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What Do We Get When Dipping a Brain Into Science?
Properties of the Scientific Mind

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Abstract

I argue that scientific cognition can be accounted for in a massive modularity theoretical framework. Scientific cognition is then described as a culturally informed reflection, allowed by meta-representational abilities, upon the mandatory output of preliminary modules.

Keywords: massive modularity; scientific cognition; metarepresentations; theories.

It is a rather peculiar alchemy, one must admit, to educate someone who is born for survival and reproduction so as to make a scientist out of her. Studying the properties of the scientific mind, I suggest, can be done by studying first the brain as an evolved biological organ, and then the transformation that scientific enculturation brings about. While cognitive studies of science include mostly the analysis of the semantic and inferential operations of scientists' thoughts, the methodology I adopt in this paper allows raising essential complementary questions regarding, in particular, the biological implementation of the semantically characterised cognitive processes. From this perspective, the scientist's mind is re-located exactly where it is: in between biological evolution and cultural achievement – the result of both as well as the cause of the latter. The perspective begets another look at the venerable knowledge producer.

Evolutionary psychology holds that the biology of the brain is a product, as any organ of a living organism, of evolutionary history. As a consequence, one can fruitfully understand the brain as having functions for which it has been selected, i.e., functions that increase the chances of survival and reproduction of the organism endowed with the brain in the environment where it has evolved. The overall function of the brain is to process information in such a way that it causes its owner organism to behave adaptively in his environment. Because the brain has been selected by evolution, one can assume that it is successful in this task, i.e., that it implements *ecologically rational* cognitive processes.

A second important point brought up by evolutionary psychology is that there can be no evolutionarily plausible story of a domain-general cognitive device. Rather, the constraints of evolutionary theory imply that the mind is made up of numerous cognitive devices that have their own adaptive functions. This, together with arguments from computational tractability (Carruthers, 2005), leads to a hypothesis that the mind is *wholly* composed of biologically realised cognitive devices designed to solve specific problems met by the organism in his environment. Let us call these cognitive devices modules (whether they meet all the criteria fixed by Fodor's definition is then an open empirical question). Asserting that the mind is massively modular consists in a radical denial of the existence of a domain-general cognitive ability that would pilot human thought; the mind is said to be an organised composite of numerous evolved cognitive modules.

Lastly, evolutionary psychologists tend to have a minimalist attitude towards the plasticity of the mind. This is because it is the genetic underpinning of an evolved cognitive module that is being selected for during evolutionary history. Now, the genetic endowment that causes the modular architecture of an organism's mind/brain does not change over ontogeny and with enculturation. So the genetically determined modular architecture of the mind does not change in the course of the organism's life.

While the above point is generally not controversial for animal cognition, it seems at odds with what we know of human creativity and flexibility. Cognitive scientists taking evolutionary psychology seriously have thus attempted to show what is special with human cognition. I present here my own attempt with the special case of scientific cognition.

I provide a view of scientific cognition that takes the three above constraints into account and emphasises the essential role of meta-representational abilities. I thus show that, contrary to Fodor (1983), scientific cognition can be accounted for with the functioning of cognitive modules, and that, contrary to Carey (1995) and others, the evolution of knowledge does not require changes in the architecture of the mind. The massive modularity thesis provides a view of the mind that is a promising alternative to the views that rely on plasticity and domain generality to account for scientific cognition

Modules that make us scientists

If we admit that the scientist's mind is made up of modules that implement ecologically rational cognitive processes, then the existence of scientific cognition raises the following questions: How can a species that evolved as a hunter-gatherer species do science? How can we obtain scientific rationality out of people's ecological rationality? How can we have gone beyond biologically implemented cognitive heuristics, innate naïve theories, or psychologically interpreted Kantian categories to obtain our scientific understanding of the world? My first attempt to answer these questions, however, consists in answering a more specific one: How and why are cognitive modules put to work on scientific problems?

