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Lorenzo Magnani

The Abductive Structure of Scientific Creativity

An Essay on the Ecology of Cognition

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An Essay on the Ecology of Cognition

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Of the three Universes of Experience familiar to us all, the first comprises all mere Ideas, those airy nothings to which the mind of poet, pure mathematician, or another might give local habitation and a name within that mind. Their very airy-nothingness, the fact that their Being consists in mere capability of getting thought, not in anybody's Actually thinking them, saves their Reality.

Charles Sanders Peirce, A Neglected Argument for the Reality of God, 1908

To my students

Preface

The book addresses a new approach to epistemology I call "eco-cognitive", which stresses the attention to the question of hypothesis generation and choice, that is to abduction, partially disregarded in the tradition of philosophy of science. I think the intellectual and didactic virtues of this approach resort to the conviction that dynamically seeing at the scientific enterprise in the light of the process of hypotheses generation and withdrawal can provide a unified perspective on various epistemological interdisciplinary aspects, which would otherwise remain fragmented and dispersed.

The book aims at stressing that updated analysis of scientific creativity must take into account:

- The *distributed* and *embodied* nature of scientific cognition, ultimately related to the idea of the importance of the external cognitive tools and mediators in cognition;
- The central role of the dynamics of the production and of the rational handling of hypotheses, by referring to the various *multimodal* aspects of abduction, visual/diagrammatic, verbal-propositional, emotional, and manipulative;
- The fact that science is characterized by a *maximization of abducibility*, performed thanks to specific constraints.

These topics are analyzed in terms of what I consider the main tenets of an eco-cognitive approach to the epistemology of scientific creativity[1]:

1. Chapter 1. Abduction (ἀπαγωγή, in ancient Greek, often translated as "leading away" or "reduction") is a procedure in which something that lacks classical explanatory epistemic virtue can be accepted because it has virtue of another kind: Gabbay and Woods contend that abduction presents an *ignorance-preserving* or (ignorance-mitigating) character. From this perspective abductive

[1]A considerable part of the recent academic literature—for example in social epistemology—refers the word epistemology to the whole area of cognitive reasoned activities. In this book I basically adopt its classical intended meaning, which is only referred to scientific cognition.

reasoning is a *response* to an ignorance-problem; through abduction the basic ignorance—that does not have to be considered a total "ignorance"—is neither solved nor left intact. Abductive reasoning is an ignorance-preserving accommodation of the problem at hand. My question will be: is abduction really ignorance-preserving? The answer I propose is that abduction can occasionaly be *knowledge-enhancing*, as I will further illustrate in Chap. 3, dealing with the role of models in science. To better examine these topics and to introduce new important epistemological considerations I will describe my *eco-cognitive model* (EC-Model) of abduction.

2. Chapter 2. In science we do not have to confuse the process of abducing models with the process of abducing *fictions*. Scientific models play fundamental "rational" knowledge-enhancing roles: in a static perspective (for example when inserted in a textbook) scientific models can appear fictional to the epistemologist, but their fictional character disappears if a dynamic perspective is adopted and their possible "constitutive" character (of new knowledge) is admitted.
3. Chapter 3. Also in science, as in religion, in morality, in the arts, and in common sense reasoning, knowledge can be enhanced, even when a postulated or discovered hypothesis is not characterized by the need of an empirical evaluation phase, or an inductive phase, as Peirce called it. Hence, abduction can occasionally be *knowledge-enhancing*: in science model-based reasoning often represents one of the most relevant examples of knowledge-enhancing abduction.
4. Chapter 4. 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.
5. Chapter 5. To further deepen the eco-cognitive character of abduction and hypothetical cognition in science a simple genealogy of logic is provided. Aristotle clearly states that in syllogistic theory local/environmental cognitive factors—external to that peculiar inferential process, for example regarding users/reasoners, are given up. At the same time in chapter B25 of the *Prior Analytics* Aristotle presents a seminal perspective on abduction: I contend that some of the current well-known distinctive characters of abductive cognition, and of abductive cognition in science, are already expressed, which are in tune with my EC-Model. By referring to the role of the method of analysis and of the middle terms in Plato's dialectic argumentation, considered as related to the diorismic/poristic process in ancient geometry, Aristotle is still pointing to the fundamental inferential and "distributed" role in reasoning of those externalities that substantiate the process of "leading away" (and expression which also translates what Aristotle calls ἀπαγωγή, that is "abduction").
6. Chapter 6. When dealing with the so-called "inferential problem", which affects current research in logic and epistemology, I will opt for the more general

concepts of input and output instead of those of premisses and conclusions. From this perspective abductive inferences can be first of all seen as related to logical processes in which input and output fail to hold each other in an expected relation, with the solution involving the modification of inputs, not that of outputs. The chance of finding an abductive solution still appears to depend on the Aristotelian concept of "leading away" (ἀπαγωγή), that is, on the starting of the application of a supplementary logic implementing an appropriate formal inference engine. In this perspective—and given the fact science produces and "maximizes" cognition through a process in which affirming truths implies negating truths—the most important consequence for epistemology I can clearly derive is that irrelevance and implausibility are not always offensive to reason. We cannot be sure, more broadly, that our guessed hypotheses are plausible (even if we know that looking—in advance—for plausibility is a human good and wise heuristic), indeed an implausible hypothesis can later on result plausible.

7. Chapter 7. The analysis of abductive processes illustrated in the previous chapters in terms of the effort to naturalize the logic of its special consequence relation, leads us to the emphasis on the importance of the following main aspects: "optimization of eco-cognitive situatedness", "maximization of changeability" of both input and output, and high "information-sensitiveness". Furthermore, a naturalized logic of abduction must acknowledge the importance of keeping record of the "past life" of abductive inferential praxes, contrarily to the fact that traditional demonstrative ideal systems are prototypically characterized by what I call "maximization of memorylessness". In this perspective I will provide an analysis of the importance of the *maximization of abducibility*, which is typical of science, together with a discussion of the relevance of the various aspects above for epistemology.
8. Chapter 8. In this chapter I will analyze some important aspects of the organization of research and development (R&D) in the case of biopharmaceutical companies, which represent a prototypical situation of what I call impoverished epistemic niches. At least in this case we clearly see a challenge to the epistemic integrity of modern science. Taking advantage of the logical and cognitive studies illustrated in the previous chapters, which emphasize the crucial role played in abductive cognition by the so-called "optimization of eco-cognitive openness and situatedness", this chapter first of all aims at illustrating the importance of *knowledge in motion*—in multidisciplinary, interdisciplinary, and transdisciplinary scientific research. Various subsections also introduce the hot problem of the current emergence of disparate kinds of "*epistemic irresponsibility*". Interesting cases related to the commodification and commercialization of science, marketing of technoscientific products, impoverishment of the so-called epistemological niches are illustrated, which show that human fruitful abductive cognition in science is increasingly assaulted and jeopardized, and at

the same time human creativity seriously endangered. The challenges against human abduction and epistemic rigor on the part of what I call computational invasive "subcultures" and unwelcome effects of selective ignorance are finally illustrated.

