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The Heuristic Structure of Scientific Knowledge*

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ABSTRACT

We examine two major perspectives in the literature on domain specificity in cognition: in one of them cognitive modules are "intuitive theories"; in the other they are dispositional structures. Both of these positions accept that there is a continuous line from ordinary to scientific reasoning; nevertheless they interpret this continuity differently. We propose an alternative way of understanding the relation between ordinary and scientific reasoning: the continuity thesis holds because heuristic structures play a fundamental role in both types of reasoning. Our main contention is that cognitive modules can be thought of as heuristic structures and that, since science is a complex of practices that embody different heuristic structures, science should be understood as a complex of cognitive modules.

Introduction

The idea that not only "perceptive," but also "reasoning" processes are modular has been supported by the results of a number of studies (e.g. Sperber, Premak and Premak 1995; Hirschfeld and Gelman 1994; Barkow, Cosmides and Tooby 1992; Carey and Gelman 1991) that seek to show how many of our conceptual processes are governed by domain-specific competencies. It is widely agreed upon that a plausible description of the architecture of the human mind should appeal to the operation of multiple modules each of which picks out a set of entities in the world and is responsible for processing privileged sorts of information about

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those entities. Underlying this agreement lies an important discussion regarding the nature of the cognitive modules and domains (Fodor 2000; Pinker 1997; Sperber 1996; Carey 1995; Atran 1994; Karmiloff-Smith 1991; Chomsky 1980): while modules have traditionally been thought of as innate, hardwired and encapsulated cognitive mechanisms (Fodor 1983, 2000); Susan Carey (1995) has argued in favor of a more general characterization of them − from her point of view, modules are domain-specific cognitive abilities that might be functionally individuated and described as theories. Distinct versions of modularity lead towards different notions of reasoning and, thus, to different ways of understanding the so-called "continuity thesis" (Gopnik 2002; Carruthers 2002; Carey 1995; Sperber 1996; Atran 1994), according to which there are important similarities between lay and scientific cognition. Our claim in this article is that this thesis is better understood in terms of the alignment of resources that takes place in modular structures distinctive of cognitive practices.

Some different views of modularity

Two of the prevailing positions regarding massive modularity are the following: the "theory-theory," according to which cognitive modules are informational structures that can be accounted for in terms of intuitive theories, where such theories are "cognitive structures that characterize the causal mechanisms at work in the world, and which therefore provide fodder for explanation" (Carey 1995, p. 272).[1] The second position − which Carey qualifies as the "first-order module" view (Carey 1995, p. 280) − establishes that such modules are dispositions to organize information in certain ways and which guide our reasoning while performing specific types of inference (Sperber 1996; Atran 1994; Karmiloff-Smith 1992).[2]

[1] Gopnik and Meltzoff also support a version of the theory-theory. According to them, the defining features of theories are the following: they are abstract, coherent, appeal to causality, make ontological commitments and support counterfactuals; they also allow prediction, interpretation, and explanation. Theories have some dynamic features that account for theory change (1997, pp. 32-41).

[2] Susan Carey explains the difference between these two positions in terms of their commitment to innateness. She says: "The intuitive theory view does not take innateness as a necessary property of a cognitive module ... the intuitive theory view claims young children's theories of bodies and mind as cognitive modules because they meet the criteria for intuitive theories; it is accidental that they may also be innate. In contrast, Sperber's

The first position asserts that a domain of knowledge is a set of phenomena involving the entities recognized by the theory in which they are embedded; in this sense, the domain is determined by the principles that constitute the module. In contrast, the "first-order module" view establishes that cognitive domains are not only determined by the module, but also by the environment and the evolutionary history of the organism and, thus, that the domain of a module is not a property of its internal structure. Domains are, rather, bundles of information in the organisms' environment that satisfy the module's input conditions which have been evolutionary selected (Sperber 1996, pp. 134-136).

Different versions of the continuity thesis

The two positions we have before mentioned agree in that there is a continuity between lay and scientific cognition, even though they differ as to the specific way in which the continuity is spelled out. Peter Carruthers (2002) has formulated this problem in terms of the nature and extent of the cognitive changes needed for science to begin. One of the most extreme versions of the continuity thesis is offered by Alison Gopnik (1996, 1997, 2003) who asserts that *no* changes were needed. From her point of view the processes underlying children's reasoning are *identical* to those processes that subserve scientific theory change (Gopnik 1996, p. 486; Gopnik and Meltzoff 1997, p. 3). The main idea in her proposal is that infants are born with a lot of theoretical information that is confronted with evidence and that keeps changing along cognitive development: infants are little scientists who gather data, frame hypothesis, test predictions, *develop theories*, and choose among them. The fact that children are endowed with such mechanisms indicates that adults are scientists who have renounced to exercise their scientific capacities. Gopnik asserts that

> everyday cognition . . . is simply the theory that most of us most of the time have arrived at when we get too old and stupid to do more theorizing. . . We might think of our enterprise as scientists as the further revision of the theory by the fortunate, or possibly just childish, few who are given leisure to collect evidence and think about it. (Gopnik 1997, p. 214)

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view . . . claims these domains because they meet the criteria for innate domain-specific reasoning. . ." (Carey 1995, p. 274).

Starting from this controversial and extreme version of the mentioned thesis, there are many more moderated versions of it,[3] such as those supported by the two perspectives we will discuss, that is, the theory-theory and the first-order module view.