Modules, according to the modular theory of cognition, are put to work according to the biological hardwired architecture of the mind, which directs the flow of information, thus feeding modules with specific inputs. Also, modules can select their own inputs according to their formats and domains. For instance, the view of a face-like stimulus automatically triggers the face-recognition module. At this level, learning can happen not only through enrichment of modules' databases but also through the fixation of parameters determining the domains of modules. Nested modularity, maturation of cognitive abilities through interaction with the environment, enrichment, and many other processes endow modular minds with much more flexibility and adaptive potential than might initially be thought. None of these processes, however, seems to allow for theoretical innovation as we find it in the history of science, including, for instance, the production of new theories. A brain made of nested domain-specific modules may account for much of animal cognition, but humans must have some special ability that allows innovation.

I believe that this special ability is the ability to meta-represent our own representations. Meta-representational ability allows for the processing, using and producing of representations of representations. The ability may be implemented by one or more cognitive modules. Some meta-representational modules, indeed, have an already studied evolutionary history and satisfy the requirements of evolutionary plausibility. Presumably, meta-representational abilities appear with the ability to represent the representations that others may hold – their mental state. This ability, called Theory Of Mind (TOM), is adaptive by allowing Machiavellian intelligence, the ability to manipulate others' behaviour, and is certainly at the basis of human social life, including linguistic communication.

The relevant consequence of meta-representational ability (or abilities) is that the product of mandatory modules can be *re-thought*. In other words, mental representations can be taken as input of metacognitive abilities so as to provide meta-representations that will determine the *attitude* one will hold with regard to the input representation. For instance, one can think that the input representation X provides a true or a false representation of the world through having the metarepresentations 'It is true that X' or 'It is false that X' . Metarepresentations can also express semantic relations among representations (e.g. X contradicts Y) and evidence for beliefs (e.g. A justifies my belief that B) (Sperber, 1996). More generally, metarepresentational abilities allow for the interpretation of representational output of previous (modular) heuristics and naïve theories; these representations can be reflected upon and given some further meaning through the embedding of representations. The most obvious case is when sounds uttered by some speaker are interpreted as conveying what the speaker intends to communicate (Sperber & Wilson, 1986), but interpretation is also at work when our intuitions are taken to reveal something about the world rather than directly leading to (adaptive) behaviour. This happens, for instance, when perceptive representations get embedded within a framework theory; then, the perceptive representation is metarepresented as a manifestation or consequence of some state of the matter or laws of nature. This is what happens when, for instance, we look at the light of a bulb as being a consequence of moving electrons. Cognitive studies of science have not ignored the pervasiveness of metarepresentations in science. Scientific practice, says Nancy Nersessian, "often involves extensive meta-cognitive reflections of scientists as they have evaluated, refined and extended representational, reasoning and communicative practices" (Nersessian, 2002, p. 135). Deana Kuhn has also pointed out the metacognitive skills at work in scientific thinking. These include not only meta-strategic competence (Kuhn & al., 1995), but also the ability "to reflect on one's own theories as objects of cognition to an extent sufficient to recognize they could be wrong"(1996, p.275). Metacognition and other more basic metarepresentative abilities are thus central to scientific thinking, but most interestingly for our present purpose, they also bridge the gap between lower cognitive abilities processing the input from our sense organs and other hardwired heuristics or naïve theories, and the abstract and consciously controlled thinking practices of science. In particular, problem representation consists in bringing a set of representations and previous knowledge or ideas to bear on the understanding, or interpretation, of incoming 'naïve' or intuitive representations. Problem representation allows cueing heuristics in the search of solutions. Gorman (2000) illustrates this point with Kepler's mental model of the solar system and the application of heuristics as designed and implemented in the discovery program BACON 1 of Herbert Simon and his colleagues. Kepler's particular problem representation, he explains, was necessary for the heuristics to apply and be useful. In general, the interpretation of naïve or intuitive representations make possible directing them further towards other heuristics, naïve theories or any modular processes. For instance, our interpreting of electric phenomena as a consequence of the movement of electrons activates our naïve physics theories. In those cases, metarepresentations act as *routers* of representations towards the *right* module. The routings therefore make use of ecological rationality for the development of our understanding of the world and the construction of a scientific rationality that is oriented towards truth rather than survival. This development of scientific cognition is a cultural achievement because evalutative, interpretive and routing meta-representations have been developed with scientific theories and practices during the historical evolution of science. Thus, the 'right' that qualifies the choice of modular processes and the 'scientific' or 'rational' that qualify the thoughts has now to do with the normative aspects of scientific traditions and paradigms. Problem solving using heuristics, of course, is both learned by humans and biologically given. One way the learning can happen is by using already existing heuristics for solving problems that the heuristics were not initially designed to apply to. This use of heuristics for ends they were not originally created for is coined 'exaptation' by Wimsatt (2000). He notes that "evolution, human engineering, science, and culture all systematically reuse constructs in new contexts that drive their elaboration in new directions". I suggest that *scientific thinking is well characterised as a systematic exploitation of human cognitive abilities by constructing, via metarepresentations, exaptative heuristics and intuitions.* In the next sections, I provide a more detailed characterisation: first, I argue that the exploited human cognitive abilities are innate and undergo no structural change during an individual's lifetime; second, I describe how metarepresentations exploit cognitive abilities, thereby allowing scientific cognition and reflexive beliefs.

