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Chapter 11

Updating Evolutionary Epistemology

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Abstract

This chapter critically analyzes evolutionary epistemology as a theoretical framework for the study of science as a historical and cultural phenomenon. As spelled out by Campbell in the 1970s, evolutionary epistemology has an ambitious goal: it aims at understanding the complex relations between biological evolution, especially the biological evolution of human cognition, and the cultural evolution of scientific knowledge. It eventually aims at forming an integrated causal theory of the evolution of science, starting with the evolution of human cognition. In this chapter, the author considers Campbell's project and specifies why it is still today a worthwhile project for explaining the evolution of science as a specific case of cultural evolution. But he also criticizes Campbell's evolutionary epistemology for assuming that blind variation and selective retention are the processes through which science evolves. This assumption, the author argues, is at odds with much of what we know about scientific cognition and the history of science. He advocates (1) dropping the methodological constraint of looking for processes of blind variation and selective retention at the expense of other constructive processes and mechanisms of knowledge production; but (2) retaining the integrative point of evolutionary epistemology, which implies taking seriously the results of evolutionary psychology; and (3) retaining the populational framework for explaining the history of science, which means questioning why some scientific beliefs and practices eventually spread and stabilize in a scientific

community. We end up with an updated research program for evolutionary epistemology, which faces new challenges.

Campbell on the Evolution of Scientific Knowledge

Campbell introduces evolutionary epistemology as a research program in descriptive epistemology "that would be at a minimum an epistemology taking cognizance of and compatible with man's status as a product of biological and social evolution" ("Evolutionary" 413). Evolutionary epistemology aims at providing a causal history of scientific knowledge that not only accounts for the human history of science making, but also includes accounts of the cognitive processes at the basis of this history, and of the evolutionary history of the cognitive abilities implementing these processes. Evolutionary epistemology is therefore an integrated research, which spans biology, evolutionary psychology, cognitive psychology, sociology, and history. For instance, Campbell, following Konrad Lorenz, advocates the understanding of Kant's categories of perception and thought as evolutionary products ("Evolutionary"). Thus, Campbell applies evolutionary biology to human cognition, elaborating thoughts much akin to contemporary evolutionary psychology.

Another point that Campbell makes, which was developed by David Hull and which I criticize in this chapter, is that science evolves by means of blind variation and selective retention. According to Campbell, blind variation and selective retention together make the single principle at work at the levels of natural history, thought processes, and science history. It is the principle that is generalized from Darwin's theory of natural history and applied to science studies. It is meant to account for scientists' creative thinking and the cultural evolution of science. Concerning the history of science, Campbell fully takes on Popper's account of the "logic of scientific discovery" and its principle of "conjecture and refutation." Concerning creative thought, Campbell develops his own argument, which puts at the center stage of creative thought the "eureka" phenomenon ("Blind Variation"). For Campbell, blind selection and selective retention are necessary processes of evolution: evolution implies the generation of genuinely new items, which means that the generative process cannot be biased by the value of the items (in terms of fitness); the generative process does not embed knowledge of the value of the new items. As analytical truths about evolution, or as abstract principles that can always describe, at some level, the processes of evolution, there is nothing to say against blind variation and selective retention. Yet, I argue that when one attempts to explain the detailed causal processes through which cultural evolution takes place, then, blind variation and selective retention are insufficient analytical tools.

Thus, one can distinguish several projects under the label of evolutionary epistemology. The most radical project is the application of the Darwinian selectionist model in order to account for the evolution of knowledge. I argue that this project, although inspiring, can unduly limit research about the processes—cognitive and social—at work in the production of scientific beliefs and practices. But a more modest understanding of evolutionary epistemology would advocate the two following more fundamental projects:

1. The naturalization of epistemology as passing through population thinking: population thinking for the history of science consists in analyzing scientific theories and practices as populations of thoughts and ideas that are realized in mental states of actual scientists, of behaviors that are repeated (think of, say, running a specific statistical test), of scientific tools that make the environment of scientists. Populations are sets of actual items that grow, shrink, or are maintained in time. Populations of mental states, behavior, and artifacts are the actual realization of macro-social phenomena. For instance, the success of a scientific theory is the fact that the population of mental states and behaviors associated with the theory is not shrinking with time. The naturalism involved here is concerned with ontology: one must attempt to explain what macro-social entities refer to in terms of natural, or material, entities only. Population thinking requires specifying which natural entities constitute cultural phenomena, and the processes through which these entities are distributed in human communities and their habitat.
2. The naturalization of epistemology as a theory of knowledge production that is, as Campbell puts it, "taking cognizance of and compatible with man's status as a product of biological and social evolution." In effect, this means that evolutionary epistemology is an interdisciplinary project that studies (1) biological evolution, as the cause of the existence and nature of the human cognitive apparatus; (2) cognitive psychology, as the description of the processes through which mental representations are constructed by the evolved human cognitive apparatus; and (3) history, as the description of the particular chains of social events that eventually constitute scientific evolution. This project is naturalistic because it aims at showing the connections between natural sciences, such as biology, and the social sciences, such as the history of science. There are layers of processes constructing

> elements for the next layer of processes: biological evolution constructs biological cognitive apparatuses that construct, when interacting with the environment, representations, which are elements out of which scientific knowledge is made.

While Campbell based his integrated model of scientific development on the single principle of blind variation and selective retention, which would account for natural history, the dynamic of thought, and the history of science, I argue that different processes are at work at each level and that Darwinian selectionist theory (i.e., evolution occurs via blind variation and selective retention) does not necessarily apply to scientific cognition and to the history of science. Integration does require showing how biological, cognitive, and historical explanations match and combine into a single more exhaustive account, but there is no need to assume that the explanatory principles that account, respectively, for natural history, cognition, and social history are the very same. More precisely, I point out that current theories in sociology and cognitive psychology describe mechanisms for the production of knowledge that differ from blind variation and selective retention. The conclusion is that the Darwinist selectionist model of evolution applies to the evolution of epistemic mechanisms (EEM) of the structure of the brain, but do not extend to an evolutionary epistemology of theory (EET) (typology introduced by Bradie [“Assessing”]). I argue that there are two problems with an EET that assumes blind variation and selective retention of scientific ideas and practices: the first is blind variation, and the second is selective retention.