The "first-order module" view asserts that the continuity hypothesis is sustained by the fact that the structure of ordinary conceptual modules severely constrains and thus enables the initial elaboration of the corresponding scientific fields (Atran 1994). The intuitive theory point of view considers that besides such constraints, the continuity holds on two more facts: ordinary and scientific reasoning (1) are both guided by principles that license our inferences in a particular domain, and allow us to identify the entities pertaining to it, (2) construct objective explanations that explicitly formulate the causal mechanisms that are at work in the world. These ideas, in conjunction with the supposition that the content of concepts is determined by the role that they play in their embedding theories, lead the theory-theory to affirm that conceptual change must be accounted for in terms of theory change. This *does not* imply, though, that *all* the processes underlying cognitive development mirror the processes subserving theory change: often cognitive development is dependent on theory enrichment which consists on "the acquisition of new beliefs formulated over a constant conceptual repertoire" (Carey and Johnson 2000, p. 227).

After analyzing the positions just presented, we will advance a different perspective according to which cognitive modules can be thought of as dispositional structures that need not be theory-like nor innate. We will argue that scientific knowledge has a heuristic structure; it is best characterized as a complex whole of structures which integrate heuristic rules and devices, as well as norms and standards that regulate the transformational processes of material and conceptual systems. Those structures get organized by scientific practices and, thus, from our perspective, a plausible description of the modular structure of knowledge requires taking into account not only the social and environmental factors that have been traditionally neglected, but also the role played by the evolution of the different

[3] This position has been widely discussed in the literature, i.e. Carruthers, Stich and Segal 2002; *Philosophy of Science* 63, 1996; some critical articles can also be found in Hirschfeld and Gelman 1994.

material and conceptual resources that are part of the normative environment articulated by the mentioned practices. The first-order module view is compatible with this account of scientific reasoning. Nevertheless, we will emphasize, as a point of departure to explain the sort of continuity that matters, the heuristic structure of reasoning common to both ordinary and scientific reasoning which, in both cases, can be explained as the result of an evolutionary process.

The Intuitive-Theory Theory

Peter Carruthers (2002) has pointed out that one of the most important differences between Gopnik's position – what he calls the "theorizing-theory" – and the perspective adopted by most of the advocates of the "theory-theory" is that the latter assumes that intuitive theories partly emerge through the maturation of a cognitive module, and are *not* uniquely the result of a process of theorizing analogous to the processes scientists use when constructing their sophisticated theories.

Susan Carey is an advocate of the so-called "theory-theory." From her point of view, the fact that there are deep similarities between cognitive development in children and theory change in science does not imply either that the processes subserving theory change in science are identical with the processes underlying cognitive development in infancy, nor that children are little scientists capable of formalizing their knowledge. Moreover, she asserts that the analogy between scientists and children can only work out if we specify what aspects of cognitive development depend on theory change. Many of our cognitive achievements do not result from changes of any kind and that is mainly because "they depend on core cognitive systems that emerge early in development and remain constant thereafter" (Carey and Spelke 1996, p. 516). The point is that there are different types of processes underlying cognitive development, and in order for the analogy between ordinary and scientific reasoning to work out it is necessary to distinguish between knowledge acquisition via the enrichment of an existing conceptual base and that which leads towards the acquisition of new concepts and which involves conceptual and, thus, theory change.

The distinction between enrichment and conceptual change has been associated with the distinction between "core" and "constructed" domains. A domain of knowledge is characterized as a set of phenomena that involves the entities that are picked out by a particular cognitive module, where such modules are the mental representation of domains. While "core" domains do not result from conceptual change, the acquisition of constructed theories *requires* it and, in this sense, it is possible to assert that knowledge acquisition in childhood involves theory change (Carey 2000, p. 227). Let us further examine these ideas.

Conceptual change through cognitive development

The question regarding which domains are "core" domains is not settled.[4] Nevertheless, there is a wide agreement in that "core" domains are those entities in the world in the extension of core modules, and core modules share the following characteristics: they are (i) innately specified or emerge early in infancy, (ii) widely shared even among other primates, and (iii) very stable during development (and across cultures). Moreover, core modules are very close to perceptual knowledge in that they are highly modality-specific and in that the entities and the principles that articulate them are identifiable from spatiotemporal analysis (Carey 2000, p. 226); for example, the module that represents the domain of *physical object* is specified by cohesion and spatiotemporal continuity, while the *intentional agent* domain is specified by self-generated, irregular, contingently driven motion.[5]

Constructed domains are different from "core domains" in each of the before mentioned respects, and they are originated in constructed knowledge whose acquisition *requires* conceptual change. Concepts are structured mental representations that codify the relations we establish

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[4] Some authors assert that there is conclusive evidence to establish that the psychological module (whose domain includes people and their minds), the physical object module (whose domain includes objects and the physical relations among them), and the numerosity module are first-order or core modules (Carey 1985; 1995, p. 270; 2000, p. 226; Spelke 1991, 1994; Leslie 1994; Gelman and Brenneman 1994). There is a very important debate regarding the characterization of folkbiology (Atran 1995, 1994, 1990; Carey 1995; Keil 1994; Wellman and Gelman 1992), and there is no agreement on whether the mentioned ones are the only core domains there are. Carruthers asserts that we might soon be surprised to find out that the set of innately endowed modules "is much more extensive than is generally recognized. . ." (2002, p. 17).

[5] From this perspective, core modules are constituted by a single knowledge system – that is, the processes of perceiving and reasoning that are embedded in them are guided by the same set of domain-specific principles. For a thoroughgoing discussion on this issue, cf. Carey 1985, Carey & Spelke 1994.

between them in accordance with an intuitive theory (Margolis and Laurence 1999), where such theories are cognitive structures that embody a person's ontological commitments and provide very general and intuitive explanations for the phenomena involving the entities recognized by their domain (Carey 1995, p. 272). If this notion of concept is correct, then conceptual change necessarily implies theory change and, then, it is possible to assert that constructed modules are, mainly and most importantly, intuitive theories. Their acquisition implies conceptual change (or new concept acquisition) and given that conceptual change implies theory change, the acquisition of such modules supposes theory building capacities and requires some theory development.