The innate mind and the historicity of science

I feel that an important gap in science studies is the study of the role of our primary intuitions in scientific knowledge. Social studies accord little importance to these cognitive events that are intuitions, while cognitive studies are much more focused on higher reasoning practices (induction, abduction, analogical reasoning, thought experiment, etc.). The continuity thesis, which asserts that scientific cognition is of the same nature as lay cognition, has raised important debates that could bear on the distinction and relation between reflexive and intuitive thinking, between meta-represented knowledge and direct output of non-metarepresentational modules (see Sperber, 1997, for the distinction between intuitive and reflective beliefs). However, the empirical stake of the debate has not focussed so much on the use of common sense in scientific cognition (with the exception of Atran, 1990) as on whether the higher reasoning practices of scientists are used by laymen and children. Concerning the normative rational practices, such as the use of deductive logic, psychologists have found that laymen mostly *do not* follow them, and thus do not answer the normative criteria. On the other hand, most theories in developmental psychology have asserted that children *do* think in similar ways to scientists, including hypothesis-testing, theory formation that allows them to develop theories that are incommensurable with the theories they replace, and general processes of belief formation leading to the 'scientist as child' metaphor (Gopnik, 1996). That *norms of reasoning* may not be followed by lay people comes as no surprise from the perspective of ecological rationality; and it is also unsurprising, with respect to the 'minimal plasticity of the mind' credo of massive modularity, that *creative thinking* in children and adult scientists relies on the same cognitive processes and abilities; creative thinking is not based on a cognitive ability that develops only when doing science.

From the perspective of this paper, however, the question involves the role of naïve theories, biologically implemented heuristics, and 'lower' cognitive processes with percepts as output. These are innate endowments that provide our unconscious and non-reflexive thinking and guide most of our actions; they are pervasive in day-to-day cognition, but their content is often inconsistent with contemporary scientific theories. People do not reason with quantum mechanics for grasping things and we do not normally think of ourselves as moving in a Riemann space. Scientific knowledge is not embodied in the innate endowment of the human mind. Does that mean that the study of this endowment is irrelevant for the study of scientific cognition? In other words, is this endowment fully bypassed and of no consequence in scientific cognition? Human intelligence appears to be able to extend beyond its initial limits. This is paradigmatically exemplified with conceptual change in science, where some previously held beliefs are abandoned and replaced by new beliefs incommensurable with them. In particular, conceptual changes in science have rendered the content of science at odd with intuitive beliefs. How can we have come to think, and be now so convinced, that the earth is moving around the sun while the contrary belief naturally imposes itself upon us? While knowledge enrichment can be thought of as the addition of new data to previously existing databases, conceptual change and abandonment of previously believed theories requires, on the part of the scientists, a new attitude towards the stimuli of the newly theorised domain. What are the cognitive processes accounting for these new attitudes? Conceptual change is a key problem in science studies and an account of it needs to include the events in people's minds that make these conceptual changes possible.