As an appendix, the reader may find a *Lexicon of Abductive Cognition in Science*, in which I summarize the main aspects of abduction illustrated in the present book.

I am grateful to many colleagues and friends for their helpful suggestions and much more. For valuable comments and discussions I am indebted and grateful to John Woods, Paul Thagard, Ping Li, Atocha Aliseda, Woosuk Park, Nancy J. Nersessian, Giuseppe Longo, Yukio Oshawa, Akinori Abe, Michael Leyton, Dov Gabbay, John Josephson, Walter Carnielli, Gerhard Schurz, Balakrishnan Chandrasekaran, Jon Williamson, Douglas Walton, Cameron Shelley, Sami Paavola, Luís Moniz Pereira, Thomas Addis, Giovanna Magnani, Diderik Batens, Joke Meheus, Simon Colton, Athanassios Raftopoulos, Michael Hoffmann, Ilkka Niniluoto, Theo A. F. Kuipers, Chris Sinha, Ryan D. Tweney, Ferdinand D. Rivera, Peter Flach, Antony Kakas, Oliver Ray, Luis A. Pineda, Atsushi Shimojima, Pat Langley, Demetris P. Portides, and to my collaborators Tommaso Bertolotti and Selene Arfini. Also of great help was correspondence or conversation with a number of people whose influence on various of the book's particularities is more or less palpable. I especially wish to acknowledge Hanne Andersen, Otávio Bueno, Sanjay Chandrasekharan, Marcelo Dascal, Gordana Dodig Crnkovic, Mauro Dorato, Michel Ghins, Marcello Guarini, Ricardo Gudwin, Albrecht Heeffer, Mireille Hildebrandt, Kenneth Einar Himma, Gerhard Minnameier, Margaret Morrison, Alfredo Pereira, Ahti-Veikko Pietarinen, Dagmar Provijn, João Queiroz, Chiaki Sakama, Colin Schmidt, Nora Schwartz, Frederik Stjernfelt, Mauricio Suárez, Jeroen van den Hoven, Peter-Paul Verbeek, Riccardo Viale, Marion Vorms. The preparation of the volume would not have been possible without the contribution of resources and facilities of the Computational Philosophy Laboratory (Department of Humanities, Philosophy Section, University of Pavia, Italy). This project was conceived as a whole, but as it developed various parts have become articles, which have now been excerpted, revised, and integrated into the current text.

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The eco-cognitive model of abduction II. Irrelevance and implausibility exculpated, *Journal of Applied Logic* 15, 94–129, Elsevier (chapters six and seven). I am grateful to Elsevier, Oxford University Press, and Springer for permission to include portions of previously published articles.

Pavia, Italy Lorenzo Magnani
January 2017

Contents

1 Enhancing Knowledge: Tracking the External World 1
1.1 The Ignorance-Preserving Nature of Abduction 2
1.2 The Eco-Cognitive Model (EC-Model) of Abduction: Cutdown and Fill-Up Problems 6
1.3 The EC-Model of Abduction 10
1.4 Abductive Virtues Vindicated. How Does Abduction Supply Knowledge? 13
1.4.1 Why Does Abduction Enhance Knowledge? Instinct, Inference, and Synechism: Mind and Matter Intertwined 15
1.5 Enhancing Knowledge through Reward and Punishment and the Inductive Risk 19
1.5.1 Beneficial and Detrimental Dissent: Inductive Risk. 20
1.6 Tracking the External World: Enhancing Predictive Knowledge. 22
1.7 Tracking the External World through Scientific Knowledge. 25
1.8 Tracking Human Behavior. Rendering Human Behavior Predictable through Ethics 26
References. 28

2 Distributed Model-Based Science: Scientific Models Are Not Fictions 31
2.1 Models and Fictions 31
2.2 Models Are Not Fictions. The Inconsistency of the Argument of Imperfect Fit 33
2.3 Models Are Distributed 36
2.4 Perception-Action Common Coding as an Example of "On-line" Manipulative Abduction 39
2.5 Model-Based Ignorance 42
References. 44

3 Not Everything in Scientific Cognition Is Evidence-Based: The Epistemology of Evidentially Inert Knowledge Enhancing 47
3.1 The Epistemology of Evidentially Inert Knowledge-Enhancing: Guessing Conventions in Science 48
3.1.1 Dismissing Conventions 51
3.2 The Epistemology of Evidentially Inert Knowledge-Enhancing: Abducing Scientific Models Versus Abducing Fictions 54
3.2.1 Dynamic Versus Static View of Scientific Models and the Revival of the Demarcation Problem 57
3.3 Mathematics, Deduction, and Manipulative Abduction 60
References 63

4 Epistemic Warfare: Are Scientific Models Fictions or Epistemic Weapons? 65
4.1 Are Scientific Models Fictions or Epistemic Weapons? 65
4.2 Scientific Models as Fictions in a Dynamic Perspective and Fictions as "*Façons de Parler*" 69
4.3 Are the In-Vitro Model or a Geometrical Diagram Fictions? 72
4.4 Confounding Static and Dynamic Aspects of the Scientific Enterprise 74
4.5 Resemblance and Feyerabend's Counterinduction 78
4.6 Galileo's Modeling Vindicated 82
References 86

5 The Genealogy of Abduction: Ἀπαγωγή, Geometry, and Logic Intertwined 89
5.1 Naïve Genealogy of Logic: Abduction and *Arche*-Validity 89
5.1.1 Knowledge-Enhancing Abduction and Arche-Validity 91
5.1.2 Deduction as Eco-Cognitive Immunization: Removing the Origins of Truths 93
5.2 Aristotle's Ἀπαγωγή and Its Eco-Cognitive Openness 96
5.3 Geometry and Logic: The Role of Constructions and Middle Terms in Abduction 100
5.3.1 Ἀπαγωγή and Geometry 101
5.3.2 Ἀπαγωγή, Dialectics, and Logic 102
5.3.3 Geometry and Logic Intertwined: Ἀπαγωγή and Its Eco-Cognitive Openness 104
5.4 Dialectics, Rules of Interrogation, Syllogisms: Dialectical Logic Versus Syllogistic Logic? 107
5.5 Abduction and Aristotelian Enthymeme from Signs 109
References 111

6 Maximizing Cognition in Science: Affirming Truths Implies Negating Truths: Irrelevance and Implausibility Exculpated 115
6.1 Reprise: Ignorance-Preserving, Immunization, Validity, Ἀπαγωγή Now 116
6.1.1 Ignorance-Preserving and Knowledge Enhancing Abduction 116
6.1.2 Eco-Cognitive Immunization: De-Moralizing Truth 116
6.1.3 "Recognizing" Validity 118
6.1.4 Ἀπαγωγή Now 119
6.2 EC-Model of Abduction and Logic: Relevance and Plausibility Relativized 120
6.2.1 Inferential Problems: Input and Output Versus Premisses and Conclusions 120
6.2.2 Irrelevance and Implausibility Exculpated 125
6.2.3 Becoming Relevant, Becoming Plausible: The Role of Ignorance and of Creative Agency 126
6.2.4 Abduction and the Production of a Deduction 129
References 132