Now, according to Carey, conceptual change takes place when we acquire new concepts that are not definable in terms of concepts already held (Carey 2000, p. 227). The idea underlying her proposal is that conceptual content is determined by the role concepts play in intuitive theories and, thus, that conceptual change is implicated in those cases of theory development that involve incommensurability, where two theories at different times "are incommensurable insofar as the beliefs of one cannot be formulated over the concepts of the other – that is, insofar as the two are not mutually translatable" (Carey 2000, p. 227).

The theory-theory and the continuity hypotheses

Very much of our knowledge is constructed knowledge. Therefore, a very important number of the processes underlying knowledge acquisition and cognitive development involve conceptual change. According to Carey, the history of science gives us good reasons to assert that scientific reasoning and scientific theory development involve conceptual change. Thus, it is in this process of new concept acquisition that the analogy between ordinary and scientific reasoning holds: intuitive theory building and scientific theory building are very similar not only in that they are both subserved by a process of resistance to changing theories,[6] but also in that they both involve creating mappings across systems of understanding, be they core or constructed systems. Carey and Spelke assert that the

[6] There is a documented tendency in human beings – be they children, common adults or scientists – to stick to their initial theories even when they have been showed to include contradictions or to be mistaken.

> processes for combining the representations from domain-specific systems of knowledge provide one potential mechanism of theory development and conceptual change and ... studies of young children provide a promising means to study these processes. (Carey and Spelke 1996, p. 528)

The continuity thesis also holds in that scientific and common-sense reasoning *aim* at unifying explanations. These authors affirm that

> Although human thought ultimately is based on domain – and task-specific cognitive systems, humans have both the ability and the propensity to map these systems to one another so as to arrive at better and more encompassing ways of understanding what goes on around us. These mappings are a source of conceptual change, both in children and in scientists. On this view, the unity of thought is best construed as a *goal of human reasoning, always present* although never perfectly achieved. (Carey and Spelke 1996, p. 529, *our emphasis*)

All that has been said does not imply that ordinary folk or children actually do formalize their "constructed" knowledge or explicitly marshal evidence for it. All that it implies is that children and ordinary adults must: (1) be capable of discriminating the entities that constitute the domain of their intuitive theories, (2) be able to ascertain which is the relevant data needed to evaluate the hypotheses licensed by their intuitive theories and, (3) appeal to theory-specific causal mechanisms to explain the interactions among the entities in a particular domain (Carey 1995, p. 273). In other words, it implies that common adults or children might (at different points of cognitive development), as do scientists (at different points of scientific development), explicitly formulate or recognize the underlying core principles in their initial intuitive theories. This allows them to revise and modify such principles, to generate mappings across domains, to generate new domains of knowledge and, eventually, to produce sophisticated scientific theories.

Scientific Development and Conceptual Change

We agree with the position just examined in that there is continuity between everyday and scientific reasoning. We also agree with Susan Carey in that the possibility of accounting for the similarities between the processes subserving both types of reasoning requires a better understanding of cognitive development and a much more complex picture of science than the one Gopnik offers. In particular, we think she is right in asserting that both science and ordinary cognition aim at integrating or unifying knowledge that stems from different sources so as to generate explanations, predictions and, more generally, representations that lead to a better comprehension of the world. Nevertheless, we disagree with her in that conceptual change is best characterized by (intuitive) theory change. As we will argue in what follows, a perspective which assumes that the history of science is better accounted for in terms of the integration of cognitive resources in normative environments, allows us to draw a different line from everyday to scientific cognition; one that accounts for the similarities in both types of reasoning in terms of the alignment of material and cognitive resources in normative environments which get articulated in practices.

The main idea in our proposal is that scientific conceptual change essentially relies on the acquisition of new practices which, in turn, promote or discourage the use of a given set of concepts, norms or standards. A norm, from this perspective, is a guide telling us what actions are permitted or have to be done in a given context. While standards also guide actions, their normativity takes place through material settings or devices, as well as trough institutional surveyance. In other words, a standard refers to a specific set-up or a specific value (or interval of values) of a parameter that plays a role in tuning what can be done or has to be done, or in making precise the sort of situations in which an action is permitted. For example, the atmosphere required and the techniques used for producing bottle water for human consumption have to satisfy several standards of purity, temperature, etc.[7]

Scientific development as the succession of different (and incompatible) theories

Scientific knowledge has traditionally been characterized as theoretical knowledge: it is supposed to be the result of a certain type of method that leads us from observation to theories. Theories are often conceived of as sets of (true and justified) beliefs that are coherently articulated as propositional structures which are either true or false. From this

[7] There are of course also conceptual standards. Grammar plays the role of a standard of correct writing. Often, as in the case of grammar, the concepts of standard and norm are interchangeable, at least in many contexts.

perspective, scientific knowledge growth should be accounted for in terms of the dismissal of false or incoherent theories and the postulation of new ones that eliminate the possible contradictions or explanatory limits of the old theories. In this sense, theory change is supposed to be a good measure of scientific knowledge growth and the epistemic attitude that scientists take towards different theories is supposed to play a central role in its explanation.

The ideas just mentioned, among others, have led philosophy of science to put a very strong emphasis on the task of providing criteria for theory choice and to dismiss the (epistemic) role that settings or situations (involving the different aims, values and norms sustained by different scientific communities) might have in a plausible account of scientific development. In short, scientific knowledge has been accounted for solely in terms of the structure and dynamics of the theoretical structures proposed by scientists and, therefore, philosophy of science has become a philosophy of theory development.

Many sociologists of science (e.g. Biagoli 1993; Shapin and Schaffer 1985) have argued that science is a much more complicated enterprise, and that in order to account for scientific knowledge development it is necessary to take into account many cultural or social factors that play an important role in the determination not only of which theories will be taken seriously, but also which lines of research will be undertaken.[8] Sociologists, for example, have shown the importance of studying the so-called "local cultures" of science in order to understand how scientific standards are determined. Nowadays several philosophers of science have taken notice of the importance of values, practices and cultural settings in understanding science (e.g. Rouse 1996), eventhough often they remain close to a theoretical account of science (Kithcer 1993; Giere 1988).