Blind variation does not describe properly the generation of new scientific ideas and practices, because the processes of discovery might not differ so radically from the processes that enable the spread of the idea. In other words, discovering and learning a scientific concept, a theory, or a practice rely on partly identical cognitive mechanisms. This is in stark contrast with biological evolution, where genetic variation occurs at molecular levels following principles that have nothing to do with the principles of selection, which occur at the level of the reproductive success of the organisms having traits whose development was favored by the genetic variant. Rather than blind variation, the cognitive processes of discovering and learning are grounded in (a) the evolved cognitive abilities and principles that characterize the human mind, (b) previously acquired knowledge and skills, and (c) the constructed social environment.

Selective retention does not describe properly the spread of new scientific ideas and practices because these are constantly changing, being interpreted and reinterpreted by different scientists in different context. The question is therefore why, in spite of these changes, the ideas remain strikingly similar, at least for a given time and within a given community. There are diverse social and cognitive mechanisms that determine how types of representations stabilize in the scientific community. Expressing an idea, interpreting it, applying the idea to new contexts or problems, learning a practice, and so on: these are complex processes that are not processes of replication. First, it is rarely the intention of the scientists to faithfully replicate and, second, there are many cognitive mechanisms involved, whose function is not replication. These mechanisms inevitably induce variations that, sometimes, converge towards the same type.

In brief, the processes that lead to biological, cognitive, and cultural constructs are not necessarily of the same kind. Biological stages are indeed characterized by blind variation and selective retention, but cognitive stages are achieved through the functioning of evolved capacities of perception, understanding and learning. Finally, cultural stages involve, of course, social interactions allowing mental and public representations to stabilize within the population of scientists, through processes such as education, feedback loops, and so on. There is a wealth of social and cognitive processes out of which scientific knowledge is constructed and spread. In the spirit of evolutionary epistemology, one goal is to integrate the results from evolutionary psychology, the psychology of science (including psychology on creativity), and the sociology of science. But this integration cannot but be hindered by further attempts to impose the Darwinian selectionist model on all processes, at all levels, of knowledge making. In the next sections, I consider the limits of blind variation for explaining scientific creativity. I then specify some of the research questions and challenges that integrating evolutionary psychology to the study of scientific creativity raises. Second, I consider the limits of selective retention for explaining the spread and success of scientific ideas and practices. I then specify some of the challenges that evolutionary epistemology faces.

Blind Variation Does Not Accurately Describe the Processes of Scientific Creativity

Blind variation and selective retention require a decoupling of variation and selection. But are psychological processes of scientific belief formation based on blind hypothesis formation? An important motive for including blind variation in scientific cognition comes from Popper's arguments against inductivism: it is never sufficient to gather data for creating knowledge; scientists have to develop new hypotheses for accounting for the data. Induction does not solve the problem of scientific creativity, "trial and error" does.

Kronfeldner develops a careful analysis of how blind variation is understood when describing scientific hypothesis formation ("Darwinian"). It is not, she warns us, to be understood as completely random variation, since hypothesis formation is strongly constrained by human cognitive capacities, sociohistorical context, and the state of knowledge. It remains that creative hypothesis formation is blind, meaning that the occurrence of new ideas is not influenced by factors that determine the selection of these new ideas. More precisely, it is blind in the sense that generative processes are not attached to any justification of the hypothesis. The idea behind this "blind as unjustified" account of hypothesis generation is in line with Popper's criticism of induction. A scientific hypothesis is justified (corroborated would be a better term here) when it has passed many attempts to falsify it. The thesis thus specified says little, as Maria Kronfeldner remarks, of the cognitive processes of discovery and hypothesis formation. So we remain with blind variation being a random production of ideas, but within a subdomain of possibilities constrained by psychological and contextual facts. However, Campbell brings another interesting specification of cognitive processes: a satisfying halting procedure. As he himself notes, blind search implies an enormous number of possible thought trials to be searched before one can select a solution. The tremendous number of nonproductive thought trials that blind variation and selective retention necessarily produce make the cognitive system unfit for survival, where decisions need to be taken quickly (e.g., when facing a predator) and where energy resource is rare and scarcely allocated ("Blind Variation").

Campbell's solution to the above problem is to postulate the existence of a simple stopping rule for the search: being selected when answering some criteria. Campbell is aware of the problem of informational explosion that blind search can create (he refers to Newell et al.); he acknowledges the credibility of the heuristic approach. He consequently allows its system to incorporate "shortcuts" to full blind variation and selective retention processes, thus making a nested hierarchy of selective retention processes ("Evolutionary"). Domain-specific heuristics, innate knowledge, or Kantian categories are such shortcuts because they allow compiling the solution without blind search or through limiting the blind search to a restricted domain. It thus turns out that even if one follows Campbell's ideas on human cognition, explaining the generation of ideas still requires specifying human-specific cognition, while the explanatory role of blind variation is small. Campbell nonetheless quickly points out that (1) such human cognitive abilities are themselves produced through blind variation and selective retention; and (2) “such shortcut processes contain in their own operation a blind-variation-and-selective-retention process.” Within the perspective of evolutionary psychology, the first point is granted, at least to the extent that the cognitive processes result from evolved cognitive abilities.