7 Science Maximizes Abducibility: The Optimization of Eco-Cognitive Situatedness in Ampliative Inferences 135
7.1 Abductive Cognition and the Optimization of the Eco-Cognitive Situatedness 135
7.1.1 A Logic of Abduction Is Eco-Cognitively Disciplined 135
7.1.2 Anthropomorphizing the Logic of Abduction 138
7.1.3 A Logic of Abduction Is Naturalized 140
7.1.4 A Logic of Abduction Is Distributed: Benacerraf's Dilemma Revisited 142
7.1.5 Deductive Consequence Repels Information, Logic Programs Are Information-Sensitive 144
7.2 Comparing Traditional Demonstrative Inferences and Abductive Inferences 148
7.2.1 Some Basic Cognitive Features of Traditional Demonstrative Inferences 148
7.2.2 Abductive Inferences 149
7.2.3 Multimodal Abduction Is Present in Traditional Deductive Proofs: The Role of Definitory and Strategic Rules 154
References 158

8 Human Creative Abduction Assaulted: Impoverishing Epistemological Niches 161
8.1 "Knowledge in Motion" Defended: Favoring Scientific Abduction through the Eco-Cognitive Openness. 162
8.1.1 Marketing Technoscientific Results. 165
8.2 Jeopardizing Human Abduction through Impoverished Epistemological Niches. 168
8.2.1 Epistemic Irresponsibility I: Expensive Drugs Now and the Undisciplined Commodification of Abduction in Science 168
8.2.2 Epistemic Irresponsibility II: How to Avoid the Eco-Cognitive Shutdown of Creative Abduction. 173
8.2.3 Epistemic Irresponsibility III: Neoliberalism Assaults to Epistemic Integrity of Biopharmaceutical Research. 177
8.3 Optimizing the Eco-Cognitive Situatedness: Human Creative Abduction Between Academia and Corporations 182
8.3.1 "The Symbiotic Model of Innovation" and the Precompetitive Collaborations 184
8.4 Computational Invasive "Subcultures" Jeopardize Human Creative Abduction in Science 187
8.5 Science Impoverished: Encouraging Epistemic Irresponsibility Through Ignorance 191
References. 194

Conclusion 199

Lexicon of Abductive Cognition in Science 205

Index 219

Chapter 1
Enhancing Knowledge

Tracking the External World

Abduction is a procedure in which something that lacks classical explanatory epistemic virtue can be accepted because it has virtue of another kind: (Gabbay and Woods 2005) contend (GW-Schema) that abduction presents an *ignorance-preserving* or (ignorance-mitigating) character. From this perspective abductive reasoning is a *response* to an ignorance-problem; through abduction the basic ignorance—that does not have to be considered a total "ignorance"—is neither solved nor left intact. Abductive reasoning is an ignorance-preserving accommodation of the problem at hand. Is abduction really ignorance-preserving? To better answer this question I will take advantage of my *eco-cognitive model* (EC-model) of abduction and of three examples taken from the areas of both philosophy and epistemology.[1] It will be illustrated that through abduction, knowledge can be enhanced, even when abduction is not considered an inference to the best explanation in the classical sense of the expression, that is an inference necessarily characterized by an empirical evaluation phase, or an inductive phase, as Peirce called it. Peirce provides various justifications of the knowledge enhancing role of abduction: these justifications basically resort to the conceptual exploitation of *evolutionary* and *metaphysical* ideas, which clearly show that abduction is constitutively akin to truth, even if certainly always ignorance-preserving or mitigating in the sense that the "absolute truth" is never reached through abduction. In Chap. 3 I will illustrate further examples that indicate the knowledge enhancing role of abduction: the case of abducing conventions in empirical science and the process of abducing those models which play the "constitutive" function of enhancing knowledge.

[1] As I already noted in the preface, a considerable part of the recent academic literature refers the word epistemology to the whole area of cognitive reasoned activities. In this book I adopt its classical intended meaning, which is only referred to scientific cognition.

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1.1 The Ignorance-Preserving Nature of Abduction

Following Gabbay and Woods' contention, it is clear that "[…] abduction is a procedure in which something that lacks epistemic virtue is accepted because it has virtue of another kind" (Gabbay and Woods 2005, p. 62). For example: "Let S be the standard that you are not able to meet (e.g., that of mathematical proof). It is possible that there is a lesser epistemic standard S' (e.g., having reason to believe) that you do meet" (Woods 2013, p. 370). Focusing attention on this cognitive aspect of abduction, and adopting a logical framework centered on practical agents, (Gabbay and Woods 2005) contend that abduction (basically seen as a *scant-resource* strategy, which proceeds in the absence of knowledge) presents an *ignorance-preserving* (or, better, an *ignorance mitigating*) character. Of course "[…] it is not at all necessary, or frequent, that the abducer be wholly in the dark, that his ignorance be total. It needs not be the case, and typically isn't, that the abducer's choice of a hypothesis is a blind guess, or that nothing positive can be said of it beyond the role it plays in the subjunctive attainment of the abducer's original target (although sometimes this is precisely so)" (Woods 2013, p. 249). In this perspective, abductive reasoning is a *response* to an ignorance-problem: one has an ignorance-problem when one has a cognitive target that cannot be attained on the basis of what one currently knows.

How can we simply define ignorance, in the perspective of ignorance preservation? Ignorance is always ignorance with respect to something, say the proposition that p or the theory T. Ignorance is being in a state of not knowing that (or whether) p or of not knowing what T says and/or whether it's true; moreover, ignorance always provides a condition of cognitive immunization which impedes the agent to recognize how much she ignores (Arfini and Magnani 2015). If we are epistemic gradualists, then we are ignorant with respect to something to the extent that we lack the degree of knowledge that would remove it. Following Peirce's rational fallibilism, the doctrine that there is no absolute certainty in knowledge, we should consider the instability of what the agent considers her more or less reliable knowledge. Abduction is an inferential tool which empowers the individual to enhance her finite knowledge, so she can face an ignorance problem —for instance if she notices something is missing from her comprehension of a matter. While the knowledge-generating processes are usually studied in order to provide models for abductive inferences, the issue concerning how and what kinds of ignorance interact with those knowledge-generating processes is unsurprisingly overlooked.[2]

[2]In (Magnani et al. 2016) two types of ignorance are illustrated. They are defined in the *dynamic* interplay with the two types of abduction, selective and creative (cf. below Sect. 1.2). The first type of ignorance is set within the limits of the agent's cognitive environment and it is grounded on her own central information, which corresponds to the agent's topics of expertise and usual employment; she can easily reach them and her ignorance about them is minimal. This type of ignorance involves the part of illusion about the actual knowledge the agent has on her field of expertise. The second type of ignorance concerns peripheral information, which corresponds to what is still within the agent's cognitive system but that is not in her dominion of expertise, or that she is broadly ignorant about. This kind of ignorance does necessitate more than the agent's ordinary expertise in order to be understood: it requires more patience and resources to be integrated

We said above that abductive reasoning is a *response* to an ignorance-problem and that one has an ignorance-problem when one has a cognitive target that cannot be attained on the basis of what one currently knows. Typically ignorance problems trigger one or other of three responses. In the first case, one overcomes one's ignorance by attaining some additional knowledge (subduance). In the second instance, one yields to one's ignorance (at least for the time being) (surrender). In the third instance, one abduces (Woods 2013, Chap. 11) and so has some positive basis for new action even if in the presence of the constitutive ignorance.