Susan Carey seems to agree with this critical vision of the traditional picture of science; nevertheless, the idea that conceptual change implies incommensurability is intrinsically associated with such traditional view of science. This is so because the inference mentioned – if there is conceptual

[8]Faucher, Mallon, Nazer et al. criticizing Gopnik's account of scientific knowledge have argued, that science is a norm governed activity and the norms that govern such activity "…not only affect what scientists do, they also affect … which theories are accepted, which theories are taken seriously, and which theories are rejected" (2002, p. 8).

change, then there are two (partially) incommensurable theories – assumes that every time a concept changes, a new theory – one that is (partially) *not* translatable, and thus not fully evaluable from the perspective of the old theory – is postulated. The (partial) incompatibility between the new and the old theories obliges scientists to choose the one among them that they consider best – i.e. the theory which has more explanatory power, more predictability, or any of the epistemic virtues considered necessary in order for theories to be acceptable. From this it follows that conceptual change does not only lead scientists to change their appreciation of a particular theory, but to stop believing (or accepting) a theory and to start believing a new one. In other words, conceptual change implies theory *replacement* and, thus, it would seem reasonable to assert that scientific development is best accounted for in terms of the succession of (sometimes incompatible) theories.

In what follows we will use two different examples to show that scientific knowledge is best thought of as the pool of resources that are available to carry out the transformation of material and conceptual systems. This pool of resources is articulated by the practices involved in carrying out a given task. Thus, a plausible description of scientific knowledge growth requires taking into account the way in which cognitive resources, as well as other type of resources, get integrated into scientific practices, and eventually whole scientific traditions. Such practices promote the use of particular concepts and heuristic structures that – when considered successful – tend to be adopted by other practices. A heuristic structure is, according to us, a collection of heuristic procedures, norms and standards that regulate processes of transformation of material and conceptual systems.[9] Different scientific practices are typically confronted with different types of problem. This, among other factors, leads them to hierarchically organize and to assign specific functions to the processes that constitute heuristic procedures. Such particular ways of organizing heuristic procedures gives rise to different heuristic structures. The repeated use of a heuristic structure leads to its

[9] Heuristic procedures are processes of transformation of material or conceptual systems that might have as a consequence the implementation of a heuristic rule (Martínez 2003, p. 56). Heuristic rules are rules with a distinctive bias closely related with the structure and function of a cognitive module. For example, the use of a representational heuristic points to a modular structure that guides inferences of a certain sort.

refinement – that is, towards a clear differentiation of its functions – which, at the same time, leads towards its modularization – i.e., to its decomposability into relatively independent parts that, at least to some extent, can be modified or replaced without modifying or replacing other parts and without loosing its function. This modularization is vinculated with the encapsulation and domain restricted applicability of its components.

Now, the norms that are constitutive of heuristic structures can refer to very different things, for example: (1) to the type of reasoning acceptable in modeling probabilistic phenomena in concrete situations, (2) to the type of abstraction appropriate for modeling a given type of phenomena, (3) to the type of situations in which a given heuristic rule should or could be used appropriately, (4) to compare prices in a supermarket or evaluate risks associated with possible actions. They can also be implicit in a taxonomy presupposed in the formulation of a problem; mathematical modeling in physics is associated with specific structures of norms that have to be learnt implicitly (by learning to use a given mathematical equation to generate models of phenomena, for example). To the extent that they are successful in solving an important class of problems and that the heuristic structure in question gets refined and modularized it is possible to export such structure to other domains (chemistry or economics say) and try to use such resources as a point of departure for modeling other type of phenomena. This perspective will lead us to assert that the notion of conceptual change has to be inserted into a more complex account of the evolution of norms and standards, and thus to a different formulation of the continuity thesis.

Understanding the relation between theories: the epistemic role of technology

It is often assumed that conceptual change requires theory change. The orthodox account of the "Copernican revolution" is a classical example of this assumption. Copernicus theory, so the account goes, *substituted* Ptolemy's model of the structure of the planetary system. Copernicus provided not only a more accurate and better model for a given set of phenomena, but also showed that Ptolemy was wrong and, thus, that his model had to be abandoned.[10] It is commonly asserted that, analogously,

[10]This account is historically misleading: very seldom scientific change can be characterized as changes of theories. For the moment we will assume that it is basically correct at least in some cases.

the classical Newtonian theory of mechanics was shown to be false and substituted, at the beginning of the 19th century, by quantum mechanics. Such an account of the relation between classical and quantum mechanics leaves completely aside some interesting interpretations of the historical record. For example, it rules out the possibility that some physical systems have classical states, some others have quantum states and still others have both, but that there is *no* systematic way of characterizing those systems as having quantum *and* classical states (Cartwright 1995; Martínez 2003).

The just mentioned possibility is sustained by the idea that quantum mechanics is a theory that aims at understanding how quantum states evolve and interact, so that it will only seldom predict facts about the classical states of a system. An underlying assumption in this proposal is that there is no universal principle that allows us to relate quantum and classical states and, thus, that the descriptions of quantum states are *contingently* related to classical states. From this perspective, every description of a quantum state is related with a classical description via the use of technological systems. In other words, the construction of the interphases between quantum and classical states *requires* the use of technology: the different technological systems that have been developed since the end of the XIX century have allowed scientists to formulate successful predictions by exploiting "accidentally" established causal relations – relations that are the product of a particular historical development of the causal structure of the world – between the quantum and the macroscopic levels.[11]

The main idea in this example is that technology plays an important role in the characterization of what there is, not as part of a simple instrumentalistic account of theories, but rather as part of an account in which the norms implicit in the construction and use of technological devices enter into the construction of models of phenomena. We cannot go further in the explanation of how technological mediation plays a role in the conformation of basic epistemic categories in science (such as prediction

[11] The inferences that technological systems allow us to make in particular situations *need not* be valid with respect to other technological systems. That is, while technology allows us to map the relations among states and to explain them, it does not lead us progressively towards a general characterization of the structure of the world. More generally, the idea is that "frozen accidents" can be the basis of what appears to us as fundamental causal structure (like some aspects of DNA structure, for example) of the world. Cartwright (1995) presents another examples of such causal accidentally.

and reliability) and, thus, in the establishment of epistemic criteria that determine when a given theory is acceptable.[12] Nevertheless, it should be clear that it is not plausible to think of scientific development mainly as a process of substituting (or replacing) theories.