The existence of conceptual change raises two questions for cognitive psychologists: first, what are the cognitive processes that make conceptual change possible? Much work has been done in cognitive studies of science on this topic. Most notably, Nersessian (1992) has analysed the role of physical analogy, the construction of thought experiments and limiting case analyses. Carey has also pointed out the role of mappings across cognitive domains for the creation of new domains (e.g. Carey & Spelke, 1994). There is general agreement that conceptual change involves metarepresentational abilities; the debated point is on the necessary development of these abilities and their complexities for conceptual change to be possible (see Carey & Johnson, 2000). The second question is: What are the cognitive processes that are implemented *once conceptual change is achieved*?

I argue that the cognitive processes allowing conceptual change have little effect on the structure of the mind and its component abilities; all that is needed is enrichment of meta-representational knowledge. The same intuitions and abilities sustain pre-conceptual change and post-conceptual change cognition. In other words, although the cognitive development of children and adults is obviously relevant to science studies, if only because people are being educated, or not, in a culture impregnated with science, the ontogenic developments do not change the genetically determined modular architecture of the mind. I henceforth defend a strong continuity thesis, which asserts that the infant and the mature scientist have the same cognitive abilities (after maturation) organised in an identical way. By contrast, Carey and Gopnik defend a weak continuity thesis which asserts that only the discovery processes need be identical in child and scientific cognition. Carey and Gopnik both hypothesise that conceptual change in science is based on isomorphic changes in people's mind. They thus develop a theory of cognition that differs from the minimal plasticity of the structure of the mind defended here. For Carey and Spelke (1994), scientific development provides, with conceptual change, a counter example to a Sperberian picture, where cognitive development (ontongeny) is characterised by enrichment of innate modules only, and conceptual change is enabled by metacognitive abilities. “Reflection by itself”, they say, “will not produce conceptual change” (pp. 180). What is at stake, for cognitive studies of science, is whether the innate abilities mentioned above (naïve theories, innate heuristics) are put to work in scientific cognition, or whether scientific cognition relies on other abilities that develop during ontogeny. If we are in the latter case, then cognitive studies of science should concentrate on the role of the acquired abilities at work in scientific cognition rather than, as I have argued up to now, on the innate abilities designed by evolution. Evolutionary psychology would then not be immediately relevant to science studies and the task would be to discover, with other means, the developed cognitive abilities sustaining scientific cognition.

Regarding the fixity of the modular architecture of the mind, I will not argue against Churchland and Gopnik or Karmiloff-Smith because their models all rely on domain-general abilities or important plasticity of the mind. I have mentioned that my reasons for not adopting these theories come from evolutionary psychology. Carey’s framework, however, is the most compatible with the one defended in this paper. Carey distinguishes core theories from intuitive theories: core theories are those theories that are innate endowment and which account for the behaviour of infants, while intuitive theories are constructed during cognitive development. Examples of core theories are the already mentioned naïve physics, naïve psychology, and naïve quantitative reasoning. Examples of intuitive theories are number cognition, after, among other things, the integration of the concepts of zero and infinity and the construction of mappings between numbers and geometry. Children also develop, Carey argues, an intuitive theory of biology, which arises after conceptual change in the concept of living things. A third example of intuitive theory is provided by conceptual change in the years 4 to 12 in the interrelated concepts of matter, weight and density (see Carey & Spelke, 1992: 184-194).

For Carey, core theories are modules in a sense akin to the one already used in this paper, but Carey further takes intuitive theories to be modules, thus rejecting the criterion of innateness as a necessary property of cognitive modules (1995, p. 274). Although the problem may appear merely terminological, there are some reasons to insist that modules be defined as cognitive organs, and thus answer some kind of innateness criterion (such as being determined by the genotype). At bottom, the distinction is between semantic criteria of identification (Carey: identifying a theory on the basis of which people explain the phenomena pertaining to its domain) *versus* realist-existential assertions about the structure of the mind (Sperber-Atran: identifying cognitive organs). Semantic analysis of the cognitive processes is certainly the best analysis, if not the only possible one, for cognitive psychology. But the integration of cognitive psychology with biology – from either brain imaging or evolutionary psychology – imposes and allows stronger, existential, claims for ‘modules’. The integration is desirable not only for the reduction of semantic properties to biological ones – a naturalistic programme of its own – but also because the semantic functioning of the mind is likely to be highly constrained by its physical implementation. In other words, the embodiment of the mind is likely to have some consequence on its functioning. One is not only interested in a detailed account of what the mind does (a semantic-functional account), but also in how it *actually* does it (a realist account). Defining modules as cognitive organs raises the empirical problem of distinguishing between the initial endowment of the mind as what is genuinely modular, and later cognitive achievements as developed upon modular abilities. There is no *a priori* reason that later cognitive achievements be implemented in the same way as modular abilities or have the same epistemic properties. Cognitive processes implemented through modular abilities are even probably very different from cognitive processes implemented through intuitive theories. This is because:

