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Scientific innovation as eco-epistemic warfare: the creative role of on-line manipulative abduction

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Abstract Humans continuously delegate and distribute cognitive functions to the environment to lessen their limits. They build models, representations, and other various mediating structures, that are thought to be good to think. The case of scientific innovation is particularly important: the main aim of this paper is to revise and criticize the concept of scientific innovation, reframing it in what I will call an *eco-epistemic perspective*, taking advantage of recent results coming from the area of *distributed cognition* (common coding) and *abductive cognition* (manipulative). Taking advantage of this eco-cognitive perspective the article outlines how innovative scientific modeling activity can be better described taking advantage of the concept of "epistemic warfare", which sees scientific enterprise as a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from non epistemic (for example fictions, falsities, propaganda) weapons.

Keywords Abduction · Creativity · Epistemic warfare · Chance discovery · Epistemic niches

1 The eco-cognitive situatedness of chance discovery and the role of abduction

As defined by Oshawa and McBurney (2003), a chance is a new event or situation conveying both an opportunity and a risk in the future. Recently, a number of contributions have acknowledged the abductive dimension of seeking chances with relation to science (Magnani 2005, 2010; Magnani and Bardone 2008; Abe 2009). As maintained by Magnani and Bardone (2008) and Abe (2009), the process of

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chance detection (and creation) is resulting from an inferential process—mainly abductive—in which the agent exploits latent clues and signs signaling or informing the presence of an action opportunity (Magnani and Bardone 2008).

Accordingly, an inference is a form of sign activity in which the word sign encompasses several types of sign, for instance, symbol, feeling, image, conception, and other representation (Peirce 1931–1958, 5.283). Moreover, the process of inferring—and so the activity of chance seeking and extracting—is carried out in a distributed and hybrid way (Magnani 2010). This approach considers cognitive systems in terms of their environmental situatedness: instead of being used to build a comprehensive inner model of its surroundings, the agent's perceptual capacities are seen as simply used to obtain "what-ever" specific pieces of information are necessary for its behavior in the world: not only the agent represents the external world but also modify it delegating representations to the environment to promote possible manipulations of them. The agent constantly "adjusts" its vantage point, updating and refining its procedures, in order to uncover a piece of information. This resorts to the need of specifying how to efficiently examine and explore and to the need of "interpreting" an object of a certain type. It is a process of attentive and controlled perceptual exploration through which the agent is able to collect the necessary information: a purposefully moving through what is being examined, actively picking up information rather than passively transducing (Thomas 1999). In this sense, humans like other creatures are ecological engineers, because they do not simply live their environment, but they actively shape and change it looking for suitable chances, epistemic for example, like in the case of scientific abductive cognition.

Generally speaking, the activity of chance-seeking as a plastic behavior is administered at the eco-cognitive level through the construction and maintenance of the so-called cognitive niches (Magnani 2009). The various cognitive niches humans live in are responsible for delivering those clues and signs informing about an (environmental) chance. So, the mediating activity of inferring as sign activity takes place (and is enhanced) for the presence of the so-called eco-cognitive inheritance system (Odling-Smee et al. 2003). That is, humans can benefit from the various eco-cognitive innovations as forms of environmental modifications brought about and preserved by the previous generations. Indeed, many chance-seeking capacities are not wired by evolution, but enter one's behavioral repertoire because they are secured not at the genetic level, but at the eco-cognitive one—in the cognitive niches. The second important point to mention is that humans as chance extractors act like eco-cognitive engineers (Magnani and Bardone 2008; Bardone 2011). Accordingly, they take part in the process of extracting chances by performing smart manipulation of the environment in order to turn an external constraint into a part of their extended cognitive system.

Humans as eco-cognitive engineers are also chances-maintainers. Humans act so as to preserve those chances (and "chances of chances") that have been proved as successful and worth pursuing. That is what allows us to have an eco-cognitive inheritance that, in turn, enriches or even creates the behavioral chances a community or a group of people has for surviving and prospering.

