Abstract

The recent epistemological and cognitive studies concentrate on the concept of abduction, as a means to originate and refine new ideas. Traditional cognitive science and computational accounts concerning abduction aim at illustrating discovery and creativity processes in terms of theoretical and “internal” aspects, by means of computational simulations and/or abstract cognitive models. I will illustrate in this paper that some typical internal abductive processes are involved in scientific reasoning and discovery (for example through radical innovations). Nevertheless, especially concrete manipulations of the external world constitute a fundamental passage in science: by a process of manipulative abduction it is possible to build prostheses (epistemic mediators) for human minds, by interacting with external objects and representations in a constructive way. In this manner it is possible to create implicit knowledge through doing and to produce various opportunities to find, for example, anomalies and fruitful new risky perspectives. This kind of embodied and unexpressed knowledge holds a key role in the subsequent processes of scientific comprehension and discovery.

Keywords: Epistemic mediators; Abduction; Manipulative reasoning; Optical diagrams; Morphodynamics of discovery

1. Theoretical and manipulative reasoning

Science is one of the most explicitly constructed, abstract, and creative forms of human knowledge. In the twentieth century Reichenbachian and Popperian [1,2] distinction be-
tween logic of discovery and logic of justification, and Kuhnian ideas about irrationality of conceptual change and paradigm shift [3] brought philosophers of science to the direct conclusion that a logic of discovery, and then a rational model of discovery, cannot exist.

Today researchers have by and large abandoned this attitude by concentrating on the concept of abduction pointed out by C.S. Peirce as a fundamental mechanism by which it is possible to account for the introduction of new explanatory hypotheses in science.

Abduction is the process of inferring certain facts and/or laws and hypotheses that render some sentences plausible, that explain or discover some (eventually new) phenomenon or observation; it is the process of reasoning in which explanatory hypotheses are formed and evaluated. There are two main epistemological meanings of the word abduction [4]: (1) abduction that only generates “plausible” hypotheses (“selective” or “creative”) and (2) abduction considered as inference “to the best explanation”, which also evaluates hypotheses. An illustration from the field of medical knowledge, is represented by the discovery of a new disease and the manifestations it causes which can be considered as the result of a creative abductive inference. Therefore, “creative” abduction deals with the whole field of the growth of scientific knowledge. This is irrelevant in medical diagnosis where instead the task is to “select” from an encyclopedia of pre-stored diagnostic entities.

Theoretical abduction1 certainly illustrates much of what is important in creative abductive reasoning, in humans and in computational programs, but fails to account for many cases of explanations occurring in science when the exploitation of environment is crucial. It fails to account for those cases in which there is a kind of “discovering through doing”, cases in which new and still unexpressed information is codified by means of manipulations of some external objects (epistemic mediators). The concept of manipulative abduction2 captures a large part of scientific thinking where the role of action is central, and where the features of this action are implicit and hard to be elicited: action can provide otherwise unavailable information that enables the agent to solve problems by starting and by performing a suitable abductive process of generation or selection of hypotheses.

Many attempts have been made to model abduction by developing some formal tools in order to illustrate its computational properties and the relationships with the different forms of deductive reasoning [6]. Some of the formal models of abductive reasoning are based on the theory of the epistemic state of an agent [7], where the epistemic state of an individual is modeled as a consistent set of beliefs that can change by expansion and contraction (belief revision framework). These kinds of logical models are called sentential [4]. They exclusively deal with selective abduction (diagnostic reasoning)3 and relate to the idea of preserving consistency. Exclusively considering the sentential view of abduction does not enable us to say much about creative processes in science, and, therefore, about the nomological and most interesting creative aspects of abduction. It mainly refers to the

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1 Magnani [4,5] introduces the concept of theoretical abduction. He maintains that there are two kinds of theoretical abduction, “sentential”, related to logic and to verbal/symbolic inferences, and “model-based”, related to the exploitation of internalized models of diagrams, pictures, etc., cf. below in this paper.

2 Manipulative abduction and epistemic mediators are introduced and illustrated in [4].

3 As previously indicated, it is important to distinguish between selective (abduction that merely selects from an encyclopedia of pre-stored hypotheses), and creative abduction (abduction that generates new hypotheses).
selective (diagnostic) and merely explanatory aspects of reasoning and to the idea that abduction is mainly an inference to the best explanation [4].

