental designs and the specification of empirical results.

Scientific Success or Failure of a Theory

We have mentioned some of the components that give a theory its most persistent identities: the Core and the Frame: an image that tolerates broad interpretative variability and a series of constraints that anchor the core, respectively. We have also mentioned the dynamic components of a theory, which are also parts of its identity but are more susceptible to change. However, there is also another, highly relevant, feature of the dynamic component of a theory: the fact that it allows the emergence of falsifiable elements that will determine the success or failure of that theory. In other terms, if all of the falsifiable elements proved to be truly encompassed by the proposed theory (correspond to it), such a theory would become extremely potent, though this is probably an ideal situation. If, in turn, none of those falsifiable elements proved to be encompassed by the theory, we could consider eliminating such a theory. Finally, it could be the case that only some of the falsifiable elements proved to be encompassed by the proposed theory and some of them not. In this case, the greater the number of falsifiable elements that were to resist refutation, the more successful such a theory would become.

In other words, the empirical statement of a theory is that all the systems to which it is intended to apply, can actually be encompassed by that theory.

Discussion: The Pragmatics of Explanation

Having explained the general components of a theory, it is necessary to establish the relationship between theory, subject and context. It is precisely in this relationship that a theory is sustained, rejected or developed. A subject (P), from his or her personal knowledge[2] (PK) based upon a specific context, establishes the relations between the components of a theory for explanatory and predictive ends. One can therefore assert that this is a pragmatic model, where

$$P\,(PK)\{C, F, P, D, E\}$$

The introduction of a pragmatic perspective implies that the subject is the one to sustain a theory. According to Stegmüller (1976):

> When we ask a question like what it means that a person or group of persons, e.g., a research team, *has* a theory, *accepts* a theory, or *holds* a theory, we are undoubtedly turning to a pragmatic context (p. 165). Let us return now to the task of explicating the notion ‘holding a theory’. A necessary condition, if a person is to hold a theory, is that this person believes certain propositions… (p.168). A person P holds the physical theory T (p. 169).

A consequence of the critique of logical positivism is the re-introduction of the subject in the scene of knowledge. In particular, pragmatic approaches to science imply a contextualized view of scientific activity, where the contextualization anticipates the activity of the subject as a builder and sustainer of theories. Theories are formalized for people to use them, not for their own self-affirmation. Logical formalization can model parts of reality but it cannot model the very relationship

[2] Polanyi (1974) asserts that the allocation of meaning is an act of personal knowledge. ‘Q is true’ refers the personal assertion of Q. The formalization of meaning is created based on its practice, based on tacit knowledge, which acts in a subsidiary fashion upon the explicit focus. So, *understanding* the meaning of formal characters is a non-formal operation.

between logical systems and reality. The formalization of theories is an essential tool of philosophy of science because it contributes to a more precise definition of scientific knowledge. However, it should not be forgotten that scientific description is based on tacit knowledge, on formally un-specifiable know-how (Polanyi 1968, 1970, 1974). If this personal knowledge that sustains a model is annulled, one runs the risk of isolating formalization from its role within its sustaining pragmatic relationship. That is to say, one would conclude that the formal model *is* the described phenomenon, that the formal *explanans* is (or generates) the *explanandum*. This is a clear example of a categorical error, often observed in computationalism.[3] The formal model is considered a member of the class of cognitive phenomena, placing it into the category of phenomena that the model was supposed to explain. In the same way that the orthodox cognitive viewpoint develops algorithmic simulations and concludes that the mind is algorithmic, a dynamic systems theory that build models on the basis of non-linear equations can conclude that the mind is a series of equations. Certainly, the pragmatic view of science favors an appropriate conceptualization of the role of formal analysis in cognitive science.

The pragmatic model presented here is based on contemporary post-positivistic positions. In spite of the inevitable heterogeneity of philosophy of science, it is possible to find some areas of convergence, representing a turn in the classical way science has been understood. What follows is a presentation of some assumptions derived from this post-positivistic convergence, upon which the proposed model is sustained.