In summary, chances are provided by the continuous eco-cognitive activity of humans as chance extractors. But what exactly happens when agents are involved in cognitive processes related to scientific innovation? In the following sections I will delineate some basic aspects of conceptual innovation in science, taking advantage of an eco-epistemic perspective, suitably intertwined with recent results coming from the area of distributed and abductive cognition.

2 Epistemic niche construction: external models in common coding

From a general cognitive point of view, if we comply with a conception of the mind as "extended", we can hypothesize a kind of co-evolution between mind and cognitive niches. We can say that the mind's guesses—both instinctual and reasoned—can be classified as plausible hypotheses about "nature" because the mind grows up *together with* the representational delegations[1] to that "nature" that the mind itself has made throughout the history of culture by constructing those cognitive niches I have quoted in the previous section. Consequently, contrarily to the standard view of XX century philosophy of science, not only scientific models are never abstracts/ideal, they are always distributed. Indeed, in the perspective of distributed (and embodied) cognition (Hutchins 1999) a recent experimental cognitive research (Chandrasekharan 2009) further provides deep and fresh epistemological insight into the old problem of abstractness and ideality of models in scientific reasoning. The research illustrates two "concrete" external models, as functional and behavioral approximations of neurons, one physical (in-vitro networks of cultured neurons) and the other consisting in a computational counterpart, as recently built and applied in a neural engineering laboratory. These models are clearly recognized as external systems—external artifacts more or less intentionally[2] prepared, exactly like concrete diagrams in the case of ancient geometry—interacting with the internal corresponding models of the researchers, and they aim at generating chances for discovering new concepts and control structures regarding target systems.

The external models in general offer more plasticity than the internal ones and lower memory and cognitive load for the scientist's minds. They also incorporate constraints imposed by the medium at hand that also depend on the intrinsic and immanent cognitive/semiotic delegations (and the relative established conventionality) performed by the model builder(s): artificial languages, proofs, new figures, examples, computational simulations, etc.[3] It is obvious that the information (about

[1] Representational delegations are those cognitive acts that transform the natural environment in a cognitive one.

[2] We have to note that manipulative abduction (cf. below in this article) also happens when we are *thinking through doing* (and not only, in a pragmatic sense, about doing). This kind of action-based cognition can hardly be intended as performed through completely intentional and/or conscious acts (Magnani 2009).

[3] On the cognitive delegations to external artifacts see (Magnani 2009, chapter three, Section 3.6). A useful description of how formats also matter in the case of external hypothetical models and representations, and of how they provide different affordances and inferential chances, cf. Vorms (Vorms 2010).

model behavior) from models to scientists flow through perception (and not only through visualization as a mere representation—as we will see below, in the case of common coding also through "movements in the visualization [which] are also a way of generating equivalent movements in body coordinates" (Chandrasekharan 2009, p. 1076).

Perception persists in being the vehicle of model-based and motor information to the brain. We see at work that same perception that Peirce speculatively analyzed as that complicated philosophical structure I have illustrated in details in a recent book on abductive cognition.[4] Peirce explains to us that some basic human model-based ways of knowing, that is *perceptions*, are abductions, and thus that they are hypothetical and withdrawable. Moreover, given the fact that judgments in perception are fallible but indubitable abductions, we are not in any psychological condition to conceive that they are false, as they are unconscious habits of inference. Hence, these fundamental—even if non scientific—model-based ways of cognizing are constitutively intertwined with inferential processes. *Unconscious* cognition enters these processes (and not only in the case of some aspects of perception—remind the process, in scientific modeling, of "thinking through doing", I have just quoted above in footnote 2), so that model-based cognition is typically performed in an unintentional way. The same happens in the case of emotions, which provide a quick—even if often highly unreliable—abductive appraisal/explanation of given data, which is usually anomalous or inconsistent. It seems that, still in the light of the recent results in cognitive science I have just described, the importance of the model-based character of perception stressed by Peirce is intact. This suggests that we can hypothesize a continuum from construction of models that actually *emerge* at the stage of perception, where models are operating with the spontaneous application of abductive processes to the high-level model activities of more or less intentional modelers (Park 2011; Bertolotti 2012), such as scientists.[5]

The cognitive mechanism carefully exploited and illustrated in (Chandrasekharan 2009) takes advantage of the notion of *common coding*,[6] recently studied in cognitive science and closely related to embodied cognition, as a way of explaining the special kind of "internal-external coupling", where brain is considered a control

[4] The complicated analysis of some seminal Peircean philosophical considerations concerning abduction, perception, inference, and instinct, which have to be considered still important to current cognitive and epistemological research, is provided in (Magnani 2009, chapter five).