If what we have been putting forward is correct, then it is plausible to assert that the development of new concepts in science often implies the development of technological systems (that is, bundles of models, devices and material conditions). So that conceptual change *does not* only imply theory change: it must also imply changes in models, devices, and material conditions that allow us to make successful predictions and that lead us to plausible explanations. Furthermore, if we accept that quantum mechanics can be a good guide to develop models of certain phenomena and classical mechanics a good guide to develop models of others, and that the possible characterization of a phenomena as in the interphase of classical and quantum theory might be particularly enlightening, then we can affirm that quantum and classical mechanics are *not* exclusive. The changes suffered by the concept of physical system when the quantum theory was proposed did not imply the abandonment (or disbelief, or replacement) of one theory in favor of another new and correct one. It is in this sense that such changes *did not* imply *a change in theory*. We do not want to deny that conceptual change involves theory replacement in some cases, but the claim is that, at least in science, it often *does not* involve such replacement. If we think in terms of models this idea is clearer: in the same sense that acquiring a new set of tools does not lead us to trash another set, to find out that a certain model that allows us to calculate the position of a planet next month is not quite accurate in certain circumstances does not lead us to replace it with another. Rather, we have to learn where such model better fits into the geography of our conceptual and normative landscape. In what follows we will reinforce this conclusion through a discussion regarding the autonomy of traditions in science.

[12]The criteria in question are, in part, determined by basic epistemic categories, so that if technological mediation plays an important role in the conformation of the latter, it will also do so in the establishment of the former.

The autonomy of scientific traditions and the evolution of standards

Many studies have been carried out to show the relevance of experimental work in science (e.g. Galison 1987; Pickering 1984). They often emphasize the fact that experiments are not used to infer something from the prevailing theories; in many and very important cases experiments are used to generate autonomous knowledge. Hacking (1983) has stressed the idea that the autonomy of experimental traditions stems from the stability of the phenomena with respect to alternative theories that might be used to describe them. Beyond this, Martínez (2003) has proposed that such autonomy refers not only to other theories, but also to experimental knowledge and other scientific traditions.

The main idea in our proposal is that an experimental technique is a collection of heuristic procedures aimed at the transformation of a material system and at establishing accurate predictions. What is a prediction and what is an accurate prediction depends on norms that are part of the normative environment of a scientific practice (that often incorporate theories). The development of a technique for the production of a protein, for example, involves changes in norms and standards that often lead to new concepts or classifications of things and phenomena, but not necessarily involves a change of theory. The following example aims to show that the history of science should not be thought of as the history of theory change, but rather in terms of the integration of different cognitive resources. The account of scientific knowledge development attached to our view of scientific history allows us to take into account the specific manner in which the different existing perspectives can be used in a profitable manner so that a better understanding of the world is achieved.

It is often asserted that the concept of evolution as a directed process was abandoned once Darwin advanced his new theory of evolution. While it is true that a very important achievement of Darwin's evolutionary theory was that it allowed integrating the results established by different evolutionary theories developed during the 19th and 20th century biology, it does not seem very precise to assert that Darwin's "historicist" concept of evolution completely substituted the notions underlying the mentioned theories.[13] The differences and similarities between the proposed theories are complex and, from our point of view, they have to do with the special weight that their authors gave to the concepts of evolution prevailing in the different biological traditions:[14] for example, Spencer's notion of evolution was basically sustained in the development of embryology; Haeckel's was more directed towards morphology, and Darwin's was formulated through a "population perspective" that was related to biogeography.

An important problem in the philosophy of biology is to explain how it happened that from the "local" (i.e., in embryology, paleontology, biogeography, etc.) ways of understanding evolution an agreement was reached regarding the importance of Darwin's theory for the development of a unified vision of biology. But it is our contention that this important problem cannot be reduced, in any interesting way, to our epistemic attitude towards a theory or a series of theories.[15] From our perspective science is a bundle of autonomous traditions and, thus, in order to understand its development it is necessary to recognize the role they play in the integration of practices.

A scientific tradition is a specific way of posing problems, generating explanations and, in general, of producing knowledge that stems from distinctive scientific practices that exploit sociological and cognitive resources in a stable manner. Two importantly different types of traditions are the theoretico-mathematical and the historical: while the first one aims at constructing models that lead to the quantification of purely qualitative theories, a historical tradition seeks at understanding processes. In biology, a very important theoretical tradition stems from Darwin's writings: from this perspective, an evolutive transformation is the result of the differences

[13]As Richards (1992) has pointed out the concept of evolution has evolved a lot since Darwin, and the idea that this conceptual proposal did not recur to teleological assumptions is a matter of degree and emphasis.

[14]An important difference between Darwin's theory and the rest of them is the thought that "natural selection" explained evolution. The fact that this, to our eyes, "crucial" difference among the proposed theories was ignored during the XIX Century supports the idea that Darwin's evolutionism is the result of a sum of factors converging from different practices and traditions.