Ontological Pluralism and Theorization

It is not an aim of science to reduce the ontology of every discipline to a unique ontological atomism dictated by physics. Each discipline has its own ontology, necessary for explaining and describing its levels of analysis (Bem 2001). Ontological pluralism is a consequence of accepting different levels of analysis and the contextualization of knowledge in a series of specific questions from each discipline that cannot be answered with an atomistic micro-ontology outside their level of description.[4] For that reason, each theory has fundamental assumptions according to its level of description of the phenomena and according to its own structure. Ontological pluralism allows us to work with more than one theory simultaneously, appealing to any of them pragmatically, depending on our specific

[3] The introduction of facts that belong to a particular logical category into another one implies a categorical mistake. The logical type or category to which a concept belongs is the collection of ways in which it can be used with logical legitimacy. When two terms belong to the same category it is possible to put them together, but a categorical error is made when two terms belonging to different categories are combined. In philosophy of mind the main categorical error is to represent the events of mental life as if they belonged to a certain class of categories when in reality they belong to another (Ryle 1949).

[4] In fact, the notion of ontology does not just depend on a particular scientific theory but also on our own humanity. Suppose that a certain person survives for 10,000 years. Her view of reality, ontology and epistemology would be totally different from ours. Where we see objects, she would see configurations; her entire world would be processes, some more stable (like the mountains) and others more ephemeral (like living beings). What we call objects would be a successive series of processes of integration, decomposition, separation and condensation. Our temporality, our spatiality, our very humanity is the frame through which we know.

question and the most suitable level of description in order to answer it. In the proposed model, ontological pluralism admits the co-existence of two or more theories with different ontologies. As will be discussed later, such theories may be analyzed and compared by means of this model.

Supra-Truths versus Knowledge Ecology

We could think of truth in a universal and absolute sense as a *supra-truth*, that is, a truth that does not depend on a specific context. There is no particular level of analysis for this acontextual notion of truth. An acontextual truth, without subject or sustenance, implies a notion of infinity where not just the temporal limit disappears but also its significance. No theory can describe truth as understood in this sense; the notion of truth can only be sustained within a context (Gershenson 2004; Rorty 1982). Neither does truth, in a pragmatic sense, exist in a situation of doubt because one always assumes the capability of distinguishing truths from non-truths with reference to a contextualized personal knowledge. Rather than implying a nostalgic vision derived from the desire for a supra-truth beyond human knowledge, this affirms the possibilities in order to locate the validity of scientific knowledge within a contextualized vision of knowledge. In the proposed model, the subject is the one who sustains the theory, which is not limited to a core and a frame, or even the prototypes, but which also includes the application domains, the empirical extensions and even tacit knowledge. Furthermore, statements within a theory cannot be analyzed in isolation but only as a whole.

Intra-Theoretical Generalization and Inter-Theoretical Comparison

The proposed meta-theoretical model can be applied to different theories with one common research approach. The process of generalization is carried out on each component of a theory (generalizing and specifying the core, the frame, prototypes, application domains, empirical extensions and explanatory strategies). In this way, one can undertake a rational reconstruction of the set of theories that make up a general research approach.

Comparison is also possible between theories belonging to different research approaches. This is possible even when two generalized theories have global differences (i.e., due to different application domains), even if their cores and frames are identical (Stegmüller 1976). This could even happen in the case of theories that are different at the empirical level when the dynamic elements are different and therefore the achievements of the theories are not the same. On the other hand, if there is no formal identity, relations of partial equivalence can be studied. It then becomes possible to compare certain aspects of the core, frame, explanatory strategies or other components.

Comparisons between theories are also present in Kuhn's works. Kuhn declares that it is wrong to claim a relation of synonymy between incommensurability and impossibility to compare. After all the controversy surrounding Kuhn's supposed irrationality, as a consequence of his *Structure of scientific revolutions*, during the 60s and 70s, this author sustained that incommensurability is predicable of theories, which thereby limited the applicability of this concept. Furthermore, during the 80s, Kuhn stated, in his article entitled *Commensurability, comparability and communicability*, that incommensurability is only predicable of some terms, and, so, it becomes now a local phenomenon (Kuhn 1983) which leaves enough room for comparisons. Nevertheless, terms such as paradigm and incommensurability, encouraged many discussions between philosophers of science, which resulted in great efforts to try to refine the meaning of such concepts. In the meta-theoretical model proposed here, the non-T-theoretical concepts provide the relative empirical ground for the theory, and, hence, the meanings of such terms are not determined by the theory in question. It is possible, of course, for those concepts which are non-T-theoretical within the theory we are interested in, to be determined by another theory. However, in the case that two rival theories share the same empirical ground, meaning that they include the same non-T-theoretical concepts, comparison between the theories will be achievable, alongside analyzing their fertility. This is probably an issue of degree. It could be, for example, that the two theories do not entirely share their empirical ground, but, do at least share a part of it; and as Quine states, although it would be a mistake to consider the statements of a theory in isolation, it would also be a mistake to deny the double dependence of science on language and experience (Quine 1951).