[5] On the puzzling problem of the "modal" and "amodal" character of the human brain processing of perceptual information, and the asseveration of the importance of grounded cognition, cf. (Barsalou 2008a, b).

[6] "The basic argument for common coding is an adaptive one, where organisms are considered to be fundamentally action systems. In this view, sensory and cognitive systems evolved to support action, and they are therefore dynamically coupled to action systems in ways that help organisms act quickly and appropriately. Common coding, and the resultant replication of external movements in body coordinates, provides one form of highly efficient coupling. Since both biological and nonbiological movements are equally important to the organism, and the two movements interact in unpredictable ways, it is beneficial to replicate both types of movements in body coordinates, so that efficient responses can be generated" (Chandrasekharan 2009, p. 1069): in this quoted paper the reader can find a rich reference to the recent literature on embodied cognition and common coding.

mechanism that coordinates action and movements in the world. Common coding hypothesizes

> [...] that the execution, perception, and imagination of movements share a common representation (coding) in the brain. This coding leads to any one of these three (say perception of an external movement), automatically triggering the other two (imagination and execution of movement). One effect of this mechanism is that it allows any perceived external movement to be instantaneously replicated in body coordinates, generating a dynamic movement trace that can be used to generate an action response. The trace can also be used later for cognitive operations involving movement (action simulations). In this view, movement crosses the internal/external boundary as movement, and thus movement could be seen as a "lingua franca" that is shared across internal and external models, if both have movement components, as they tend to do in science and engineering (Chandrasekharan 2009, p. 1061).

Common coding refers to a representationalist account, but representation supports a motor simulation mechanism "which can be activated across different timescales—instantaneous simulation of external movement, and also extended simulations of movement. The latter could be online, that is, linked to an external movement (as in mental rotations while playing Tetris, see (Kirsh and Maglio 1994)), or can be offline (as in purely imagined mental rotation)" (Chandrasekharan 2009, p. 1072). Furthermore

1. given the fact models in science and engineering often characterize phenomena in terms of bodies and particles, motor simulations are important to understand them, and the lingua franca guarantees integration between internal and external models;
2. the manipulation of the external models creates new patterns that are offered through perception to the researchers (and across the whole team, to possibly reach the shared "manifest model"),[7] and "perturbs" (through experimentation on the model that can be either intended or random) their movement-based internal models possibly leading "[...] to the generation of nonstandard, but plausible, movement patterns in internal models, which, in combination with mathematical and logical reasoning, leads to novel concepts" (cit., p. 1062);
3. this hybrid combination with mathematical and logical reasoning, and possible other available representational resources stored in the brain, offers an example of the so-called multimodality of abduction.[8] Not only both data and theoretical adopted hypotheses, but also the intermediate steps between them—i.e. for

[7] I contend that the so-called *abstract model* can be better described in terms of what Nersessian and Chandrasekharan (2009) call *manifest model*: when the scientific collective decides whether the model is worth pursuing, and whether it would address the problems and concepts researchers are faced with, it is an internal model and it is manifest because it is shared and "[...] allows group members to perform manipulations and thus form common movement representations of the proposed concept. The manifest model also improves group dynamics" (Chandrasekharan 2009, p. 1079).