[15]We do not want to imply that theory selection is *not* a problem for philosophy of science, but it is not all. Scientific knowledge growth is a very complex process and the possibility of explaining the similarities between ordinary and scientific reasoning depends on taking into account several factors that are required for conceptual change to take place.

in the reproductive success of organisms in a population in virtue of the function of some heritable characteristics possessed by the organisms in question. At the same time, the discussion regarding the extent to which the explanations via natural selection are applicable is attached to the recognition of the importance of appealing to explanations of processes that are distinctive and have explanatory power in virtue of their origin – that is, of appealing to the type of explanation that is at the center of historicist traditions.

To assert that these traditions in biology are autonomous is to say that the type of explanation offered by each of them is valid and important to the achievement of a better comprehension of evolution. Such autonomy relies (at least to an important extent) on the use of different heuristic structures of reasoning which lead to the identification of what is considered important or relevant within the practices constituting a given tradition. If our short reconstruction of a complex story is acceptable, then we can justifiably assert that the notion of evolution prevailing in contemporary biology is not mainly (or most importantly) the result of theory change or theory election; rather it is the result of a complex process in which different practices (incorporating different heuristics structures and norms) evolved and interacted. More generally, we can assert that the heuristic structures that articulate scientific practices impose constraints upon them, so that scientific knowledge can be said to have a heuristic structure.[16]

The Heuristic Structure of Scientific Knowledge

From what we have argued so far it follows that the notion of scientific knowledge as a final result which is always explicitly formulated in coherent theories is too narrow to account for the actual way in which such knowledge grows and develops. Moreover, far from being the result of some internal deliberation that takes us from some (true) premises to some (true) conclusions, scientific knowledge is a complex structure of "internal" and "external" cognitive resources that are implicit and explicit in practices and that are embodied in institutions, as well as in material and conceptual

[16]Eraña (2003) and Martínez (2003) have argued that human rationality has also a heuristic structure. This is an important sense in which the continuity thesis seems to be true. We will develop this further in the next section.

environments. The complexity of the situations which cognition has to deal with helps to explain the fact that cognition does not take place through algorithms but through heuristics, and thus helps us to explain the importance of its social distribution in practices. Let us see whether the first-order module view is compatible with these ideas.

The "first-order module" view

Two of the main advocates of the so-called "first-order module" view are Scott Atran and Dan Sperber. This last author characterizes a cognitive module as

> a genetically specified computational device in the mind/brain that works pretty much on its own on inputs pertaining to some specific cognitive domain and provided by other parts of the nervous system (e.g. sensory receptors or other modules). (Sperber 1996, p. 120)

The main idea in this proposal is that such modules are evolutionarily adapted structures that have privileged access to the relevant information about the entities that fall in the appropriate domain. These structures are not content-rich and, thus, they need not include any explicit understanding of the underlying principles that guide our perception or reasoning in the domain (Carey 1995, p. 274). In other words, modules are not theory-like structures. Rather, they are cognitive dispositions that lead us to organize information in specific ways or that allow us to discriminate when certain information is to be regarded as constitutive of a concept.

Susan Carey asserts that the position just mentioned has serious empirical and conceptual problems. The empirical problems relate to the fact that the only data supporting it is the cross-cultural universality found in living kind classification schemes. But, according to her, such data is no evidence in favor of the thesis that folk biology is a first order module: many empirical studies (e.g. Carey 1985; Keil 1994; Wellman and Gelman 1992) have provided us with good reasons to think that the two fundamental aspects that characterize Atran's folk biology – a universal taxonomic organization of categories of animals and plants, and an essentialist view of the properties held by animals and plants that guides our reasoning in the domain – are most probably *not* domain-specific.[17] The just mentioned studies have established that those aspects in Atran's folk biology that are domain-specific – i.e., teleological growth – are probably not innate, nor theory neutral.

Regarding the conceptual problems, Carey considers that the idea that cognitive modules do not explicitly characterize the causal mechanisms at work in the world is conceptually misleading. As we mentioned before, from her point of view, core knowledge develops early and is represented in core domains. A cognitive domain can only be considered as a core domain if it is very close to perceptual knowledge in the sense that the principles that guide our reasoning in the domain are the same as the principles that guide our perception in it. In other words, in all and every core domain, reasoning and perception are guided by a single knowledge system. Since the two components that characterize Atran's folk biology do not satisfy this definition, it cannot be considered as a core domain. If it is not a core domain, then it must be a constructed domain, but constructed domains have theory-like structures.

Even if we accepted that there is not enough empirical support for the idea that folk biology is innate, or a core module, there is no reason to affirm that cognitive modules *cannot* be conceived in terms of dispositional structures. The inference that Carey wants to draw from non-innate to theory-like seems to be valid only if we accept the assumption according to which if it is not possible to show that a module is innate, then it is necessary to posit a theory-like structure in order to account for it.[18] This assumption can also be formulated in terms of the following supposed

[17]The idea is that essentialism and taxonomic structure are probably innate, but must surely *not* specific to folk-biological classification (Carey 1995, p. 276). Furthermore, Carey asserts that "... folk biology as characterized by Atran and Sperber *cannot be a first-order module*" because "... having an essential nature or being part of a taxonomic structure – the key features of Atran's folk biology – are not identifiable from spatiotemporal analysis" (Carey 1995, p. 279, *our emphasis*).

[18]Carey (1995) asserts that cognitive modules are *not* necessarily *innately specified* – in fact, she thinks, most of them are constructed during the course of development – but they *do* necessarily include an understanding of the principles underlying our intuitive theories. This assertion is stronger than the one manifested in the text, since it implies that the necessary and sufficient conditions for modules are those established by the criteria of intuitive theories and, thus, that *all* modules should be characterized as theoretical structures.

dilemma: cognitive modules are either theory-like structures that can be acquired during the course of development or they are innate structures that develop without necessarily exploiting our theory building capacities.