- Modules, as cognitive organs, should implement cognitive processes that are ecologically rational, since they have been selected for increasing the chance of survival and reproduction. Intuitive theories need not be ecologically rational, but may have different properties stemming from the conditions in which they developed (e.g., answering some culturally developed criteria of rationality).
- While modular abilities implement their processes on cognitive devices whose biological hardwire is directly informed by genes, intuitive theories need to develop their physical implementation during learning.
- It seems implausible that modules as cognitive organs could transform in any drastic way: organs such as the hand or the liver, can change within a rather limited range; their basic structure is encrypted in the genes and cannot change without genetic mutation.

However, pursuing the analogy between physiology and the architecture of the mind suggests an answer for the problem of the implementation of intuitive theories. Notice, indeed, that we can use our hands and liver in ways that are certainly not the function they have been selected for. Organs can enlarge their actual functioning beyond the limits of their evolved designed function. For instance, we can use our hands to play the piano, while they certainly have evolved for grasping, and we can use our liver for the digestion of Champagne, while it more probably has evolved for digesting the food consumed by hunter-gatherers. The hypothesis is therefore that hunans can use their cognitive modules in novel ways, for which they were not designed by evolution. This, in turn, can lead to conceptual change and the development of new intuitive theories. Atran and Sperber’s work (Atran, 1990, 1998; Sperber, 1996) provides an account of theory change along these lines. Implementations of new theories, they assert, do not replace modular abilities, but on the contrary continue to rely on them. Atran uses neo-Darwinian theory to illustrate theory implementation without replacement. Neo-Darwinian theory has a notion of species as sets of animals that live in the same ecological niche and that can interbreed. This notion is incommensurable with the naïve notion of species, which is essence-based and associated with a favoured rank within the folk taxonomy. However, Atran argues, the adoption of neo-Darwinism does not cause the elimination of naïve pre-theoretical intuitions. What happens, rather, is that naïve thinking still provides the basic intuitions and percepts upon which scientists reflect so as to interpret them within a neo-Darwinian framework. So the ecologist doing fieldwork still perceives animals as entities at the generic species level and with essences as intrinsic teleological causes. But in his university office, the same ecologist will interpret his data thus gathered through his basic cognitive abilities, especially naïve biology, in the light of the most recent scientific theories. Naïve biology is a cognitive organ that presumably evolved as an adaptive skill for the hunter-gatherer (we can also suppose that some kinds of naïve biology are present in other animals' cognitions); it is nonetheless put to work to do science, a function it did not evolve for. Scientific reflection upon the output of the naïve biology module bestows a theory that is inconsistent or incommensurable with naïve biology. The new theory does not emerge through the transformation of the module, which continues to provide the same intuitions and percepts; it emerges due to a reflective attitude upon the module's output. The cognitive processes sustaining the theory therefore lie in the functioning of the naïve biology module, together with some sets of meta-representations which provide the context for the interpretation of the outputs of the module. *Scientific enculturation need not generate new cognitive structures. It is, on the contrary, implemented through enrichment only, consisting of beliefs that will constraint future interpretations and reflections upon our primary intuitions.*