2. The internal side of scientific change

2.1. The internal side of abductive reasoning

If we want to provide a suitable framework for analyzing the most interesting cases of conceptual changes in science we do not have to limit ourselves to the sentential view of theoretical abduction but we have to consider a broader inferential one: the model-based sides of creative abduction (cf. below).

From Peirce’s philosophical point of view, all thinking is in signs, and signs can be icons, indices or symbols. Moreover, all inference is a form of sign activity, where the word sign includes “feeling, image, conception, and other representation” [8, 5.283], and, in Kantian words, all synthetic forms of cognition. That is, a considerable part of the thinking activity is model-based. Of course model-based reasoning acquires its peculiar creative relevance when embedded in abductive processes, so that we can individuate a model-based abduction.

Hence, we must think in terms of model-based abduction (and not in terms of sentential abduction) to explain complex processes like scientific conceptual change. Different varieties of model-based abductions [9] are related to the high-level types of scientific conceptual change [10]. Following Nersessian [11], the term “model-based reasoning” is used to indicate the construction and manipulation of various kinds of representations, not mainly sentential and/or formal, but mental and/or related to external mediators.

2.2. Finding inconsistencies by radical innovation

It is well known that the derivation of inconsistencies contributes to the search for alternative, and possibly new, hypotheses [1,12]. Surely surprise and curiosity are related to the detection of inconsistencies [4, Chapter 6]. Internal model-based abductive ways of generating a hypothesis that explains some phenomenon or conceptual problem that produced the question are heuristically linked to the activity itself both of finding that certain puzzling phenomenon or that particular conceptual problem or of eliciting that certain “hidden” phenomenon or conceptual problem. Hence, they are related to the activity of finding and producing chance.4 We will see that also from the perspective of a kind of reasoning we can call external (i.e., manipulative) typical templates of epistemic acting are still devoted to generate inconsistencies and curiosities as new trends to reach—abduce—new hypotheses.

I have illustrated above that from Peirce’s philosophical point of view, all inference is a form of sign activity, where the word sign includes “feeling, image, conception, and other representation” [8, 5.283]. That is, a considerable part of the inference activity is model-based. Hence, many model-based ways of reasoning are performed in a manipulative way.

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4 It is clear that the phenomenon of chance discovery and production, and so of serendipity, can be seen in the light of the role played by epistemic mediators and external representations, as described in Section 3.
by using external tools and mediators (cf. the following section). Manipulative abduction \[4\] happens when we are thinking through doing and not only, in a pragmatic sense, about doing. So the idea of manipulative abduction goes beyond the well known role of experiments as capable of forming new scientific laws by means of the results (nature’s answers to the investigator’s question) they present, or of merely playing a predictive role (in confirmation and in falsification). Manipulative abduction refers to an extra-theoretical behavior that aims at creating communicable accounts of new experiences to integrate them into previously existing systems of experimental and linguistic (theoretical) practices. The existence of this kind of extra-theoretical cognitive behavior is also testified by the many everyday situations in which humans are perfectly able to perform very efficacious (and habitual) tasks without the immediate possibility of realizing their conceptual explanation.

In the following section manipulative abduction will be considered from the perspective of the relationship between unexpressed knowledge and external representations. The power of model-based reasoning and abduction (both theoretical and manipulative) mainly depends on their ability to extract and render explicit a certain amount of important information, unexpressed at the level of available data. They have a fundamental role in the process of transformation of knowledge from its \textit{tacit} to its \textit{explicit} forms, and in the subsequent elicitation and use of knowledge. Let us describe how this happens in the case of “external” model-based processes.

3. Extracting knowledge through manipulative abduction

3.1. Unexpressed knowledge

As pointed out by Polanyi in his epistemological investigation, a large part of knowledge is not explicit, but tacit: we know more than we can tell and we can know nothing without relying upon those things which we may not be able to tell \[13\].

Hutchins \[14\] illustrates the case of a navigation instructor that for 3 years performed an automatized task involving a complicated set of plotting manipulations and procedures. The insight concerning the conceptual relationships between relative and geographic motion came to him suddenly “as lay in his bunk one night”.