However, acquired skills and knowledge should also be taken into account for understanding generative processes. This might not be a minor point, since learning itself is probably not a blind variation and selective retention process. The second point, that the evolved cognitive mechanisms themselves implement blind variation and selective retention, is even more problematic: it is an empirical claim about human cognition that has received little support from contemporary cognitive psychology. The set of possible constraints that affect both creation and reception goes well beyond “pre-adaptations” or “developmental constraints,” which Stein and Lipton show to bias both biological and scientific evolution (“Where Guesses”).

The variations that make up new knowledge are guided by both ideas acquired from the cultural background and evolved mental mechanisms. This is granted by Campbell. What make these variations not blind is that these same processes are involved in modulating the success of these generated ideas. This is because the ideas that can be easily learned and that are built upon existing cognitive resources are more likely to be successful than ideas that have no such grounds. The reception of a new scientific idea depends on the understanding of the communicated idea. But this understanding is itself a creative process whose success is rendered possible because the audience has similar cognitive abilities and shares the same background knowledge as the one expressing new ideas. Finally, the background knowledge involved in the generation of ideas also contributes to their relevance to the community having the background knowledge. For instance, the relevance of calculus—and its cultural success—is increased by its applications to mechanics. But Newton invented calculus exactly for solving problems in mechanics. These aspect of science making constitute a strong connection between generations by individual scientists and selection by the scientific community. There is therefore a coupling between variation and success such that blind variation cannot be said to properly characterize scientific creativity and the success of scientific ideas and practices. At a minimum, the Darwinist framework seems, at this point, to hinder rather than foster research, as it unwarrantedly denies connections between creative processes and factors of reception.

Campbell is misled by the examples he takes as paradigmatic thought processes because he heavily relies on scientists’ intellectual discoveries and their phenomenological accounts, such as the Eureka phenomenon and Poincare's essay on mathematical creativity. But according to Campbell's own emphasis on the cognitive apparatus as an evolved organ, scientific inventions can hardly be taken as paradigmatic of cognition in general: the cognitive apparatus evolved to cope with day-to-day needs and dangers. Rather than scientists' discoveries, it is the ability to solve problems present in the environment that determined the selection of the genetic basis of human psychology that is best likely to characterize the function of evolved cognitive abilities. The human brain, in particular, evolved when the human species was hunting and gathering, and our cognitive apparatus is therefore designed for coping with the tasks of the hunter-gatherer as performed in the manner of our ancestors. Science, on the other hand, is a very recent cultural achievement; science making cannot be a biological function of the human brain. The challenge for the evolutionary epistemologist is then to explain how scientific cognition is done with the means of a brain that evolved for hunting and gathering. Taking evolutionary psychology seriously requires that the theories of cognition—including scientific cognition—be compatible with some evolutionary history of the biological function of cognitive processes. Thinking of human evolved cognition, evolutionary psychologists such as Gerd Gigerenzer et al. have emphasized fastness and frugality, which provide obvious advantages in the face of natural selection (*Simple Heuristics*). Others have emphasized the domain specificity of cognitive processes, leading to the thesis that the mind is massively modular (Barkow et al.). In comparison, it is implausible that blind variation and selective retention evolved as domain-cognitive processes, on top of which "shortcuts," such as heuristics, would further evolve. Evolutionary psychology recenters the investigation of cognition on real-world tasks rather than on abstract problem solving (such as scientific theorization) because it requires assessing the adaptive behavior enabled by cognitive processes.[1]

Challenge Ahead: From Evolved to Scientific Cognition

From Ecological to Scientific Rationality

The assertion that the biological functions of cognitive processes are designed (through evolution) for coping with the environment (so as to ensure survival and reproduction) leads to the investigation of "ecological rationality" as a property of cognitive processes (Gigerenzer et al.).

Evolutionary epistemology, by its very definition, must be compatible with the above principles of evolutionary psychology. How can we pass from ecological rationality to scientific rationality? The latter is oriented towards the discovery of truth, while the former is oriented towards gains in fitness.[2] I suggest that key factors that lead from ecological rationality to scientific rationality are communication and the social aspects of knowledge making. The fact that communication and social interaction constitute essential parts of scientific practice is nearly a truism. Communicating new ideas and convincing peers of their truth are core activities of scientists. Scientists also constantly assess the truth or plausibility of what other scientists communicate.

The importance of communication in the social evolution of science is actually much present in Popper's epistemology. Commenting on Campbell's evolutionary epistemology, Popper emits a criticism, which he claims to be related to the difference between man and animal, and especially between human rationality or human science and animal knowledge ("Replies"). Popper stresses the argumentative practice that is at the heart of science and that makes criticism possible. In doing so, Popper points out that science is a social practice that involves people communicating and judging each others' communications. It is this fact that put the problem of truth and scientific rationality back into scientific cognition.

With regard to truth, Popper says: "I think that the first storyteller may have been the man who contributed to the rise of the idea of factual truth and falsity, and that out of this the ideal of truth developed; as did the argumentative use of language." The ideal of truth and the practice of argumentation therefore stem from social interactions; they are constitutive of scientific cognition because science is a social activity, with argumentation at its core (Mercier and Heintz, "The Place" and "Scientists"). On this basis, new constraints on scientific cognition arise: scientific cognition must conform to the rules of scientific rationality, which is made of historically developed normative ideas about truth-preserving cognitive processes. Through this complex path, going through social interaction, scientific cognition becomes rational in the normative sense, rather than ecologically rational. In Campbell's evolutionary accounts of the history of science, both individual cognition and social processes are given due roles, but not so as to account for the evolution of the factors of success of scientific ideas: the evolution of normative ideas about what it takes to be scientifically justified. The factors of selection of scientific ideas are immutable.