For Carey, some core theories might be overthrown and replaced by intuitive theories: this is conceptual change. For Sperber and Atran, core knowledge (or naïve theories or modular abilities) are biological endowments that do not disappear with cognitive development, even when knowledge that is inconsistent with core knowledge is elaborated. Beliefs obviously change, but this does not alter or transform the architecture of the mind, which consists of an arrangement of modular abilities constraining information flows. Thus, change of beliefs and the evolution of knowledge do not create new intuitions or perceptive abilities (neither ontogenetically nor historically); new beliefs, cultural and historical variations, always rely on the same basis of intuitions: the output of biologically realised cognitive devices. This hypothesis is corroborated by the fact that scientists act and think in everyday life exactly as laypeople. The expert in quantum mechanics continues to see a cup as a cup, rather than as a complex of interacting elementary particles; the biologist, as Atran points out, continues to see the tree as a tree, even if this category has no scientific counterpart; and the psychologist continues to understand people as intentional agents, even when he adopts the most radical behaviourist theories. In a sense, contemporary science is highly unintuitive: While beliefs vary greatly, phenomenology varies comparatively little (e.g., through the trained repartition of attention and other non-structural changes).

Another difference between Carey and Sperber-Atran lies on the biological basis of mental theories that develop during ontogeny. Because Carey uses a semantic criterion for distinguishing abilities, she is not able to distinguish between abilities that reflect the working of a (biological) cognitive device and abilities that cut across and use cognitive devices. A semantic criterion is not sufficient for the circumscription of cognitive domain of (biologically realised) modules. Carey consequently postulates the existence of mental devices that develop during ontogeny: the intuitive theories. These intuitive theories have a status in between modular innate abilities and scientific theories. They are mental devices as innate modules, but they are developed in the same way as scientific theories. In their argumentation against Sperber, Carey and Spelke present intuitive theories as the necessary mental ground of scientific theories. The counter-argument that I have presented, however, consists in showing that the mental ground of scientific theories need not be a mental cognitive device of its own that somewhat mirrors the content of scientific theories. Such a view seems to stem from a persistent simplification of the constitution of scientific theories, which are reduced to sets of beliefs and its ensuing reasoning abilities, i.e., a semantic characterisation of scientific theories. With this simplistic view, the development of science and conceptual change is indeed in need of its mental counterparts: the same theories and change put within the mind of the scientists. Consideration of the problem of the physical implementation of scientific theories, however, raises new problems and show the limits of Carey's purely semantic analyses. At the level of the brain, I have argued that scientific cognition is implemented by modular primary abilities together with reflection – including semantic evaluation – upon their output. Likewise, Erana and Martinez (2004) have argued against a semantic reductive view of scientific theories, pointing out the complex of mental, cultural and artifactual interacting components of scientific theories. Taking into account the physical implementation of the scientific theories outside the brains of the scientists similarly allows Erana and Martinez to argue against Carey's and in favour of Sperber-Atran's view of cognition.

Let me clarify my criticism: I fully agree with Carey and Spelke that there must be some mental implementation of the semantic content of theories. I have no argument against the idea of intuitive theories, insofar as they describe semantic properties of people's cognition. But I have invoked the importance of specifying their physical implementation and rejected, on biological grounds, the hypothesis that non-innate theories are implemented by their own cognitive device. I have hinted at an account of an implementation of non-innate knowledge and theories by calling on the working of biologically realised modular abilities, including meta-representational abilities. I have defended the theory that asserts that the cognitive architecture of the mind is innately fixed and does not vary with learning. At first glance, this may appear to contradict our knowledge that beliefs, scientific beliefs included, greatly vary in space and time. But the historicity of science is not a counter-argument to the thesis that there is an innate mind, i.e., a genetically determined fixed structure of cognitive abilities. On the contrary, it is the innate mind that provides the dynamics of scientific development. I have thus sketched a view of the mind where conceptual change is implemented through the working of pre-conceptual change cognitive devices and the processing action of meta-representations. The latter can feed in modules with new representations, thus exploiting the module processes for further inferences – this is what happens, for instance, when the light of a bulb is understood *as* the manifestation of the movement of very small objects (electrons). Meta-representations can also distinguish among illusory and revealing intuitions through giving them a semantic status. They provide new meaning to these intuitions by embedding them in acquired knowledge.

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