We can find a similar situation also in the process of scientific creativity. Too often, in the cognitive view of science, it has been underlined that conceptual change just involves a \textit{theoretical} and “internal” replacement of the main concepts. But usually researchers forget that a large part of this processes are instead due to \textit{practical} and “external” \textit{manipulations} of some kind, prerequisite to the subsequent work of theoretical arrangement and knowledge creation. When these processes are creative we can speak of manipulative abduction (cf. above).

For example, in the simple case of the construction and examination of diagrams in elementary geometrical reasoning, specific experiments serve as states and the implied operators are the manipulations and observations that transform one state into another. The geometrical outcome depends upon practices and specific sensory-motor activities performed on a non-symbolic object, which acts as a dedicated external representational medium supporting the various operators at work. There is a kind of an epistemic negoti-
ation between the sensory framework of the problem solver and the external reality of the diagram [5]. It is well known that in the history of geometry many researchers used internal mental imagery and mental representations of diagrams, but also self-generated diagrams (external) to help their thinking.

This process involves an external representation consisting of written symbols and figures that for example are manipulated "by hand". The cognitive system is not merely the mind-brain of the person performing the geometrical task, but the system consisting of the whole body (cognition is embodied) of the person plus the external physical representation. In geometrical discovery the whole activity of cognition is located in the system consisting of a human together with diagrams.

An external representation can modify the kind of computation that a human agent uses to reason about a problem: the Roman numeration system eliminates, by means of the external signs, some of the hardest parts of the addition, whereas the Arabic system does the same in the case of the difficult computations in multiplication. The capacity for inner reasoning and thought results from the internalization of the originally external forms of representation [15].

The external representations are not merely memory aids: they can give people access to knowledge and skills that are unavailable to internal representations, help researchers to easily identify aspects and to make further inferences, they constrain the range of possible cognitive outcomes in a way that some actions are allowed and others forbidden. They increase the chance discoverability. The mind is limited because of the restricted range of information processing, the limited power of working memory and attention, the limited speed of some learning and reasoning operations; on the other hand the environment is intricate, because of the huge amount of data, real time requirement, uncertainty factors.

3.2. The extra-theoretical dimension of discovery: templates of epistemic acting and epistemic mediators

I have introduced above the notion of tacit knowledge. Now I propose an extension of that concept. There is something more important beyond the tacit knowledge “internal” to the subject—considered by Polanyi as personal, embodied and context specific. We can also speak of a sort of tacit information “embodied” into the whole relationship between our mind-body system and suitable external representations. An information we can extract, explicitly develop, and transform in knowledge contents, to solve problems.

Peirce gives an interesting example of model-based abduction related to sense activity: “A man can distinguish different textures of cloth by feeling: but not immediately, for he requires to move fingers over the cloth, which shows that he is obliged to compare sensations of one instant with those of another” [8, 5.221]. This surely suggests that abductive movements have also interesting extra-theoretical characters and that there is a role in abductive reasoning for various kinds of manipulations of external objects. All knowing is inferring and inferring is not instantaneous, it happens in a process that needs an activity of comparisons involving many kinds of models in a more or less considerable lapse of time. All these considerations suggest, then, that there exist a creative form of thinking through doing, fundamental as much as the theoretical one: manipulative abduction.
(see [4] and [5]). As already said manipulative abduction happens when we are thinking through doing and not only, in a pragmatic sense, about doing.

Various templates of manipulative behavior exhibit some regularities. The activity of manipulating external things and representations is highly conjectural and not immediately explanatory: these templates are hypotheses of behavior (creative or already cognitively present in the scientist’s mind-body system, and sometimes already applied) that abductively enable a kind of epistemic “doing”. Hence, some templates of action and manipulation can be selected in the set of the ones available and pre-stored, others have to be created for the first time to perform the most interesting creative cognitive accomplishments of manipulative abduction.

Some common features of the tacit templates of manipulative abduction, that enable us to manipulate things and experiments in science are related to: (1) sensibility towards the aspects of the phenomenon which can be regarded as curious or anomalous; manipulations have to be able to introduce potential inconsistencies in the received knowledge and so to open new possible reasoning opportunities (Oersted’s report of his well known experiment about electromagnetism is devoted to describing some anomalous aspects that did not depend on any particular theory of the nature of electricity and magnetism); (2) preliminary sensibility towards the dynamical character of the phenomenon, and not to entities and their properties, common aim of manipulations is to practically reorder the dynamic sequence of events into a static spatial one that should promote a subsequent bird’s-eye view (narrative or visual-diagrammatic), fruitful for further outcomes; (3) referral to experimental manipulations that exploit artificial apparatus to free new possible stable and repeatable sources of information about hidden knowledge and constraints (Davy set-up in terms of an artifactual tower of needles showed that magnetization was related to orientation and does not require physical contact); (4) various contingent ways of epistemic acting: looking from different perspectives, checking the different information available, comparing subsequent events, choosing, discarding, imaging further manipulations, re-ordering and changing relationships in the world by implicitly evaluating the usefulness of a new order (for instance, to help memory).