The mapping of relations between components can also be compared, in terms of their explanatory value. For example, to carry out a brief comparison of orthodox computationalism and the more recent cognitive dynamic approach, the generalization and comparison processes of each research approach can be elucidated (Cosmelli and Ibanez 2008). As in the case of truth, explanatory value is context-dependent. However, again, this does not mean that we should be nostalgic because we lack an objective criterion for it. Science is a human activity that deals with human purposes and interests, and it not cause for concern should such purposes and interests change over time or place.

In the proposed model, a pictorial image of the core of computationalism is given, using the metaphor of the serial computer that processes abstract symbols. Within this framework, the ontological assumptions are based on the atomization and fragmentation of cognitive phenomena. These restrictive assumptions are based on tools from the processes of serial calculi. The explanatory assumptions are based on decomposition and localization, also known as a homuncular strategy. This research approach makes use of computer simulation and formal derivation as explanatory strategies (based on the symbolic calculi). Application domains are based on the description of cognitive phenomena, which are separable and explicable by means of the processes of serial formalization (e.g., chess games, expert systems). The computer-developed prototypes have been based mainly on the computational simulation of the interesting phenomena.

On the other hand, the more recent dynamic approaches to cognition (i.e., synergetic, dynamic approach to cognition, field theories of cognition, etc) have a core that is based on the brain (or cognition in general) as a dynamic system represented by a time-space topology. The framework of this core is based on the ontology of processes and on ontological pluralism. The tools of mathematical complexity theory are considered the language of cognition. The explanatory strategies are sustained by emergent descriptions (of downward causation type) and derivations of mathematical laws (differential equations). The theoretical prototypes are strongly endorsed by computational simulations (not on the basis of symbolic processes like in computationalism, but on the basis of mathematical equations).

Although in a brief description of the two meta-theoretical models they seem to be remarkably different, the common use of computer simulation and formalization present in both approaches should not be ignored. Whether both approaches are intrinsically related or not is not clear. Nevertheless, dynamic approaches have extended the empirical extensions towards scopes not traditionally approached by the orthodox computationalism. A systematic meta-theoretical analysis can shed light on these aspects of both research programs (Ibáñez 2007b; Ibáñez and Cosmelli 2008).

Counter-Arguments to the Proposed Meta-Theoretical Model

Finally, two counter-arguments can be made against this meta-theoretical model: one coming from a logicist perspective, which does not include the subject in the analysis of scientific knowledge, and the other from a sociological point of view, which dissolves the subject into the scientific community. One cannot affirm *ipso facto* that the logicist and sociological perspectives make these criticisms, but a counter-argument appears to be expressed differently by the two viewpoints. Both counter-arguments, despite their apparent antimony, are based on a common concept of subject. This is the Cartesian concept of subject, separated from its community and subjectively isolated from the world (Cornejo 2006). Therefore, the meta-criteria of both counter-arguments consist of the elimination of this isolated and subjective subject, whether via transcendentalization using formal logic or through the dissolution of the subject into the scientific community. Let us examine these counter-arguments.

(a) The philosophy of science should be based on abstract formal logic; if it includes the subject, one will no longer be doing theory of science, but rather, theory of the psychological subject.

The above argument supposes that scientific knowledge is adequately represented by formal logic, which is necessary and sufficient for science. Scientific knowledge would not require any other knowledge that might act in a subsidiary fashion to explain phenomena. This implies that scientific knowledge does not need a subject in a particular context to establish the truth of knowledge.

When conceptualizing subjective knowledge one must not confuse privacy with solipsism. Many thoughts are subjective because of the fact that they are private but they do not imply an idiosyncratic language or thinking that is un-translatable for another listener. We establish truth values based on our personal knowledge in a shared world and experience. Comprehension is the consequence of a participative world. Language and experience do not imply the negation of inter-subjectivity. If the subject does not possess an isolated and dangerous subjective knowledge then there is no reason to deny its specific dimension.