Campbell faces a dilemma. He can adopt the views of evolutionary psychology and assume that human cognition in general, and scientific cognition in particular, is ecologically rational. He then misses essential features of scientific cognition, which aims at truth and objectivity. Alternatively, he can adopt a scientific-centered view of human cognition. He then abandons the vow to be compatible with theories of man as the product of biological evolution. Putting communication, social interaction, and their cognitive bases at the center stage of the evolution of science should help solve the dilemma.

Scientific Creative Thinking from Massively Modular Minds

Another difficulty with relating evolved and scientific cognition comes from the apparent flexibility and creativity of scientific thinking. Evolved cognition, by contrast, seems not to allow for such features in human cognition: evolved cognition is constituted by a set of cognitive mechanisms that have evolved to deal with specific adaptive problems—modules. As evolutionary psychologists have hypothesized, the mind is massively modular. Fodor has argued that central cognition, in particular the processes issuing in belief formation, are not modular (*The Mind* and *The Modularity*). Fodor's arguments in *The Modularity of Thought* appeal to scientific cognition as the archetypical cognitive performance, which shows that belief formation relies on cognitive processes that can draw on any information held in the mind. Scientists, or so it seems to Fodor, have unrestricted access to their stored information, which could not be so if the human mind were massively modular. In spite of the difficulties it comes with, as those forcefully pointed out by Fodor, the massive modularity hypothesis remains the standard account of human evolved cognition among evolutionary psychologists. So the challenge is to show how a massive modular mind can be flexible enough to produce new scientific ideas.

Cognitive flexibility is defined as the ability to adapt cognitive processing strategies to face new and unexpected conditions in the environment. It involves learning how to deal with new types of problems by implementing new computations. These learning abilities and exploratory strategies seem not to be attainable with massively modular minds—which are composed of task-specific cognitive devices. The massive modularity hypothesis also imposes important constraints on the architecture of the mind and on the consequent flow of information: an input is processed by the modules to which it meets the input conditions, which produces an output acting as an input for further modules, depending on the architecture of the mind, until the processing comes to a halt. The communication between modules is relatively limited, and strongly constrained by the cognitive architecture.

How can we account, with this hypothesis, for the known flexibility, diversity, malleability, and creativity of human behavior? How can we account for the human ability to integrate information from different domains? It is a challenge that proponents of the massive modularity hypothesis have taken seriously. Sperber argues that flexibility and context sensitivity are attained, at the psychological level, because most modules are learning modules ("In Defense" and "Modularity"). Learning can happen not only through the enrichment of modules' databases but also through the fixation of parameters determining the domains of modules.

Development, according to Sperber, also includes learning that is reflected in modular architecture: learning modules produce dedicated modular subsystems for acquired capabilities. Last, in order to account for context sensitivity, Sperber argues that modules do not process inputs in a mandatory way ("Modularity"). One of Fodor's characteristics of modules is that once an input meets the input conditions of a module, the module is automatically triggered and runs its full course. Sperber argues on the contrary that a module is activated not just in view of its input condition, but also in view of the relevance of the input, that is, its expected cognitive effect (such as acquisition of new and useful information) and effort for processing it. Nested modularity, enrichment, maturation of cognitive abilities, development of new modules through learning, maximization of cognitive efficiency are features of the modular mind that provide much flexibility. How do they support scientific cognition?

Carruthers argues for a "moderately massive modularity" where the language module is given a special role serving as the medium of intermodular integration and conscious thinking ("Moderately"). Without denying the role of the above principles of flexibility, context sensitivity, and integration, I would like to emphasize the role of metarepresentations in generating new integrated knowledge, and sustaining conceptual change in science. The flexibility of the human mind, indeed, 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 some of the content of science at odds 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 the abandonment of previously believed theories requires, on the part of scientists, a new attitude towards the stimuli of the newly theorized domain. What are the cognitive processes accounting for these new attitudes? 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 has analyzed the role of physical analogy, the construction of thought experiments, and limiting case analyses ("In the Theoretician"). Carey has also pointed out the role of mappings across cognitive domains for the creation of new domains (e.g., Carey, *Conceptual*; Carey and Spelke, "Domain-Specific"). There is general agreement that conceptual change involves metarepresentational abilities. Scientific cognition heavily relies on the ability to metarepresent our own representations, and thus to think reflectively. Metarepresentational ability allows for the processing, using, and producing of representations of representations. One or more cognitive modules may implement the ability. Some metarepresentational modules, indeed, have an already studied evolutionary history and satisfy the requirements of evolutionary plausibility. Presumably, metarepresentational 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' behavior, and is certainly at the basis of human social life, including linguistic communication.

The relevant consequence of metarepresentational ability (or abilities) is that the cognitive output of modules can be rethought. In particular, metarepresentational abilities enable making epistemic evaluation of the output of modules. For instance, I perceive that the sun is traveling around the earth, but I know that this perception is misguiding. When a perceptive representation gets embedded within a framework theory, the perceptive representation is metarepresented as a manifestation or consequence of some state of the matter or of some laws of nature. Scientific practice, says Nancy Nersessian, "often involves extensive metacognitive reflections of scientists as they have evaluated, refined and extended representational, reasoning and communicative practices" ("The Cognitive" 135). Deana Kuhn has also pointed out the metacognitive skills at work in scientific thinking. These include not only metastrategic competence, 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" (275). Metarepresentational abilities are thus central to scientific thinking. Most interestingly for our present purpose, they also bridge the gap between lower cognitive abilities processing the input from our sense organs, hardwired heuristics and naïve theories, and the abstract and consciously controlled thinking practices of science.[3] I therefore suggest that scientific thinking is well characterized as a systematic exploitation of human cognitive abilities by exploiting, via metarepresentations, existing heuristics and intuitions.