Gooding [16] refers to this kind of concrete manipulative reasoning when he illustrates the role in science of the so-called “construals” that embody tacit inferences in procedures that are often apparatus and machine based. The embodiment is of course an expert manipulation of objects in a highly constrained experimental environment, and is directed by abductive movements that imply the strategic application of old and new templates of behavior mainly connected with extra-theoretical components, for instance emotional, esthetical, ethical, and economic.

The whole activity of manipulation is devoted to building various external epistemic mediators that function as an enormous new source of information and knowledge. Therefore, 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 (for example exploiting the resources of visual imagery).5

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5 It is difficult to preserve precise spatial and geometrical relationships using mental imagery, in many situations, especially when one set of them has to be moved relative to another.
From the point of view of everyday situations manipulative abductive reasoning and epistemic mediators exhibit very interesting features: (1) action elaborates a *simplification* of the reasoning task and a redistribution of effort across time [14], when we need to manipulate concrete things in order to understand structures which are otherwise too abstract [17], or when we are in presence of *redundant* and unmanageable information; (2) action can be useful in presence of *incomplete* or *inconsistent* information—not only from the “perceptual” point of view—or of a diminished capacity to act upon the world: it is used to get more data to restore coherence and to improve deficient knowledge; (3) action enables us to build *external artifactual models* of task mechanisms instead of the corresponding internal ones, that are adequate to adapt the environment to the agent’s needs; (4) action as a *control of sense data* illustrates how we can change the position of our body (and/or of the external objects) and how to exploit various kinds of prostheses (Galileo’s telescope, technological instruments and interfaces) to get various new kinds of stimulation: action provides some tactile and visual information (e.g., in surgery), otherwise unavailable. Also natural phenomena can play the role of external artifactual models: under Micronesians’ manipulations of their images, the stars acquire a structure that “becomes one of the most important structured representational media of the Micronesian system” [14, p. 172]. The external artifactual models are endowed with functional properties as components of a memory system crossing the boundary between person and environment (for example they are able to transform the tasks involved in allowing simple manipulations that promote further visual inferences at the level of model-based abduction). The cognitive process is *distributed* between a person (or a group of people) and external representation(s), and so obviously *embedded* and *situated* in a society and in a historical culture.\(^6\)

### 3.3. Mirroring hidden properties through optical diagrams

An interesting epistemological situation I have recently studied is the one concerning the discovery role played by some special epistemic mediators in the field of non-standard analysis, an “alternative calculus” invented by Abraham Robinson [19], based on infinitesimal numbers in the spirit of Leibniz method. It is a kind of calculus that uses 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. I maintain that in mathematics diagrams play various roles in a typical abductive way. Two of them are central:

- they provide an intuitive and mathematical *explanation* capable of facilitating the understanding of concepts difficult to grasp, that appear hidden, obscure, and/or epistemologically unjustified, or that are *not expressible* from an intuitive point of view;

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\(^6\) Magnani [4, Chapter 6] stresses the importance of the so-called preinventive forms in abductive reasoning. Intuitively an anomaly is something surprising, as Peirce already knew “The breaking of a belief can only be due to some novel experience” [8, 5.524] or “[…] until we find ourselves confronted with some experience contrary to those expectations” [8, 7.36]. Therefore it is not strange that something anomalous can be found in those kinds of structures the cognitive psychologists call preinventive. Cognitive psychologists have described many kinds of preinventive structures and their desirable properties, that constitute particularly interesting ways of “irritating” the mind and stimulating creativity [18]: they are certainly of interest for creative reasoning and chance discovery and production.
Fig. 1. An optical diagram shows an infinitesimal neighborhood of the graph of a real function.

- they help create new previously unknown concepts.