From this perspective the general form of an abductive inference can be symbolically rendered as follows. Let α be a proposition with respect to which you have an ignorance problem. Putting T for the agent's epistemic target with respect to the proposition α at any given time, K for his knowledge-base at that time, K^* for an immediate accessible successor-base of K that lies within the agent's means to produce in a timely way,[3] R as the attainment relation for T, $\rightsquigarrow$ as the *subjunctive* conditional relation, H as the agent's hypothesis, $K(H)$ as the revision of K upon the addition of H, $C(H)$ denotes the conjecture of H and H^c its activation. The general structure of abduction can be illustrated as follows (GW-schema)[4]:

1. $T!\alpha$	[setting of T as an epistemic target with respect to a proposition α]
2. $\neg(R(K, T)$	[fact]
3. $\neg(R(K^*, T)$	[fact]
4. $H \notin K$	[fact]
5. $H \notin K^*$	[fact]
6. $\neg R(H, T)$	[fact]
7. $\neg R(K(H), T)$	[fact]
8. If $H \rightsquigarrow R(K(H), T)$	[fact]
9. H meets further conditions $S_1, ..., S_n$	[fact]
10. Therefore, $C(H)$	[sub-conclusion, 1–9]
11. Therefore, H^c	[conclusion, 1–10].

It is easy to see that the distinctive epistemic feature of abduction is captured by the schema. It is a given that H is not in the agent's knowledge-set. Nor is it in its immediate successor. Since H is not in K, then the revision of K by H is not a knowledge-successor set to K. Even so, $H \rightsquigarrow R(K(H), T)$. So we have an ignorance-preservation, as required (cf. (Woods 2013, p. 370)).

[*Note*: Basically, line 9. indicates that H has no more plausible or relevant rival constituting a greater degree of subjunctive attainment. Characterizing the S_i is the

---

with the central information. In order to abduce inside this kind of ignorance it becomes necessary
(Footnote 2 continued)
to change the eco-cognitive system of the agent and enhancing it with the perspective that even in a zone with peripheral information there still are plenty useful chances to discover.

[3] K^* is an accessible successor of K to the degree that an agent has the know-how to construct it in a timely way; i.e., in ways that are of service in the attainment of targets linked to K. For example if I want to know how to spell "accommodate", and have forgotten, then my target can't be hit on the basis of K, what I now know. But I might go to my study and consult the dictionary. This is K^*. It solves a problem originally linked to K.

[4] That is Gabbay and Woods Schema.

most difficult problem for abductive cognition, given the fact that in general there are many possible candidate hypotheses. It involves for instance the *consistency* and *minimality* constraints.[5] These constraints correspond to the lines 4 and 5 of the standard AKM schema of abduction,[6] which is illustrated as follows:

1. E
2. $K \not\vdash E$
3. $H \not\vdash E$
4. $K(H)$ is consistent
5. $K(H)$ is minimal
6. $K(H) \vdash E$
7. Therefore, H

(Gabbay and Woods 2005, pp. 48–49)

where of course the conclusion operator $\vdash$ cannot be classically interpreted].[7]

Finally, in the GW-schema $C(H)$ is read "It is justified (or reasonable) to conjecture that H" and H^c is its activation, as the basis for *planned* "actions".

In sum, in the GW-schema T cannot be attained on the basis of K. Neither can it be attained on the basis of any successor K^* of K that the agent knows then and there how to construct. H is not in K: H is a hypothesis that when reconciled to K produces an updated $K(H)$. H is such that if it were true, then $K(H)$ would attain T. The problem is that H is *only hypothesized*, so that the truth is not assured. Accordingly Gabbay and Woods contend that $K(H)$ *presumptively* attains T. That is, having hypothesized that H, the agent just "presumes" that his target is now attained. Given the fact that presumptive attainment is not attainment, the agent's abduction must be considered as preserving the ignorance that already gave rise to her (or its, in the case for example of a machine) initial ignorance-problem. Accordingly, abduction does not have to be considered the "solution" of an ignorance problem, but rather a response to it, in which the agent reaches presumptive attainment rather than

[5] In the case of inner processes in organic agents, this sub-process— here explicitly modeled thanks to a formal schema—is considerably implicit, and so also linked to unconscious ways of inferring, or even, in Peircean terms, to the activity of the instinct (Peirce 1931–1958, 8.223) and of what Galileo called the *lume naturale* (Peirce 1931–1958, 6.477), that is the innate fair for guessing right. This and other cognitive aspects can be better illustrated thanks to the alternative eco-cognitive model (EC-Model) of abduction I will sketch below, Sect. 1.2.

[6] The classical schematic representation of abduction is expressed by what (Gabbay and Woods 2005) call AKM-schema, which is contrasted to their own (GW-schema), which I am just explaining in this subsection. For A they refer to Aliseda (1997; 2006), for K to Kowalski (1979), Kuipers (1999), and Kakas et al. (1993), for M to Magnani (2001) and Meheus (Meheus et al. 2002). A detailed illustration of the AKM schema is given in (Magnani 2009, Chap. 2, Sect. 2.1.3).

[7] The target has to be an explanation and $K(H)$ bears R^{pres} [that is the relation of presumptive attainment] to T only if there is a proposition V and a consequence relation $\vdash$ such that $K(H) \vdash V$, where V represents a *payoff proposition* for T. In turn, in this schema explanations are interpreted in consequentialist terms. If E is an explanans and E' an explanandum the first explains the second only if (some authors further contend if and only if) the first implies the second. It is obvious to add that the AKM schema embeds a D-N (deductive-nomological) interpretation of explanation, as I have already stressed in (Magnani 2001, p. 39).

actual attainment. $C(H)$ expresses the conclusion that it follows from the facts of the schema that H is a worthy object of conjecture. It is important to note that in order to solve a problem it is not necessary that an agent actually conjectures a hypothesis, but it is necessary that she states that the hypothesis is *worthy of conjecture*.