Our contention here is that the mentioned dilemma is false: cognitive modules need not be innately specified, nor theoretical structures. A third possibility is suggested by Karmiloff-Smith when she asserts that "nature specifies initial bases or predispositions that channel attention to relevant environmental inputs, which in turn affect subsequent brain development" (1992, p. 5). From her point of view, the dispositions triggered by the relevant information might be innately specified; however, the contents of cognitive modules – even if constrained by such specifications – are crucially affected by our interactions with the information which we have available to us (Karmiloff-Smith 1991, p. 174). This author has argued that the plasticity observed in the brain in the first stages of development gives us good reasons to think that modularization takes place in early infancy; once this process has been consolidated; the modules would begin working together. If this is correct, then even if up to now there is not enough evidence to establish folk biology as a "core module," it is conceptually plausible to assert that cognitive modules are not necessarily innately determined, though they are dispositional and *not* theory-like structures. Analogously, we claim that congnitive modules are dispositional in the context of a given practice and can be developed through certain historical paths depending on the cultural context.

Conceptual change, the "actual" and the "cultural" domain of modules

Another important supposition in Carey's critique is that the determination of the content of concepts is a function of the role they play in the theories in which they are embedded. This idea has usually been formulated as the thought that the determination of the domain of a core module depends on the information that it has to process in order to fulfill its biological function (and the function of the module is to process a specific range of information in a specific manner). In other words, the domain of application of a module is that – and only that – which corresponds to its internal structure; thus, to every cognitive domain must correspond a mental entity whose contents are determined by the underlying core principles that allow us to identify the entities pertaining to the domain.

The main idea is that without an understanding of such principles or of the causal mechanisms at work in the domain, it is impossible to reason about the pertinent entities.

Against this supposition, Sperber (1996) has convincingly argued that a module is not *necessarily* – and not exclusively – applicable to the functions for which it was originally designed. In order to understanding the way in which the domain of a cognitive module is determined, we need, rather, to make a distinction between what he calls the "actual," the "proper," and the "cultural" domain of a module. The "actual" domain of a module is characterized in terms of *all* the information available in the environment in which the organisms that possesses the module develops, and which can satisfy the input conditions of the module in question. The "proper" domain is constituted by the information that the module has to process in order to satisfy its biological function. The "cultural" domain of this module is characterized by Sperber in the following terms:

> A cognitive module stimulates in every culture the production and distribution of a wide array of information that meets its input conditions. This information, being artefactually produced or organized by the people themselves, is from the start conceptualized, and therefore belongs to conceptual domains that I propose to call the module's *cultural domain(s)*. In other words, cultural transmissions causes, in the actual domain of any cognitive module, a proliferation of parasitic information that mimics the module's proper domain. (Sperber 1996, p. 141)

The basic idea is that the cultural domain refers to the range of information which we have at our disposal and which enables us to build concepts of, for example, animal species with which we have never interacted (e.g., dinosaurs, Cyclopes, dragons). A point that Sperber stresses is the fact that we human beings can change our environment at a velocity that natural selection cannot keep pace with; so it is not implausible to suppose that the specific features of the human organism are adaptations to characteristics of the environment that have changed significantly or have ceased to exist. If this is correct, then it would seem as if, on the one hand, the actual domain of any cognitive module is probably not even approximately coextensive with its proper domain, and, on the other hand, that a cognitive module cannot be initially an adaptation to its cultural domain. Concerning the first of these conclusions, Sperber says:

> The actual domain of any cognitive module is sure [...] to include a large amount of cultural information that meets its input conditions. This results neither from accident nor from design. It results from a process of social distribution of information. (Sperber 1996, p. 139)

An important point raised by the distinction just examined is that there are some abilities, concepts, and beliefs that are easily acquired and that are at the core of our reasoning processes. Starting from them we elaborate all sorts of speculations that lead toward more sophisticated and to less stable forms of knowledge.[19] In other words, while it is true that the structure of concepts can remain relatively stable, the conceptual elaboration which enables us to understand the internal structure of these concepts can vary so much that it may even lead us to develop concepts that differ from those which we initially maintained or from those held in other communities.

If what we have said so far is correct, then the domain of a module is not a property of its internal structure. Rather, the determination of such domain is a function of the relations existing between various modules and, thus, we can assert – following Sperber – that the content of a concept is a relational and not a theory-determined property.

This notion of cognitive module is not committed with the idea that conceptual change should be explained in terms of theory change. Since concept possession does not depend on the possession of an intuitive theory but on practical dispositions to make certain types of inference, conceptual change – rather than appealing to theory change – should appeal to the specific ways in which the input conditions of cognitive modules evolve. The main idea is that the way in which the different domains of a module are established and interconnected may vary significantly in different cultural contexts, since this depends both on the information available in the environment in which individuals develop, and on the aims and values appreciated by the community in which the said subjects are immersed. Since humans in different environments are exposed to different sorts of information, the privileged input that triggers the module may be different

[19]Atran establishes that “Rather than theories making categories, it is the domain-specific structure of categories that severly constrains, and thereby renders possible any theoretical (or culturally peculiar “cosmological”) elaboration of them” (Atran 1994, p. 317).

in different environments, and thus the organization of the information in question might be so different that it might bring about new concepts.

If ours is a good description of the core module view, then such a perspective would be compatible with the idea developed before according to which science is a cultural phenomenon. We agree with the Sperber-Atran view in that science is a set of widely distributed and causally linked representations that have a long-lasting life and a very good chance of being transmitted. Nevertheless, from our point of view it is important to emphasize that science, as well as other parts of culture, is a network of practices in which material systems embody important standards which help to explain the fate of representations.

An alternative version of the continuity thesis

The notion of conceptual change that we have advanced does not imply the negation of the continuity hypothesis. Nevertheless, the continuity in question does not lie in the fact that cognitive development, as scientific knowledge growth, is best described as a process of theory change. The continuity we sustain relies on the fact that ordinary and scientific cognition are both grounded on the development of heuristic structures which have a modular structure arising not only from the distinctive features of the heuristic rules employed, but also arising from the situated structure of norms and standards. The continuity thesis holds because ordinary and scientific reasoning both seem to have a heuristic structure. Let us examine these ideas in detail.