In the construction of mathematical concepts many external representations are exploited, both in terms of diagrams and of symbols. I am interested in my research in diagrams which play an optical role—microscopes (that look at the infinitesimally small details), telescopes (that look at infinity), windows (that look at a particular situation), a mirror role (to externalize rough mental models), and an unveiling role (to help create new and interesting mathematical concepts, theories, and structures).\(^7\)

The role of an “optical microscope” that shows the behavior of a tangent line is illuminating. In standard analysis, the change $dy$ in $y$ along the tangent line is only an approximation of the change $\Delta y$ in $y$ along the curve. But through an optical microscope, that shows infinitesimal details, we can see that $dy = \Delta y$ and then the quotient $\Delta y/\Delta x$ is the same of $dy/dx$ when $dx = \Delta x$ is infinitesimal (see Fig. 1 and, for details, [20]). This removes some difficulties of the representation of the tangent line as limit of secants, and introduces a more intuitive conceptualization: the tangent line “merges” with the curve in an infinitesimal neighborhood of the contact point.

Only through a second more powerful optical microscope “within” the first (I call this kind of epistemic mediator microscopes within microscopes), we can see the difference between the tangent line and the curve. Under the first diagram, the curve looks like the graph of

$$f'(a)x,$$

i.e., a straight line with the same slope of its tangent line;\(^8\) under the second, the curve looks like

$$f'(a)x - \frac{1}{2}f''(a).$$

This suggests nice new mental representations of the concept of tangent line: through the optical lens, the tangent line can be seen as the curve, but through a more powerful optical lens the graph of the function and the graph of the tangent are distinct, straight, and

\(^7\) The epistemic and cognitive role of mirror and unveiling diagrams in the discovery of non-Euclidean geometry is illustrated in [5].

\(^8\) This is mathematically justified in [20].
parallel lines. The fact that one line is either below or above the other, depends on the sign of $f''(a)$, in accordance with the standard real theory: if $f''(x)$ is positive (or negative) in a neighborhood, then $f$ is convex (or concave) here and the tangent line is below (or above) the graph of the function.

However, this easily mirrors a sophisticated hidden property. Let $f$ be a two times differentiate function and let $a$ be a flex point of it. Then $f''(a) = 0$ and so the second microscope shows again the curve as the same straight line: this means that the curve is “very straight” in its flex point $a$. Of course, we already know this property—the curvature in a flex point of a differentiable two times function is null—which comes from standard analysis, but through optical diagrams we can find it immediately and more easily (the standard concept of curvature is not immediate).

Some diagrams could also play an unveiling role, providing new light on mathematical structures: it can be hypothesized that these diagrams can lead to further interesting creative results.

I stated that in mathematics diagrams play various roles in a typical abductive way. We can add that:

- they are epistemic mediators able to perform various abductive tasks in so far as,
- they are external representations which provide explanatory and abductive results also fruitful in some aspects of creative reasoning chance discovery and production.

4. The morphodynamics of discovery

We have seen that the “bodily” manipulation of external objects is central to delineating new conceptual perspectives and solutions (cf. the previous section concerning the features of the tacit templates of manipulative abduction and external epistemic mediators). Hence, an intentional “action” in the world is able to add a prosthesis to the mind, by expanding its possibilities and by suggesting new information worth to be analyzed.

Traditional cognitive science accounts refer to the computational perspective, that describes cognition as the operation of a special mental “computer” that computes different internal symbolic representations. This approach is considered too reductive, since it is based on the functionalist hypothesis (which cannot render the external dimension of cognition), and on a computation of static entities.

Interesting insights on the problem of hypotheses generation and discovery, in terms of dynamical evolution of complex systems, come from a different contrasting approach: the dynamical approach to cognitive science. We can use the mathematical tools of dynamical systems to study cognition by thinking to a cognitive system not just as a computer, but as a dynamical system, consisting of mind, body, and external environment, mutually and simultaneously influencing and coevolving. This also justifies the pragmatic and “embodied” aspects of cognition. This kind of cognitive modeling is able to describe abductive processes as embedded dynamical entities “unfolding” in time. Hence, by means of the tools provided by a dynamical modeling it is possible to underline the importance of manipulative skills in scientific cognition [21].