This model is not a model of the psychological subject; it is a model of the theory of science *sustained by a subject*. Once the transcendentalized subject has been displaced from Cartesian logic, it is possible to conceive of an ecological rationality that does not follow the canons of formal logic (Gigerenzer 1992). The use of formal knowledge is normally supported by non-formal and implicit knowledge (Gershenson 2004) relevant to understanding what is being done (Edmonds 1996). Central mathematical notions (e.g., the notion of infinity in set theory) imply meanings that are impossible to formalize and are indispensable to comprehending the meanings themselves (Longo 1999; Lakoff and Núñez 2000). There is a background of knowledge that is used to comprehend formal affirmations (Searle 1978, 1991, 1992). The role of implicit metaphors and analogies as a basic form of tacit knowledge is relevant not only to neurocognitive phenomena (Cornejo et al. 2009; Ibáñez et al. 2010a, c) and our general knowledge (Johnson 1991; Indurkhya 1992; Gibbs 1994; Lakoff 1993; Nerlich et al. 2003; Venville and Treagust 1997) but also to scientific activity (Lakoff and Johnson 1980; Lakoff and Núñez 2000; Baake 2003; Brown 2003; Davidson 1978; Eisemberg 1992; Gentner and Jeziorski 1993; Leary 1990; Longo 2003; Ortony 1993; Paton et al. 1994; Petruccio 1993; Root-Berstein 2003).

A model of science that takes into account the specifically human character of knowledge will avoid an excessive reduction of the scientific methods. Again, this does not mean that formalization in philosophy of science should be discarded, as such an elimination would once again suppose the Cartesian split that we attempt to overcome. On the contrary, this model involves including formal analysis within an ecologically based or bounded rationality. This model is not an irrational or idiosyncratically subjective model. It is a model of ecological rationality in which the formalization made by scientists is not necessarily based on the exclusive syntactic use of knowledge but on the coordination between formalization and tacit knowledge (all knowledge that is not formalized in the model but which is used to understand the model and to coordinate the adaptation between the model and reality).

(b) The subject as such is irrelevant, as the scientific community or a specific culture are the ones to establish knowledge's pragmatic relationship.

This argument is also based upon a series of suppositions: knowledge depends on a particular context and a scientific community is the one to establish the degree of scientific validity. Therefore, there must be social representations or discourses that determine beliefs and truth values. However, there is a supposition required to sustain the counter-argument: just as with the previous thesis, this is a Cartesian subject, isolated and idiosyncratically subjective. Because if not, what need would there be for eliminating or dissolving the subject in the community? There is a supposition that the subject is not part of a particular context and that subjectivity is an isolated solipsistic property. Because of this, the model must be eliminated, appealing to the cosmovision of a community that is paradoxically made up of subjects that are simultaneously dissolved (Cornejo 2004, 2007; Cornejo et al. 2007).

If the Cartesian view of the subject is removed, then there is no reason to eradicate the subject. The pragmatic and contextualist perspectives envision the subject as inter-subjectively constituted. In this way, the notions of meaning and interpretation are not depersonalized by putting them into a metaphysical realm of social knowledge. On the other hand, meaning and interpretation continue to be context-dependent, as the subject which sustains them has been constituted inter-subjectively.

Conclusion

We have presented here a meta-theoretical tool for the comparison of theories in the field of cognitive science. The study of mind necessarily implies different paradigms and refers to differing processes and levels of analysis. The pragmatic model of meta-theoretical analysis allows cognitive theories to be described, integrated and compared. This model has been explicitly and implicitly applied in the meta-theoretical analysis of the social neuroscience research approach (Ibáñez et al. 2009a, b); to propose alternatives to computationalist approaches to research (Ibáñez 2007b; Cosmelli and Ibanez 2008; Barutta et al. 2010a) to analyze the naturalization of consciousness from the neuroscience approach (Ibáñez 2007a; Barutta et al. 2010b) and to investigate the dynamic approaches to cognition (Ibáñez 2008). We presented here the explicit meta-theoretical tool to allow further comparisons in the cognitive sciences.

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