Briefly, considering H justified to conjecture is not equivalent to considering it justified to accept/activate it and eventually to send H to experimental trial. H^c denotes the *decision* to release H for further work in the domain of enquiry in which the original ignorance-problem arose, that is the activation of H as a positive *cognitive* basis for action. Woods usefully observes:

> There are lots of cases in which abduction stops at line 10, that is, with the conjecture of the hypothesis in question but not its activation. When this happens, the reasoning that generates the conjecture does not constitute a positive basis for new action, that is, for acting *on* that hypothesis. Call these abductions *partial* as opposed to full. Peirce has drawn our attention to an important subclass of partial abductions. These are cases in which the conjecture of H is followed by a decision to submit it to experimental test. Now, to be sure, doing this is an action. It is an action *involving* H but it is not a case of acting *on* it. In a full abduction, H is activated by being released for inferential work in the domain of enquiry within which the ignorance-problem arose in the first place. In the Peircean cases, what counts is that H is withheld from such work. Of course, if H goes on to test favorably, it may then be released for subsequent inferential engagement. But that is not abduction. It is induction (Woods 2013, p. 371).

We have to remember that this process of evaluation and so of activation of the hypothesis, is not abductive, but inductive, as Peirce contended. Woods adds: "Epistemologists of risk-averse bent might be drawn to the idea that what I am calling partial abduction is as good as abduction ever gets and that complete abduction, inference-activation and all, is a mistake that leaves any action prompted by it without an adequate rationale. This is not an unserious objection. Suffice it to say that there are real life contexts of reasoning in which such conservatism is given short shrift, in fact is ignored altogether. One of these contexts is the criminal trial at common law. Another is various kinds of common sense reasoning" (Woods 2013, p. 371).

In the framework of the GW-schema it cannot be said that testability is intrinsic to abduction, such as it is instead maintained in the case of some passages of Peirce's writings.[8] This activity of testing, I repeat, which in turn involves degrees of risk proportioned to the strength of the conjecture, is strictly cognitive/epistemic and inductive in itself, an experimental test, and it is an intermediate step to release the abduced hypothesis for inferential work in the domain of enquiry within which the ignorance-problem arose in the first place.[9]

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[8] When abduction stops at line 10. (cf. the GW-schema), the agent is not prepared to accept $K(H)$, because of supposed adverse consequences.

[9] Hintikka usefully notes (see also below p. 12), and I agree with him, that Peirce was right in denying the role of "naked" induction in forming new hypotheses. At the same time he warns us about the use of the word induction in the case of the testing of hypotheses: "[…] I do not think that it is instructive to call such reasoning inductive, but this is a merely terminological matter" (Hintikka 2007, p. 55). I myself I am referring here to tests as instrumental/empirical "inductive" ones, in the spirit of Peircean special use of the word induction that Hintikka stigmatizes. Of course, in the case of human agents and in a perspective about "testing" I am not endorsing here, tests might

Through abduction the basic ignoranc—that does not have to be considered total "ignorance"—is neither solved nor left intact: it is an ignorance-preserving accommodation of the problem at hand, which "mitigates" the initial cognitive "irritation" (Peirce says "the irritation of doubt").[10] As I have already stressed, further action can be triggered—-in a defeasible way—either to find further abductions or to "solve" the ignorance problem, possibly leading to what the "received view" has called the *inference to the best explanation* (IBE).

It is clear that in the framework of the GW-schema the inference to the best explanation—if considered as a truth conferring achievement justified by the empirical approval—cannot be a case of abduction, because abductive inference is constitutively ignorance-preserving. In this perspective the inference to the best explanation involves the generalizing[11] and evaluating role of *induction*. Of course it can be said that the requests of originary thinking are related to the depth of the abducer's ignorance.

1.2 The Eco-Cognitive Model (EC-Model) of Abduction: Cutdown and Fill-Up Problems

From a general philosophical perspective (with, and beyond, Peirce) the condition 9. (cf. the GW-schema) is, as Woods himself admits "more a hand-wave than a real condition. Of course the devil is in the details. […] I myself I am not sure" (Woods 2011, p. 242). Obviously consistency and minimality constraints were emphasized in the classical view of abduction established by many classical logical accounts, more oriented to illustrate *selective abduction* (Magnani 2001)—for example in diagnostic reasoning, where abduction is merely seen as an activity of "selecting"

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be considered some sorts of mental assessment, such as for example the coherence of an abduction, (Footnote 9 continued)

a test in which no physical actions are involved. If such assessments are informed by knowledge gained by a thinker through previous experience, then those mental assessments take the character of implicit inductions, here intended in the classical sense of the term.

[10] "The action of thought is excited by the irritation of doubt, and ceases when belief is attained; so that the production of belief is the sole function of thought" (Peirce 1987, p. 261).

[11] By illustrating abductive/inductive reasoning of preservice elementary majors on patterns that consist of figural and numerical cues in learning elementary mathematics Rivera and Rossi Becker monitor the subsequent role of induction. In performing the abductive task to the general form/hypothesis the subjects referred to the fact they immediately saw a relationship among the drawn cues in terms of relational similarity "[…] within classes in which the focus was *not* on the individual clues in a class *per se* but on a possible invariant relational structure that was perceived between and, thus, projected onto the cues" (Rivera and Rossi Becker 2007, p. 151). Through the follow-up inductive stage of generalizations the subjects tested the hypotheses just examining *extensions* (new particular cases beyond what was available at the beginning of the reasoning process). This process was also able to show subjects's disconfirmation capacities: they acknowledged their mistakes in generating a bad induction, which had to be abandoned, in so far as they were checked as insufficient in fully capturing in symbolic terms a general attribute that would yield the total number of toothpicks in new generated cues.

from an encyclopedia of pre-stored hypotheses—than to analyze *creative* abduction (abduction that generates new hypotheses).[12]

For example, to stress the puzzling status of the consistency requirement, it is here sufficient to note that Paul Feyerabend, in *Against Method* (Feyerabend 1975), correctly attributes a great importance to the role of contradiction in generating hypotheses, also against the role of similarity, and so implicity celebrates the value of creative abductive cognition. Speaking of induction and not of abduction (this concept was relatively unknown at the level of the international philosophical community at that time), he establishes a new "counterrule". This is the opposite of the neopositivistic one that it is "experience" (or "experimental results") which constitutes the most important part of our scientific empirical theories, a rule that formed the core of the so-called "received view" in philosophy of science (where inductive generalization, confirmation, and corroboration play a central role). The counterrule "[…] advises us to introduce and elaborate hypotheses which are inconsistent with well-established theories and/or well-established facts. It advises us to proceed counterinductively" (Feyerabend 1975, p. 20). Counterinduction is seen more as reasonable than induction, because appropriate to the needs of creative reasoning in science: "[…] we need a dream-world in order to discover the features of the real world we think we inhabit" (p. 29). We know that counterinduction, that is the act of introducing, inventing, and generating new inconsistencies and anomalies, together with new points of view incommensurable with the old ones, is congruous with the aim of inventing "alternatives" (Feyerabend contends that "proliferation of theories is beneficial for science"), and very important in all kinds of creative reasoning.[13]

Since for many abductive problems there are—usually—many guessed hypotheses, the abducer needs reduce this space to one. This means that the abducer has to produce the best choice among the members of the available group: "It is extremely difficult to see how this is done, both formally and empirically. Clause (9) [in the GW-schema] is a place-holder for two problems, not one. There is the problem of finding criteria for hypothesis *selection*. But there is the prior problem of specifying the conditions for *thinking up* possible candidates for selection. The first is a 'cutdown' problem. The second is a 'fill-up problem'; and with the latter comes the received view that it is not a problem for logic" ((Woods 2011, p. 243) emphasis added).