A common and very well supported assumption in contemporary epistemology and in cognitive sciences is that humans have limited abilities to process information. Departing from it, Gigerenzer (2000) has convincingly stated that such limitations are clearly manifested in the use of heuristic rules which underlie in the construction of simplified models of the world that allow human beings to undertake fast and *rational* decisions. Martínez (2003) has further established that human rationality is best described in terms of the use of heuristic procedures which serve as a guide to inferences and – just as the well known heuristic rules that supposedly underlie in our probabilistic reasoning – are biased in specific ways.[20] A heuristic structure is a set of heuristic procedures that take place in a normative environment and that are hierarchically organized in order to face particular tasks.

As we have been arguing, there are good reasons to assert that everyday knowledge should be thought of in terms of a series of judgments in specific domains which are sustained in different dispositions or procedures that lead us to organize the available information in specific ways so as to undertake particular inferences or actions and, eventually, to transform material or conceptual systems. This idea can also be formulated in the following terms: human cognition is best described as a complex process that involves multiple reasoning competences or, in other words, multiple cognitive modules. If this is correct and if we accept that there should exist certain degree of convergence between the notion of rationality applicable to human beings and a good description of everyday reasoning, then there must be certain degree of convergence between rationality and modularity. Let us see.

From our point of view, when an organism is confronted with specific types of problems, when it undertakes specific inferences, or when it performs a specific reasoning, the information available gets hierarquically organized so as to promote the integration of the different ranges of information associated to different modules. Such integration is possible because human beings are rational, where being rational is not having a domain-general capacity, but various domain-specific competencies. As we mentioned before, there are good reasons to assert that human rationality is best characterized as a bundle of heuristic procedures which are leading to the generation of inferential chains that allow us to use as input of a given module the output of a different one. This is where modularity and rationality converge: modules are cognitive dispositions that have access to limited ranges of information and that "provide humans with ways [...] of organizing the information they may gather" (Sperber 1996, p. 143) about the entities that fall into their domains, and being rational is precisely being able to organize this information in a way that allows us to

[20]The characteristics of the before mentioned biases are an important aspect of heuristic structures since they point toward the sort of implicit processing of information that takes place while using the mentioned procedures.

undertake particular actions, inferences or decisions. Rationality provides the normative environment in which our cognitive resources interact.

If what we have just said is correct and if we accept the notion of heuristic structure here advanced – i.e. a collection of processes related through norms and standards that allow us to transform material and conceptual systems via the available cognitive resources which are part of the proper domain of the heuristic structure –, then it is reasonable to assert that the modules that guide and sustain our everyday reasoning have a heuristic structure. Analogously, as we have argued before, the practices and traditions that constitute science and that serve as guides for scientific reasoning have a heuristic structure: they can be described as collections of functionally related heuristic procedures hierarchically organized and directed to the carrying out of a certain type of task or the solution of a given type of problem.

Heuristic structures – both in science and in lay cognition – should not be understood as mere patterns of reaction triggered by given circumstances: the deployment of the practical abilities involved in cognition is not merely an explicit processing of symbols; rather, it is the result of a series of coordinated actions that take place in the normative environment of a complex of situations, where the norms are often not explicit (but implicit) in the underlying practices. A laboratory technique is a good example of a heuristic structure: the implicit processing of symbols that takes place in the use of the techniques via the interactions with material systems and with other agents is guided by implicit norms and standards. A good example of a heuristic structure in everyday cognition is provided by Hutchins (1996) when he describes the cognitive structure that drives a ship to its destiny: the task in question requires the participation of agents and artifacts and the coordination of multiple actions that involve material and conceptual resources, these resources are articulated by practices in a normative environment.

Now, the different ways of establishing the hierarchies of the functions associated to heuristic procedures can be understood as part of its modular structure; such modularity gives way to the modification of a heuristic structure by parts and, thus, allows the generations of different variants of heuristic structures that can be compared, evaluated and that, eventually, will propagate, transform, or be extinct. If our proposal is accepted, then cognitive modules can be thought of as heuristic structures and, since science is a complex of practices that embody different heuristic structures, we can affirm that science is a complex of different cognitive modules.

Conclusions

We have argued in favor of a perspective according to which a plausible description of scientific knowledge growth requires taking into account the role that the different scientific practices and traditions play in the evolution of concepts, theories, devices and other available cognitive resources. This view of the scientific enterprise has lead us to assert that conceptual change implies the acquisition of new practices which promote or discourage the use of a given set of concepts, norms or standards.

If our proposal is accepted, then the continuity thesis can be thought of in terms of the heuristic structures that underlie and guide ordinary and scientific reasoning. Both types of reasoning can be described as processes of transformation of material or conceptual systems which is governed or guided by a set of heuristic procedures, norms and standards. A collection of these procedures is what we have called a heuristic structure, so that ordinary and scientific reasoning can be said to have a heuristic structure. Moreover, heuristic structures can be said to be modular because the functions assigned to the processes that constitute them can be clearly differentiated and each of them is applicable to a restricted range of information. Thus, ordinary and scientific knowledge can be said to have a modular structure.

In conclusion, from our point of view, giving a plausible account of cognitive development (or knowledge growth) requires taking into account the social distribution of knowledge. Heuristic structures are a plausible way of doing so since, in the same sense as concepts, they are social structures – i.e. they do not correspond to internal states within the individuals who use them. As we mentioned before, the content of concepts depends, in part, on a process of social distribution of information which is not internal to an individual. Analogously, the stabilization, entrenchment, or extinction of the different heuristic structures depends on their usefulness in specific scientific practices.

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