A dynamical system can be considered a set of quantitative variables that changes continually and concurrently in time in accordance with dynamical laws described by some set
of equations. It is the state of the system that changes: that is, the overall look of the system in a certain instant. We can study the behavior of the system by analyzing the change in its states. If a system can be described dynamically, this means it has \( n \) characteristics (e.g., position, mass, etc.—in the case of classical physical systems) evolving simultaneously in time. These characteristics can be measured, in any given instant, and associated to a real number. Therefore, the overall state of the system can be thought as an ordered set consisting of \( n \) real numbers, and the state space can be thought as isomorphic to a space of real numbers, the \( n \) dimensions of which correspond to the different system characteristics (the phase space). The evolution of the system in time corresponds to a sequence of points, a trajectory, inside the phase space. This sequence can usually be described mathematically as a function of time, considered an independent variable, giving a solution to the system of differential equations. The idea that the behavior of the system can be understood geometrically by a trajectory of points in a space, that is, describable in terms of positions and change of positions in a space of possible overall states, it is the central insight of dynamical systems theory. We can then describe the system in terms of attractors, stability, and catastrophes, features largely invisible from a classical perspective, but fundamental to describe some cognitive processes underlying abduction.

We speak about morphodynamics of discovery when considering discovery and production in the light of the “geometrical” framework above. The main idea is that a complex system, as the cognitive one, can be described in terms of a configurational structure. That is, different mental states are defined by their geometrical relationships within a larger dynamical environment. This suggests that the system, in any given instant, possesses a general morphology we can study by observing how it changes and develops. The term morphodynamics refers to those theories whose aim is to explain morphologies and iconic, schematic, Gestalt-like aspects of structures, whatever their underlying physical substrate may be, using the mathematical theory of dynamical systems [22].

To set the morphology of the system it is interesting to identify mental states with attractors. Some dynamical systems are so complex, behaving non-linearly and erratically, jumping from a point in the space of their states to another very different in a brief time (as the states of the atmosphere). However, notwithstanding these sudden changes, a dynamical system has a series of states, the attractors, which tend to remain stable (Fig. 2). A system can have a lot of attractors, contemplating more than a single stable state, arranged in some topological way.

The arrangement of attractors can be thought as controlled by the setting of the parameters in the equations that govern the system’s dynamics. The shape and location of attractors change as these parameters vary. There could be certain critical settings of parameters where complete qualitative discontinuities and transformations in the arrangement of attractors occur (they can move, disappear or emerge). These discontinuities are responsible for the evolution of mental processes.

The concept of attractor, together with the interesting concepts of adumbration and anticipation, studied in the philosophical tradition of phenomenology, can offer interesting

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9 The so-called naturalized phenomenology aims at supporting phenomenology with scientific explanations, neurophysiological, mathematical, physical, etc. [23].
insights to understand how external representations and action support the “mind” in discovering and unveiling new concepts [24]. Imagine the overall state space of the cognitive system as a geometrical surface in which possible mental states (represented by attractors) interact. Like in the case of the intuitive representation of the relativistic conception of gravitation, we can see this surface as a flat horizontal rubber sheet. Attractor corresponds to the attractive zone in which we can imagine to place a large sphere. Its weight will stretch the sheet down and distort the system. Therefore, if we imagine the behavior of the cognitive system as a small ball that moves inside the rubber sheet, we can easily see how the structure, the “shape” of the space, affects its motion. The parameters responsible for the behavior of the system determine the “weight” of the attractor, then the shape of the surface (one of the influencing factors is just what here is called manipulative abduction).

5. Conclusion

It is clear that the manipulation of external objects helps human beings in reasoning and discovery and so in their creative tasks. I have illustrated the strategic role played by the so-called traditional concept of “implicit knowledge” in terms of the recent cognitive and epistemological concept of manipulative abduction, considered as a particular kind of abduction that exploits external models endowed with delegated cognitive roles and attributes. Abductive manipulations operate on models that are external and the strategy that organizes the manipulations is unknown a priori. In the case of “creative” manipulations of course the result achieved is also new, and adds properties not previously contained.

I have described various “templates” of manipulative behavior which account for the most common cognitive and epistemic behaviors related to scientific discovery and chance production. I have stressed the importance of producing inconsistencies by radical innovation at the level of internal abductive processes but also in the case of manipulative thinking, where epistemic mediators constitute interesting ways of finding anomalies and “curious” events, unexpected dynamical features of phenomena, contingent ways of epis-
temic acting, and manage incomplete data and information to anticipate new trends and hidden objects and properties.

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