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[12] I have proposed the dichotomic distinction between selective and creative abduction in (Magnani 2001). In the same book I have illustrated the so-called Select and Test Model (ST-model). It is an epistemological model of medical reasoning, which can be described in terms of the classical notions of abduction, deduction and induction; it describes the different roles played by such basic inference types in developing various kinds of medical reasoning (diagnosis, therapy planning, monitoring). The model is consistent with the Peircean view about the various stages of scientific inquiry in terms of "hypothesis" generation (abduction), deduction (prediction), and induction. The model has been used to implement medical knowledge-based systems of medical reasoning in artificial intelligence (AI).

[13] A rich treatment of the basic "paraconsistent" logical perspectives concerning abduction and the role of inconsistencies is contained in (Carnielli 2006).

Here we touch the core of the ambiguity of the ignorance-preserving character of abduction. Why?

- Because the cognitive processes of generation (fill-up) and of selection (cutdown) can both be sufficient—even in the absence of the standard inductive evaluation phase—to *activate* and accept [clause (11) of the GW-schema above] an abductive hypothesis, and so to reach cognitive results relevant to the context (often endowed with a knowledge-enhancing outcome). In these cases the *instrumental* aspects (which simply enable one's target to be hit)[14] often favor both abductive generation and abductive choice, and they are not necessarily intertwined with plausibilistic concerns, such as consistency and minimality.[15]

In these special cases the best choice is immediately reached without the help of an experimental trial (which fundamentally characterizes the received view of abduction in terms of the so-called "inference to the best explanation"). Not only, we have to strongly note that the generation process alone can suffice, as demonstrated by the case of human *perception*, where the hypothesis generated is immediate and unique. Indeed, perception is considered by Peirce, as an "abductive" fast and uncontrolled (and so automatic) knowledge-production procedure.[16] Perception, in this philosophical perspective, is a vehicle for the instantaneous retrieval of knowledge that was previously structured in our mind through more structured inferential processes. Peirce says: "Abductive inference shades into perceptual judgment without any sharp line of demarcation between them" (Peirce 1955, p. 304). By perception, knowledge constructions are so instantly reorganized that they become habitual and diffuse and do not need any further testing: "[…] a fully accepted, simple, and interesting inference tends to obliterate all recognition of the uninteresting and complex premises from which it was derived" (Peirce 1931–1958, 7.37).[17]

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[14] On instrumental and explanatory abduction see (Magnani 2009, Chap. 2): examples of the non-explanatory features of abduction are present in logic and mathematical reasoning. Chapter 2 of the quoted book gives an analysis of how the importance of non-explanatory abduction in logical and mathematical reasoning is clearly even if implicitly envisaged by Gödel. Furthermore, physics often aims at discovering physical dependencies which can be considered explanatorily undetermined. In this case abduction exhibits an *instrumental* aspect. Below in Chap. 3, Sect. 3.1 I contend that this character is sometimes related to the conventional nature of the involved scientific hypotheses.

[15] In general we cannot be sure that our guessed hypotheses are plausible (even if we know that looking for plausibility is a human good and wise heuristic), indeed an implausible hypothesis can later on result plausible. Moreover, when a hypothesis solves the problem at hand, this is enough as to count as solution of the abductive problem (even if, not necessarily a *good* solution or the *best* solution). If we want to preserve the property of plausibility, at most we can say that in some cases it is just *potential*, given the time-dependency I have just indicated. In Sect. 6.2.2 of Chap. 6 I will describe that, for example, the strange Cartesian hypothesis of a plenum vortices made of particles, destroyed by the Newtonian concept of action at distance, later on appeared fully compatible with the Einsteinian framework.

[16] In fact, for Peirce "[…] the perceptual judgments, are to be regarded as an extreme case of abductive inference" (Peirce 1931–1958, 5.181).

[17] A relatively recent cognitive research related to artificial intelligence (AI) presents a formal theory of robot perception as a form of abduction, so reclaiming the rational relevance of the speculative anticipation furnished by Peirce, cf. (Shanahan 2005).

My abrupt reference to perception as a case of abduction (in this case I strictly follow Peirce) does not have to surprise the reader. Indeed, at the of center of my perspective on cognition is the emphasis on the "practical agent", the individual agent operating "on the ground", that is, in the circumstances of real life. In all its contexts, from the most abstractly logical and mathematical to the most roughly empirical, I always emphasize the cognitive nature of abduction. Reasoning is something performed by cognitive systems. At a certain level of abstraction and as a first approximation, a cognitive system is a triple (A, T, R), in which A is an *agent*, T is a *cognitive target* of the agent, and R relates to the *cognitive resources* on which the agent can count in the course of trying to meet the target-information, time and computational capacity, to name the three most important. My agents are also *embodied distributed cognitive systems*: cognition is embodied and the interactions between brains, bodies, and external environment are its central aspects. Cognition is occurring taking advantage of a constant exchange of information in a complex distributed system that crosses the boundary between humans, artifacts, and the surrounding environment, where also instinctual and unconscious abilities play an important role. This interplay is especially manifest and clear in various aspects of abductive cognition.[18]

It is in this perspective that we can appropriately consider perceptual abduction as a fast and uncontrolled knowledge production, that operates for the most part automatically and out of sight, so to speak. This means that—at least in this light—GW-schema is not canonical for abduction. The schema illustrates what I call "sentential abduction" that is, abduction rendered by symbols carrying propositional content. It is hard to encompass in this model cases of abductive cognition such as perception or the generation of models in scientific discovery. My perspective adopts the wide Peircean philosophical framework, which approaches "inference" *semiotically* (and not simply "*logically*"): Peirce distinctly says that all inference is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" (Peirce 1931–1958, 5.283). It is clear that this semiotic view is considerably compatible with my perspective on cognitive systems as embodied and distributed systems: the GW-schema is instead only devoted to illustrate, even if in a very efficacious way, a subset of the cognitive systems abductive activities, the ones that are performed taking advantage of explicit propositional contents. Woods seems to share this conclusion: "[…] the GW-model helps get us started in thinking about abduction, but it is nowhere close, at any level of abstraction, to running the whole show. It does a good job in modeling the ignorance-preserving character of abduction; but, since it leaves the S_i of the schema's clause (T) unspecified, it makes little contribution to the fill-up problem" (Woods 2011, p. 244).

[18]It is interesting to note that recent research on Model Checking in the area of AST (Automated Software Testing) takes advantage of this eco-cognitive perspective, involving the manipulative character of model-based abduction in the practice of adapting, abstracting, and refining models that do not provide successful predictions. Cf. (Angius 2013).