[8] On the concept of multimodal abduction see (Thagard 2007).

example, models—can have a full range of verbal and sensory representations, involving words, sights, images, smells, etc. and also kinesthetic and motor experiences and feelings such as satisfaction, and thus all sensory modalities. Furthermore, each of these cognitive levels—for example the mathematical ones, often thought as presumptively *abstract* [does this authorize us to say they are fictional?]—actually consists in intertwined and flexible models (*external* and *internal*) that can be analogically referred to the Peircean concept of the "compound conventional sign", where for example sentential and logical aspects coexist with model-based features. For Peirce, *iconicity hybridates logicality*: the sentential aspects of symbolic disciplines like logic or algebra coexist with model-based features—iconic. Indeed, sentential features like symbols and conventional rules[9] are intertwined with the spatial configuration, like in the case of "compound conventional signs". Model-based iconicity is always present in human reasoning, even if often hidden and implicit;[10]

4. it is the perturbation I have described above that furnishes a *chance* for *change*, often innovative, in the internal model (new brain areas can be activated creating new connections, which in turn can motivate further manipulations and revisions of the external model): it is at this level that we found the scientific cognitive counterpart of what has been always called in the tradition of philosophy and history of science, scientific imagination.

It is worth to note that, among the advantages offered by the external models in their role of perturbing the internal ones, there are not only the unexpected features that can be offered thanks to their intrinsic materiality, but also more neutral but fruitful devices, which can be for example exemplified thanks to the case of externalized mathematical symbols: "Apparently the brain immediately translates a positive integer into a mental representation of its quantity. By contrast, symbols that represent non-intuitive concepts remain partially semantically inaccessible to us, we do not reconstruct them, but use them as they stand" (De Cruz and De Smedt 2011). For example, it is well-known that Leibniz adopted the notation *dx* for the infinitesimals he genially introduced, and called them *fictions bien fondées*, given their semantic paradoxical character: they lacked a referent in Leibnizian infinitesimal calculus, but were at the basis of plenty of new astonishing mathematical results.[11] De Cruz and De Smedt call this property of symbols

[9] Written natural languages are intertwined with iconic aspects too. Stjernfelt (2007) provides a full analysis of the role of icons and diagrams in Peircean philosophical and semiotic approach, also taking into account the Husserlian tradition of phenomenology.

[10] It is from this perspective that [sentential] syllogism and [model-based] perception are seen as rigorously intertwined. Consequently, there is no sharp contrast between the idea of cognition as perception and the idea of cognition as something that pertains to logic. Both aspects are inferential in themselves and fruit of sign activity. Taking the Peircean philosophical path we return to observations Thagard stressed when speaking of the case of abduction: cognition is basically *multimodal* (2007).

[11] To confront critiques and suspects about the legitimacy of the new number *dx*, Leibniz prudently conceded that *dx* can be considered a fiction, but a "well founded" one. The birth of non-standard analysis, an "alternative calculus" invented by Abraham Robinson (1966), based on infinitesimal numbers in the spirit of Leibniz's method, revealed that infinitesimals are not at all fictions, through an extension of the real numbers system $\mathbb{R}$ to the system $\mathbb{R}^*$ containing infinitesimals smaller in the absolute value than any positive real number.

"semantic opacity". It renders the symbols underdetermined, allowing further abductive creative processes where those same symbols can be relatively freely exploited in novel contexts for multiple cognitive aims.

3 "On-line" manipulative abduction as eco-epistemic warfare

As I have described above, humans continuously delegate and distribute cognitive functions to the environment to lessen their limits. They build models, representations, and other various mediating structures, that are thought to be good to think. Previous research in epistemology, not strictly related to the more recent research in cognitive science, has already stressed these aspects, I call eco-cognitive. Pickering depicts the role of some externalities (representations, artifacts, tools, etc.) in terms of a kind of non-human agency that interactively stabilizes with human agency in a dialectic of resistance and accommodation (Pickering 1995, p. 17 and p. 22). The two agencies, for example in scientific reasoning, originate a co-production of cognition the results of which cannot be presented and identified in advance: the outcome of the co-production is intrinsically "unpredictable". Latour's notions of the epistemological (but also de-humanizing) effect of technologies are based on his so-called "actor network theory",[12] which also stresses the semiotic role of externalities like the so-called non human agents. The actor network theory basically maintains that we should think of science, technology, and society as a field of human and non-human (material) agency. Human and non-human agents are associated with one another in networks, and they evolve together within these networks. Because the two aspects are equally important, neither can be reduced to the other: "An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what is it made of [...]. The actor network is reducible neither to an actor alone nor to a network" (Callon 1997, p. 93).