Spranzi's case study is an example of such reasoning, where an analogy is drawn between two distinct phenomena: Galileo interprets the black marks on the moon as similar to the shadows thrown by mountains on the earth ("Galilei"). Now, Spranzi argues, the analogy did not pop up out of the blue—which would have exemplified a mysterious "Fodorian" (isotropic) cognitive event. She shows, on the contrary, that it was rendered possible through a historical process of bootstrapping. In other words, the cultural context made some ideas and representations available to Galileo, making the analogy possible. We therefore have a case where the determination of scientific thinking is shown to be historical and social as well as cognitive.

Cognition does not only take place in a cultural environment: more radically, aspects of the environment itself implement or contribute to cognitive processing. For instance, Galileo perceived shadows on the moon by means of his telescope. As another instance, most scientists now perform their statistical analysis with specialized software or programming languages. Here is, therefore, another source of flexibility: scientific cognition is implemented in systems in which cognition is distributed to tools and specialists. These "distributed cognitive systems" quickly change; they have the plasticity out of which flexibility arises. In particular, new technologies are exploited, new experts are given new roles in the production of knowledge, and the architecture of the systems changes as a function of the available resources and goals. (For instance, contemporary large experiments in atomic physics require numerous researchers dealing with very specific tasks, while traditional theoretical debates require few researchers having similar expertise). This suggests that distributed cognitive systems evolve so as to respond to contextual factors such as changing means and needs. Flexible cognition is thus also achieved through the flexibility of institutions of scientific production and their associated systems of distributed cognition.

Conclusion on Evolutionary Epistemology and Scientific Innovation

An important gap in science studies is the study of the role of our primary intuitions in scientific knowledge (Heintz, "Scaffolding"). 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 metarepresented knowledge and the direct output of non-metarepresentational modules (see Sperber, "Intuitive," for the distinction between intuitive and reflective beliefs). In other words, Campbell set a research program that has not really been implemented. One possible reason was that Campbell himself skipped through it and appealed to blind variation instead, which we criticized as either being an implausible description of scientific cognition or a black box standing for the complex psychology of scientific innovation.

Selective Retention Does Not Adequately Describe Why Some Ideas and Practices Spread

According to the traditional view of evolutionary epistemology, blind variation that generates new ideas occurs within scientists' minds, while selective retention is mostly a social process involving scientists checking the work of others and choosing the best of it. Selective retention involves a process of selection that well describes the fact that not all of scientists' ideas gain the status of scientific knowledge and get distributed in the scientific community. But selective retention involves also a process of retention, and Darwinian selectionist theory holds that it is done through replication. In biology, it is DNA sequences that are replicated; in science, the replication is of beliefs, ideas, and practices. The replication happens by means of social interaction, mainly communication.

David Hull, whose work can be understood as a refinement and updating of evolutionary epistemology (*Science as a Process* and *Science and Selection*), specifies what replicators are in the evolution of science:

> the replicators in science are elements of the substantive content of science—beliefs about the goals of science, the proper ways to go about realizing these goals, problems and their possible solutions, modes of representation, accumulated data reports, and so on . . . These are the entities that get passed on in replication sequences in science. Included among the chief vehicles of transmission in conceptual replication are books, journals, computers, and of course human brains. As in biological evolution, each replication counts as a generation with respect to selection . . . Conceptual replicators interact with that portion of the natural world to which they ostensibly refer . . . only indirectly by means of scientists. (*Science and Selection* 116)

Conceptual replication is a matter of information being transmitted largely intact from physical vehicle to physical vehicle. The problem is that replication at the conceptual level does not properly describe the mechanisms through which representations are distributed and stabilized within a community. An appeal to replication is a way to black box the mechanisms of transmission. As the notion of blind variation, it prevents from developing studies that investigate actual cognitive processes and their evolved basis.

In order to make this point, I only briefly review the arguments put forward by Sperber and colleagues against selectionist models of cultural evolution (Heintz and Claidière; Sperber, *Explaining Culture*; Sperber and Claidière). The bulk of the argument is that representations do not in general replicate in the process of transmission, but rather they transform as a result of a constructive cognitive process.

In place of replication and selection, Sperber appeals to the role of several factors stabilizing the distributions of representations. Among those factors, importantly, lies the rich and universal human cognitive endowment. For instance, a natural language is known and distributed within a population not only because children learn to speak on the basis of what they hear, but also because they have an unlearned ability to learn languages. As Sperber and Cladière put it: "cultural propagation . . . is achieved through many different and independent mechanisms, none of which is central and none of which is a robust replication mechanism" (20). In particular, imitation is not the main mechanism of transmission, but only if "the notion is stretched to cover a wide variety of quite different processes" (20). Thus, the observed macrostability, as manifested by "relatively stable representations, practices and artifacts distributed across generations throughout a social group," (21) does not warrant the existence of mental processes insuring the microheritability of cultural items.

For instance, one can hear a version of the little red riding hood tale, where, say, it is not specified that the wolf is greedy and cunning. Yet, this aspect can easily be inferred from the behavior of the wolf. This inference is a constructive process that draws upon a disposition to ascribe intentions and psychological traits to agents. This inference will in turn influence how the tale will be told, again, on the basis of an understanding of what cunning and greedy people do. More generally, the utterances heard during the telling of a tale are interpreted. This is a constructive process that might rely on cognitive capacities shared by a community and that are psychological factors of attraction: they favor some interpretations more than others. The same holds for the transmission of mathematical proofs, and scientific theories and their empirical basis. For instance, many steps are being skipped in a written or uttered proof. Mathematicians in the audience just reconstruct these steps, sometimes automatically, and at other times after some effort. Background knowledge is key: no mental representation of the proof of Gödel's first incompleteness will be constructed if it is told to someone with no mathematical literacy. The proof of Gödel's first incompleteness theorem is not merely replicated. If it was so, its versions would quickly drift towards non sense. The proof is understood, which means that background knowledge and diverse cognitive processes are put to work for interpreting some written or oral version of the proof. This trivial observation demonstrate that transmission of scientific ideas and practices is not resulting from some domain general mechanism of replication, it is resulting from complex processes of understanding and communicating. Thus, "the microprocesses of cultural propagation are in good part constructive rather than preservative" (22). Consequently, Darwinian models of cultural evolution are unsatisfactory because "cultural contents are not replicated by one set of inheritance mechanisms and selected by another, disjoint set of environmental factors" (22).