In a wide eco-cognitive perspective the cutdown and fill-up problems in abductive cognition appear to be spectacularly *contextual*.[19] I lack the space here to give this issue appropriate explanation but it suffices to remember that, for example, one thing is to abduce a model or a concept at the various levels of scientific cognitive activities, where the aim of reaching rational knowledge dominates, another thing is to abduce a hypothesis in literature (a fictional character for example), or in moral reasoning (the adoption/acceptation of a hypothetical judgment as a trigger for moral actions). However, in all these cases abductive hypotheses, which are evidentially inert, are accepted and activated as a basis for action, even if of different kind.

1.3 The EC-Model of Abduction

I have contended in Sect. 1.1 above that the GW-schema is not canonical for abduction. The schema illustrates what I call "sentential abduction" that is, abduction rendered by symbols carrying propositional content. It does a good job in modeling the ignorance-preserving character of abduction; but, since it leaves the S_i of the schema's clause (T) unspecified, it makes little contribution to the fill-up problem. I also said that it is hard to encompass in this model cases of abductive cognition such as perception or the generation of models in scientific discovery. A more extended eco-cognitive perspective is needed, also able to show how the cutdown and fill-up problems in abductive cognition appear to be stunningly *contextual*.

The backbone of this approach can be found in the manifesto of my EC-Model of abduction in (Magnani 2009). It might seem awkward to speak of "abduction of a hypothesis in literature," but one of the fascinating aspects of abduction is that not only it can warrant for scientific discovery, but for other kinds of creativity as well. We must not necessarily see abduction as a *problem solving device* that sets off in response to a cognitive irritation/doubt: conversely, it could be supposed that esthetic abductions (referring to creativity in art, literature, music, etc.) arise in response to some kind of esthetic irritation that the author (sometimes a *genius*) perceives in herself or in the public. Furthermore, not only esthetic abductions are free from empirical constraints in order to become the "best" choice: as I am showing throughout this chapter, many forms of abductive hypotheses in traditionally-perceived-as-rational domains (such as the setting of initial conditions, or axioms, in physics or mathematics) are relatively free from the need of an empirical assessment. The same could be said of moral judgment: they are eco-cognitive abductions, inferred upon a range of internal and external cues and, as soon as the judgment hypothesis has been abduced and accepted, it immediately becomes prescriptive and "true," informing the agent's behavior as such. Assessing that there is a common ground in all of these works of what could be broadly defined as "diagnostic expertise" or "creativity" does not imply that all

[19] Some acknowledgment of the general contextual character of these kinds of criteria, and a good illustration of the role of coherence, unification, explanatory depth, simplicity, and empirical adequacy in the current literature on scientific abductive best explanation, is given in (Mackonis 2013).

of these forms of diagnostic or creative processes are the same, contrarily it should spark the need for firm and sensible categorization: otherwise it would be like saying that to construct a doll, a machine-gun and a nuclear reactor are all the same thing because we use our hands in order to do so!

It is important to explicitly emphasize the intrinsic relativity of the status of concepts like truth, rationality, knowledge, ignorance: their reciprocal entanglement tends to reciprocally depict the respective meanings. Here an example: it has to be said that successful abductions that are performed at the moral level I have mentioned above immediately acquire a deontological status. They are *epistemically inert* even if they increase something that we can certainly call "knowledge": the "moral" knowledge human individuals need in a given situation. The use of the word knowledge depicts the meaning of the word ignorance: at least under the perspective of the last moral case, the abductions involved *are not* ignorance-preserving, because do not preserve the subjective moral ignorance in front of the problems of moral decision making at stake. Nevertheless, the abduced hypothetical knowledge in the case of these—primarily moral—endeavors can be easily seen a piece of "false" knowledge—we can base our moral action on the basis of false premises—from the empirical and/or rational point of view, but still active and efficient, and in this case we are legitimated to call the involved abductions as basically ignorance-preserving. Indeed, common moral knowledge of beings like us is not intrinsically truth-sensitive.[20]

To conclude this section I have to say some words about the role of heuristics. From an eco-cognitive point of view, in more hybrid and multimodal (not merely inner) abductive processes, such as in the case of *manipulative abduction*,[21] the assessment/acceptation of a hypothesis is reached—and constrained—taking advantage of the gradual acquisition of consecutive external information with respect to future interrogation and control, and not necessarily thanks to a final and actual experimental test, in the classical sense of empirical science. The concept of *manipulative abduction*—which also takes into account the external dimension of abductive reasoning in an eco-cognitive perspective—captures a large part of scientific thinking where the role of action and of external models (for example diagrams) and devices 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 and/or selection of hypotheses. Manipulative abduction happens—not only in scientific cognition—when we are thinking through doing and not only, in a pragmatic sense, about doing.

Hintikka implicitly acknowledges the multimodality and hybridity of what I call *selective abduction* when, taking advantage of the intellectual atmosphere of his Socratic interrogative epistemology, observes that "[…] abduction as a method of

[20] I have illustrated the role of abduction in military intelligence in (Magnani 2011, Chap. 2), where I have extendedly treated the relationship between cognition, morality, and violence.

[21] I have introduced this concept in (Magnani 2001); cf. the commentary illustrated in (Park 2017a). See also the recent (Park 2017b).

guessing is based on the variety of different possible sources of answers. Such 'informants' must include not only testimony, observation, and experiments, but the inquirer's memory and background knowledge" (Hintikka 2007, p. 56). Moreover, Hintikka further notes that also "creative abduction", generated by a kind of *oracle*, is often needed: "But what can an inquirer do when all such sources fail to provide an answer to a question? Obviously the best the inquirer can do is make an informed guess. For the purposes of a general theory of inquiry, what Peirce calls 'intelligent guessing' must therefore be recognized as one of the many possible 'oracles', alias sources of answers. Peirce may very well have been more realistic than I have so far been in emphasizing the importance of this particular 'oracle' in actual human inquiry" (*ibid.*)

In summary, at least four kinds of actions can be involved in the manipulative abductive processes (and we would have to also take into account the "motoric" aspect (i) of inner "thoughts" too). In the eco-cognitive interplay of abduction the cognitive agent further triggers internal *thoughts* "while" modifying the environment and so (ii) acting on it (thinking through doing). In this case the "motor actions" directed to the environment have to be intended as part and parcel of the whole embodied abductive inference, and so have to be distinguished from the *final* (iii) "actions" as possible consequences of the reached abductive result.

In this perspective the proper experimental test involved in the Peircean evaluation phase, which for many researchers reflects in the most acceptable way the idea of abduction as inference to the best explanation, just constitutes a *special* subclass of the process of the adoption of the abductive hypothesis—the one which involves a terminal kind (iv) of actions (experimental tests), and should be considered ancillary to the nature of abductive cognition, and inductive in its essence. We have indeed to remark again that in Peirce's mature perspective on abduction as embedded in a cycle of reasoning, induction just plays an evaluative role. Hintikka usefully notes, and I agree with him, that Peirce was right in denying the role of "naked" induction in forming new hypotheses:

> Many philosophers would probably bracket abductive inference with inductive inference. Some would even think of all ampliative inference as being, at bottom, inductive. In this matter, however, Peirce is one hundred percent right in denying the role of naked induction in forming new hypotheses. […] It might seem that the critical and evaluative aspect of inquiry that Peirce called inductive still remains essentially different from the deductive and abductive aspects. A common way of thinking equates all ampliative inferences with inductive ones. Peirce was right in challenging this dichotomy. Rightly understood, the ampliative versus non-ampliative contrast becomes a distinction between interrogative (ampliative) and deductive steps of argument. As in Peirce, we also need over and above these two also the kind of reasoning that is involved in testing the propositions obtained as answers to questions. I do not think that it is instructive to call such reasoning inductive, but this is a merely terminological matter (Hintikka 2007, pp. 52 and 55).