Peirce too was clearly aware, speaking of the model-based aspects of deductive reasoning, that there is an "experimenting upon this image [the external model/diagram] in the imagination", where the idea that human imagination is always favored by a kind of prosthesis, the external model as an "external imagination", is pretty clear, even in case of classical geometrical deduction: "[...] namely, deduction consists in constructing an icon or diagram the relations of whose parts shall present a complete analogy with those of the parts of the object of reasoning, of experimenting upon this image in the imagination and of observing the result so as to discover unnoticed and hidden relations among the parts" (Peirce 1931–1958, 3.363). Analogously, in the case I have described in the previous section, the computational model of neuronal behavior, by providing new *chances* in terms of control, visualizations, and costs, is exactly the peculiar tool able to favor manipulations which trigger the new idea of the "spatial activity pattern of the spikes" (Chandrasekharan 2009, p. 1067).

[12] This theory has been proposed by Callon, Latour himself, and Law (Callon 1994, 1997; Latour 1987, 1988; Callon and Latour 1992; Law 1993).

It is exactly in this eco-cognitive framework that the case of scientific innovation is particularly important and provides the chance to better describe innovative scientific modeling taking advantage of the concept of "epistemic warfare", which sees scientific enterprise as a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from non epistemic (for example fictions, falsities, propaganda) weapons. We are faced with the modern awareness (typical of cognitive science) of what implicitly underlies Peircean speculations: nature fecundates the mind because it is through a disembodiment and extension of the mind in nature (that is, so to say, "artificialized") that in turn nature affects the mind. Models are built by the mind of the scientist(s), who first delegate "meanings" to external artifacts: mind's "internal" representations are "extended" in the environment, and later on shaped by processes that are occurring through the constraints found in "nature" itself; that is that external nature that consists of the "concrete" model represented by the artifact, in which the resulting aspects and modifications/movements are "picked up" and in turn re-represented in the human brain. It is in this perspective that we can savor, now in a naturalistic framework, the speculative Aristotelian anticipation that "nihil est in intellectu quod prius non fuerit in sensu". In such a way—that is thanks to the information that flows from the model—the scientists' internal models are rebuilt and further refined and the resulting modifications can easily be seen as guesses—both instinctual and reasoned, depending on the brain areas involved, that is as plausible abductive hypotheses about the external extra-somatic world (the target systems). I repeat, the process can be seen in the perspective of the theory of cognitive niches: the mind grows up together with its representational delegations to the external world that has made itself throughout the history of culture by constructing the so-called cognitive niches. In this case the complex cognitive niche of the scientific lab is an *epistemological* niche, expressly built to increase knowledge following rational methods, where "*people, systems, and environmental affordances*" (Chandrasekharan 2009, p. 1076) work together in an integrated fashion.

Hence, we have to be aware that science imposes itself as a paradigm of producing knowledge in a certain "decent" way, but at the same time it de facto belongs to the cross-disciplinary warfare that characterizes modernity: science more or less conflicts with other non scientific disciplines, religions, literature, magic, etc., and also implicitly orders and norms societies through technological products which impose behaviors and moral conducts. Of course scientific cognitive processes—*sensu strictu*, inside scientific groups as coalitions—also involve propaganda, like Feyerabend says, for instance to convince colleagues about a hypothesis or a method, but propaganda is also externally addressed to other private and public coalitions and common people, for example to get funds (a fundamental issue often disregarded in the contemporary science is the cost of producing new models) or to persuade about the value of scientific knowledge. Nevertheless the core cognitive process of science is based on avoiding fictional and rhetorical devices when the production of its own regimen of truth is at stake. Finally, science is exactly that enterprise which produces those kinds of truths which express the paradigms for demarcating fictions and so "irrational" or "arational" ways of knowing.