Opening the black box that "retention" is around the multiple processes of cultural transmission, one sees that transformation is pervasive and faithful replication is a rare limiting case of zero transformation. Theories in psychology and sociology about memory, imitation, and communication show that high-fidelity reproduction is the exception rather than the rule. The consequence is that concepts or ideas are not replicated well enough to undergo effective selection: the rate of change is such that selection cannot be consequential on evolution. How, then, can ideas and practices, including scientific ones, form cultural phenomena?

The causes of preservation and propagation often lay in the fact that constructive biases are shared in a population. I mentioned the universal human cognitive endowment, such as the ability to communicate, but, importantly, similar aspects in individuals' histories also cause shared constructive biases, such as the knowledge and practice of a scientific paradigm, which provides an interpretative framework for processing new input. In spite of the fact that transmitted representations are different from one another, the representations do not drift away through added transformations to strongly dissimilar representations. The constructed representations tend to gather around some "attractors." For instance, the mental representations of a proof do not resemble in any straightforward way to the public representations, yet they resemble each other's in relevant ways: they cluster around a perfect understanding of the proof. They will give rise to public versions of the proof which, again thanks to shared constructive mechanisms (including communicative skills), will tend to cluster around understandable versions of the proof.

The Darwinian selectionist model for thinking about the evolution of science is certainly a source of inspiration and discovery. Hull, for instance, draws on the model for explaining social processes of competition and collaboration in the sciences (*Science and Selection*). In the same way as inclusive fitness in biological evolution accounts for kinship altruism, in the sciences, scientists promote both their own work and the work of those who use their work. The works of scientists thus have "conceptual inclusive fitness." However, the Darwinian selectionist model makes erroneous assumptions about scientific cognition. Assuming that one single mechanism enables the faithful transmission of scientific ideas hinders rather than fosters the cognitive and social investigation of the processes of cultural evolution.

The criticism against selective retention as a process of scientific development can be summed up with the following points:

1. As opposed to biological evolution, there is no mechanism of replication that would insure the faithful copying of ideas and practices. Cultural transmission is realized by diverse processes that are implemented in evolved psychological mechanism, but also by learned skills, artifacts, and institutions.
2. The mechanisms of cultural transmission are not especially preservative processes. Processes of transmission involve transformations, and preservation is only a limiting case of no transformation.
3. The consequence of the above lack of faithful transmission is such that there is not enough retention for selection to operate on stable populations of cultural items.
4. Ideas and practices are maintained and spread not through faithful replication, but through attraction: transmission induces some transformation, but these transformations are systematically biased towards an "attractor." Cultural phenomena are made of clusters of resembling tokens rather than identical tokens.
5. The above points, made by cultural attraction theorists for understanding the evolution of culture in general, apply to the cultural phenomena that constitute the history of science and technology. The transmissions of scientific ideas and practices are complex processes relying on multiple mechanisms whose function is not replication. Transmission events need not be faithful and preservative. If and when they are, this needs to

be explained rather than granted. The success of an idea or a practice can be explained by attraction rather than just retention.

Challenge Ahead: The Stabilization of Scientific Beliefs and Practices

Science as Cumulated Culture

How can we obtain the stabilization of some specific ideas and practices in spite of the fact that cultural transmission is not sufficiently faithful? The hypothesis put forward by cultural attraction theory (also called cultural epidemiology; Heintz, "Cultural Attraction Theory"; Sperber, *Explaining*) is that some forms or types of ideas and practices are more likely to be produced than others. The cause of stabilization thus does not rely on the viability of transmission processes, but on the constructive processes that, in spite of small variations in input, are likely to produce outputs that resemble one another.

How can cultural attraction theory be used for explaining the stabilization of scientific beliefs and practices? It has been put to work for explaining the spread of intuitive and minimally counterintuitive beliefs: pseudoscientific beliefs (Blancke et al.; Miton et al.) and religious beliefs (Boyer), for instance. Practices of painters (Morin) have also been analyzed with cultural attraction theory.

Yet, while this type of account acknowledges the role of evolved cognitive capacities in shaping cultural phenomena, it does not seem to provide a proper framework for understanding the cumulated culture that characterizes science and technology. Explaining scientific beliefs and practices seems to raise another type of challenge because it seems so disconnected from our naive or intuitive beliefs. Some of our scientific beliefs are even downright counterintuitive (e.g., Darwinian evolution; see Atran; Gervais). Science results from a cumulative process that seems to make evolved intuitions irrelevant to understanding the history of its content. Doesn't scientific cognition stand on reason rather than evolved intuitions? The question about how to go from ecological rationality to scientific rationality arises here again, which is not surprising, since the processes of variation and retention are not essentially distinct. However, what is of special interest for this subsection is how acquired knowledge and cognitive skills become constructive mechanisms at work in the transmission of complex scientific ideas and practices.

More precisely, the cumulated aspect of cultural evolution can be grasped by considering the following:

- The input of psychological mechanisms is, most of the time, itself a socially constructed input. Currently, many of the things we perceive and that affect cognition have been anteriorly processed by humans: these include linguistic productions, of course, and human artifacts. Even when scientists study basic natural phenomena, such as the behavior of atoms, the input they use for theorizing about them involve many cultural artifacts: it is, for instance, a data chart produced by a computer after some highly controlled experiment happened. This is vividly illustrated by the activity of scientists at the CERN, who study fundamental natural phenomena but in a highly constructed social and material environment.
- Psychological constructive mechanisms are themselves the result of cultural processes. Both genetic endowment and individual history determine an individual's psychology. While evolutionary epistemology prompts us to pay special attention to evolved cognitive mechanisms, this cannot be sufficient for understanding how highly enculturated individuals think—including scientists, who benefited from a long and complex education, most of the time by way of educational institutions (and, rarely, through the sole access to scientific writings).

These are simple and, I would say, noncontroversial observations. Yet, they point to the relevance of a multiplicity of processes, and it is a challenge to integrate them in a single evolutionary account. Constructive processes at work in the transmission of scientific ideas involve "cognitive artifacts" and "learned skills" as well as evolved intuitions.

There is a fuzzy and changing set of common beliefs that regulate scientific practices. These beliefs have been sometimes characterized as epistemic claims about the value of empirical investigation, the use of mathematics, the avoidance of ad hominem arguments, and other values coming from the scientific revolution (Shapin). These shared beliefs contribute to generating types of behaviors because they are "scientific," and these behaviors stabilize in the scientific community for the same reason—being considered as scientific by the scientific community. Fuzzy subsets of common beliefs can be found at the more local levels of disciplines and research fields. The sets will include implicit and explicit beliefs, know-how and know-that, beliefs about the reliability of some instruments, beliefs about nature, and beliefs about methods of investigation. The role of education cannot be overemphasized in science: it includes memorization, but also drills of scientific practices. It importantly contributes to building shared cognitive capacities among scientific communities. These shared capacities will be involved in the construction of mental representations and public productions.

Scaffolded Attraction in the Making of Science

The important consequence of the above observations for cultural attraction theory is that factors of attraction, while they do influence cultural evolution, can themselves be contingent on historical and cultural phenomena. For instance, scientific education includes a specification of the problems worth solving and the kinds of tools that might be useful for the task: such specifications are factors of attraction because they determine what will interest scientists and how they will dedicate their efforts. But these factors of attraction are not evolved; they are themselves the product of history. Education and, more generally, enculturation will partially determine what attraction there will be. Likewise, the material environment—what kind of facilities there are, the social environment—and who talks with whom will also partially determine the content and form of cultural attractors. Enculturation and the cultural environment (material or social) constitute scaffolds for cultural attractors.[4] There is cognitive attraction caused by evolved cognition, but also scaffolded attraction caused by learned skills, knowledge, habits, and the historically built environment. The more specific challenge for evolutionary epistemology is to specify the scaffolds that are important factors of attraction in science. The cumulative aspect of science is partially expressed by the fact that there is scaffolded attraction. For instance, the success of calculus in the eighteenth century is due to the fact that it helped solving already well-known and well-specified problems: for instance, calculating an area under a curve was a well-known problem well-specified in Cartesian geometry, and calculating the speed and acceleration were problems whose importance derived from Galileo's work. In that sense, preliminary geometric and mechanistic knowledge specified ways of using calculus. The preliminary knowledge did therefore more than just enable the discovery of calculus: it is not just Newton who had to climb on the shoulders of giants, but his readers too. And it did more than just make calculus useful (increasing its cultural fitness, in Darwinian selectionist theorization): it acted as a factor of attraction towards some mathematical practices.

There are, among the ideas shared by the scientific community, normative ideas that regulate how other ideas should be produced. For instance, in many research fields, standard thought is that only experiments that show a statistical significance (a low p-value) are worth being published.[5] These normative ideas do play a role in scientific practices. In our example, experiments will be designed so that a significant difference between experimental conditions might be revealed. They also play a role in the success of ideas or representations. In our example, only papers showing a p-value lower than .05 will be published in prestigious journals. An important argument made by sociologists of science (e.g., Barnes et al.) is that all scientific ideas and practices have such a normative aspect because science is essentially a social product that involves social interactions and coordination. For instance, a scientific term includes a normative component about how it should be used: the kind of inferences it warrants, how it relates to other scientific or nonscientific terms, and its reference. There is therefore a social regulation of the use of scientific terms that will impact the interpretation and production of these terms. Such norms are also scaffolds that strongly regulate the production of representations.

The constructed material environment can also act as scaffolded attraction. The role of material tokens in science making is apparent with writing, which has been the main means for sharing beliefs and thus establishing common grounds. The pervasive reference to written artifacts obviously constrains scientific thinking: written artifacts provide to scientists a shared corpus of data, of theoretical and methodological texts. Materials in science also include cognitive tools, such as the telescope or, more recently, data-crunching computers. And they include material models of natural phenomena; for instance, the physical models of molecular structures are a research tool that has influenced the thoughts and productions of chemists (Charbonneau). The general aspect of such models is that once their cognitive role is being specified, they fully participate in the production of knowledge. Again, we have shared elements that participate in the production of mental representations and public productions. These shared elements increase the probability that some cultural items rather than others will be produced. They act as scaffolding factors of attraction. Another way to put it is that the cognitive constructive processes that will act as factors of attraction not only are in the heads of scientists but are systems that include scientists and their cognitive tools. The work on distributed cognitive systems in science (Giere and Moffatt; Nersessian et al.) is relevant to understanding the factors of attraction in the history of science.

Conclusion on Evolutionary Epistemology and Cultural Attraction Theory

The selectionist evolutionary model does appear to provide solutions to the challenge of explaining cumulated culture. Cultural items are usually faithfully copied, but sometimes, one of the relatively rare mutations turns out to be more successful than other variants. The success of a variant is mainly (but not only) determined by its ability to confront the world whose selection pressures occur in the form of experimental tests. As ideas confront the world through new experiments, some are refuted and selected out and others survive. As appealing as it is, this picture is a simplification that historians of science are not willing to use for describing scientific developments. It prevents from discovering the true underlying processes that spread ideas and practices in a community.