On the "epistemic warfare" view, scientific enterprise is considered a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from non epistemic (for example fictions, falsities, propaganda, etc.) weapons.[13] I consider scientific enterprise a complicated epistemic warfare, so that we could plausibly expect to find fictions in this struggle for rational knowledge. Are not fictions typical of any struggle which characterizes the conflict of human coalitions of any kind? During the Seventies of the last century Feyerabend (1975) clearly stressed how, despite their eventual success, the scientist's claims are often far from being evenly proved, and accompanied by "propaganda [and] psychological tricks in addition to whatever intellectual reasons he has to offer" (p. 65), like in the case of Galileo. These tricks are very useful and efficient, but one thing is the *epistemic* role of reasons scientist takes advantage of, such the scientific models I have illustrated in this paper, which for example directly govern the path to provide a new intelligibility of the target systems at hand; another thing is the *extra-epistemic* role of propaganda and rhetoric, which only plays a mere—positive or negative—ancillary role in the epistemic warfare. So to say, these last aspects support scientific reasoning providing non-epistemic weapons able for example to persuade other scientists belonging to a rival "coalition" or to build and strengthen the coalition in question, which supports a specific research program, for example to get funds.

In (Magnani 2009, chapter three) the external scientific models are called "mimetic",[14] not in a military sense, as camouflaged tools to trick the hostile eco-human systems, but just as structures that mimic the target systems for epistemic aims. In this perspective the centrality of the so called "disembodiment of the mind" in the case of semiotic cognitive processes occurring in science is also illustrated. Disembodiment of the mind refers to the cognitive interplay between internal and external representations, *mimetic* and, possibly, *creative*, where the problem of the continuous interaction between on-line and off-line (for example in inner rehearsal) intelligence can properly be addressed.

As I am trying to demonstrate in this whole paper with the description of the above models based on common coding, I consider this interplay critical in analyzing the relation between meaningful semiotic internal resources and devices and their dynamical interactions with the externalized semiotic materiality already stored in the environment (scientific artifactual models, in this case). This external materiality plays a specific role in the interplay due to the fact that it exhibits (and operates through) its own cognitive constraints. Hence, minds are "extended" and artificial in themselves. It is at the level of that continuous interaction between

[13] The characteristic feature of *epistemic* weapons is that they are value-directed to the aim of promoting the attainment of scientific truth, for example through predictive and empirical accuracy, simplicity, testability, consistency, etc.: in this perspective I basically agree with the distinction between epistemic and non-epistemic values as limpidly depicted in (Steel 2010).

[14] On the related problem of resemblance (similarity, isomorphism, homomorphism, etc.) in scientific modeling see (Magnani 2012).

on-line and off-line intelligence that I underlined the importance of what I called *manipulative abduction*.

Manipulative abduction, which is widespread in scientific reasoning (Magnani 2009, chapter one) is a process in which a hypothesis is formed and evaluated resorting to a basically extra-theoretical and extra-sentential behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (theoretical) practices. Manipulative abduction represents a kind of redistribution of the epistemic and cognitive effort to manage objects and information that cannot be immediately represented or found internally. An example of manipulative abduction is exactly the case of the human use of the construction of external models in the neural engineering laboratory I have outlined in the previous section, useful to make observations and "experiments" to transform one cognitive state into another to discover new properties of the target systems. Manipulative abduction also refers to more unplanned and unconscious action-based cognitive processes I have characterized as forms of "thinking through doing" (cf. footnote 2 above).

4 Conclusion

In this paper I have illustrated, taking advantage of recent cognitive research in scientific labs and of the concept of manipulative abduction, some eco-epistemic aspects of scientific innovation. In the light of distributed cognition, I have also offered new insight on the analysis of the two main classical attributes given to scientific models: abstractness and ideality. A related way of delineating a more satisfactory analysis of the multifarious epistemological features of scientific innovation has been illustrated by proposing the concept of "epistemic warfare", which sees scientific enterprise as a complicated struggle for rational knowledge in which it is crucial to distinguish epistemic (for example scientific models) from extra-epistemic (for example fictions, falsities, propaganda) weapons.

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