Rather than appealing to selective retention, I think the best way to pursue the program of evolutionary epistemology is to use cultural attraction theory. This move enables relaxing the assumption that selection is the only factor accounting for the stabilization of some ideas and practices. It also advocates peering into the constructive processes that will act as factors of attraction, which make some ideas more stable than others in spite of important changes occurring in the chains of transmission.

The main advantage of relaxing the assumption of Darwinian selection is that it reopens evolutionary epistemology to all the work that has been done by sociologists, historians, and cognitive scientists of science. I have alluded to the Khunian notion of paradigm and its development when talking of the fuzzy set of ideas and practices that are shared by the research community, I have pointed to the work of sociologists on the conventions and social norms that are pervasive in science making, and I have made reference to the work on distributed cognition as an important addition for describing the cognitive constructive mechanisms of scientific production. Cultural attraction theory does not provide an alternative explanation to the constructive processes of science making. It only provides a framework for connecting the evolutionary aspect of science, as a cultural domain, to the social and cognitive events described in science studies.

In the end, it might turn out that science is the most selectionist of the evolving cultural domains. But this should be explained, not just assumed. Selection might be due to specific institutions: the educational system, the systematic reliance on writing, the relative perennity of material arrangements—these all make reproduction more faithful. There are also institutions that implement the selection of ideas: in particular, the system of scientific publication and the argumentative practices that encourage systematic skepticism.

What of evolved cognitive capacities? While their role has been pointed out above, they have disappeared in the current section. In fact, my bet is that when describing the scaffolded factors of attraction, one will eventually see that they are grounded in evolved cognitive capacities. For instance, teaching institutions will be more successful in their teaching if they rely on existing learning capacities. More radically, I have argued elsewhere that the interpretation of even complex mathematical notions is geared by evolved cognitive capacities (Heintz, "Scaffolding").[6]

Conclusion

Campbell's ambition to find a unique principle accounting for biological evolution, cognition, and scientific evolution provides an oversimplified picture of cognition and culture. The naturalization of science studies passes first through an integration of cognitive and social studies of science. Imposing the Darwinist selectionist model on the evolution of science leads to bypassing too much of the results in cognitive psychology and the sociology of science.

The sociology and history of science of these last decades have pointed out the social processes at work in scientific knowledge production. These include the institutional constitution of science, the coercive strength of scientific traditions (including the norms of rationality), the self-referring aspects of scientific beliefs, the goal orientation of research, the role of trust in science, novice-expert interactions and how scientific practices are taught and learned, the reliance on external values and beliefs, and negotiations during scientific controversies. The abstract and methodological Popperian picture of conjecture and refutation is given more sociological reality, which implicates a complexification that can no longer be grasped with blind variation and selective retention. Blind variation and selective retention seem, at this stage of sociological and psychological knowledge, unable to account for the factors determining the success of scientific practices, including scientific judgments; the forms of justifications, rebuttal, and assent; types of scientific communication; and the causes of creative thinking.

Still, evolutionary epistemology is a worthwhile project for two reasons. First, it stands on a naturalistic ontology; there are beliefs and behavior. Some beliefs stabilize in the scientific community and others do not; some behaviors become common practices and others do not. This ontology comes with a research program: specifying what more holistic notions, such as "paradigm," really mean and, more generally, analyzing cultural phenomena in terms of the spread of ideas and practices in a community. Second, evolutionary epistemology requires understanding scientific knowledge production as the activity of evolved organisms—the scientists. Evolutionary psychology is thus made relevant to understanding the history of science. This, again, comes with a research program, which consists of specifying the role of evolved capacities in scientific practices and thinking.

These two related research programs have known few developments as such, but contemporary work in the history and sociology of science and work on scientific cognition are already contributions to these research programs. Evolutionary epistemology as I advocate it is thus not much more than a comprehensive framework that emphasizes the relevance of interdisciplinary investigations—psychology, sociology, and the history of science—and enables spelling out the contribution of one to the other. Evolutionary epistemology in the restrictive sense, as envisaged by Campbell and pursued by Hull, by contrast, relies on the assumption that culture evolves and knowledge is produced by means of blind variation and selective retention. I have argued that this assumption is not well grounded and furthermore prevents investigating the constructive processes through which culture and knowledge are produced and spread. I therefore advocate doing evolutionary epistemology, but only in the nonrestricted sense of the term. In the place of blind variation and selective retention, I have argued that cultural attraction is what enables the stabilization of cultural items. To understand cultural attraction, one needs to discover the constructive processes that generate new ideas and their interpretations by the scientific community.

Notes

1. To be fair, Simonton's account of creativity is compatible with Campbell's idea of cognition as blind variation and selective retention ("Creativity"). Simonton states that hypothesis formation is based on a subconscious random generation of ideas: only selected ideas come to consciousness, but a massive number of unconscious random ideas have been previously generated. However, such a process has low adaptive value because it requires computing a massive number of ideas. In addition to its low adaptiveness (the generation of a massive number of random ideas seems too costly for being selected by natural evolution), there is little empirical evidence in favor of a hidden, unconscious, chaotic generation of ideas (Sternberg).
2. For a radical analysis of the difference between truth-preserving cognitive mechanisms and fitness enhancing ones, see Stich, *The Fragmentation*.
3. Gorman, "Heuristics," 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.

4. I take the term "scaffolding" in cultural evolution from Wimsatt and Griesemer, "Entrenchment" and "Reproducing," and their analysis of cumulative cultural evolution.
5. The dominant role of the p-value is currently being challenged, with Bayesian data analysis as a competitor statistical method (Gelman et al.).
6. The case study (Heintz, *Cognition*) consisted of showing that the interpretation of the notion of infinitesimal was influenced by our object-tracking systems, which Susan Carey has shown to be involved in learning natural numbers ("Precis"; Carey and Spelke, "Science").

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