In the absence of empirical evaluation, can we attribute the *pure* abductive inclination to produce right guesses indicated by Peirce, conductive to the acquisition of truth, to the *reliability* of the process? Yes, we can, but only if we take into account the following warning, still illustrated by Hintikka: "Many contemporary philosophers will assimilate this kind of justification to what is called a reliabilist one. Such

reliabilist views are said to go back to Frank Ramsey, who said that 'a belief was knowledge if it is (1) true, (2) certain, (3) *obtained by a reliable process*' (emphasis added). Unfortunately for reliabilists, such characterizations are subject to the ambiguity that was pointed out earlier. By a reliable process one can mean either a process in which each step is conducive to acquiring and/or maintaining truth or closeness to truth, or one that as a whole is apt to lead the inquirer to truth. Unfortunately, most reliabilists unerringly choose the wrong interpretation—namely, the first one. As was pointed out earlier, the true justification of a rule of abductive inference is a strategic one" (Hintikka 2007, p. 57). The important thing is to stress that this strategic justification *does not warrant* any "specific step" of the whole process. Let us remember that abduction certainly provides new information into an argument, but this is not necessarily a true information, because it is not implied by what it is already known or accepted but it is constitutively hypothetical—that is, ignorance-preservation is constitutive, from the general logico-philosophical point of view, and Hintikka is in tune with this assumption.

1.4 Abductive Virtues Vindicated. How Does Abduction Supply Knowledge?

Even if abduction, in the perspective of the formal GW-model I have described in Sect. 1.1 above, is ignorance-preserving (or ignorance mitigating), truth can easily emerge: we have to remember that Peirce sometimes contended that abduction "come to us as a flash. It is an act of insight" (Peirce 1931–1958, 5.181)[22] but nevertheless possesses a mysterious power of "guessing right" (Peirce 1931–1958, 6.530). Consequently abduction preserves ignorance, in the logical sense I have illustrated above, but can also provide truth because has the power of guessing *right*. We have also contended that in the logical framework above the inference to the best explanation—if considered as a truth conferring achievement justified by empirical approval—cannot be a case of abduction, because abductive inference is instead constitutively ignorance-preserving.

If we say that truth can be reached through a "simple" abduction (not intended as involving an evaluation phase, that is coinciding with the whole inference to the best explanation, fortified by an empirical evaluation), it seems we confront a manifest incoherence. In this perspective it is contended that even simple abduction can provide truth, even if it is epistemically "inert" from the empirical perspective. Why? We can solve the incoherence by observing that we should be compelled to consider abduction as ignorance-preserving only if we consider the empirical test *the only way* of conferring truth to a hypothetical knowledge content. This clause being accepted, in the framework of the technical logical model of abduction I have introduced above the ignorance preservation appears natural and unquestionable. However, if we admit that

[22] Peirce makes reference to this "flash" in connection to abduction in perceptual judgments (see above footnote 16).

there are ways to accept a hypothetical knowledge content different from the empirical test, simple abduction is not necessarily constitutively ignorance-preserving: in the end we are dealing with a disagreement about the nature of *knowledge*, as Woods himself contends. As I have previously indicated, those who consider abduction as an inference to the best explanation—that is as a truth conferring achievement involving empirical evaluation—obviously cannot consider abductive inference as ignorance-preserving. Those who consider abduction as a mere activity of guessing are more inclined to accept its ignorance-preserving character.

However, *we are objecting that abduction can be in this last case still knowledge-enhancing*.

At this point two important consequences concerning the meaning of the word *ignorance* in this context have to be illustrated:

1. abduction, also when intended as an inference to the best explanation in the "classical" sense I have indicated above, is always *ignorance-preserving* because abduction represents a kind of reasoning that is constitutively provisional, and you can withdraw previous abductive results (even if empirically confirmed, that is appropriately considered "best explanations"), in presence of new information. From the logical point of view this means that abduction represents a kind of nonmonotonic reasoning,[23] and in this perspective we can even say that abduction interprets the "spirit" of modern science, where truths are never stable and absolute. Peirce also emphasized the "marvelous self-correcting property of reason" in general (Peirce 1931–1958, 5.579). So to say, abduction incarnates the human perennial search of new truths and the human Socratic awareness of a basic ignorance which can only be attenuated/mitigated. In sum, in this perspective abduction always preserves ignorance because it reminds us we can reach truths that can always be withdrawn; ignorance removal is at the same time constitutively related to ignorance regaining;
2. even if ignorance is preserved in the sense I have just indicated, which coincides with the spirit of modern science, abduction is also knowledge-enhancing because new truths can be and "are" discovered which *are not necessarily best explanations intended as hypotheses which are empirically tested*.

A similar argumentation, which resorts to better explain the conundrum of abduction as ignorance-preserving, is provided by Woods, who notes that some philosophers accept the Gabbay-Woods schema (GW-schema) for abduction but at the same time dislike its commitment to the ignorance-preservation claim. Woods' answer

[23] A logical system is monotonic if the function *Theo* that relates every set of wffs to the set of their theorems holds the following property: for every set of premises S and for every set of premises S', $S \subseteq S'$ implies $Theo(S) \subseteq Theo(S')$. Traditional deductive logics are always monotonic: intuitively, adding new premises (axioms) will never invalidate old conclusions. In a nonmonotonic system, when axioms, or premises, increase, their theorems do not (Ginsberg 1987; Lukaszewicz 1970; Magnani and Gennari 1997). Following this deductive nonmonotonic view of abduction, we can stress the fact that in actual abductive medical reasoning, when we increase symptoms and patients' data [premises], we are compelled to abandon previously derived plausible diagnostic hypotheses [theorems].

resorts to say that this hesitancy flows from how those philosophers *epistemologically* approach the general question of knowledge. It is not logic of abduction in question but the epistemological adopted perspective (Woods 2013, Chap. 11). I have just said that knowledge can be attained in the absence of evidence; there are propositions about the world which turn to be true by virtue of considerations that lend them no evidential/empirical weight. They are true beliefs that are not justified on the basis of evidence. Is abduction related to the generation of knowledge contents of this kind? Yes it is.

Abduction is guessing reliable hypotheses, and humans are very good at it; abduction is akin to truth: it is especially in the case of empirical scientific cognition that abduction reveals its more representative epistemic virtues, because it provides hypotheses, models, ideas, thoughts experiments, etc., which, even if *devoid of initial* evidential support, constitute the fundamental rational building blocks for the generation of new laws and theories which only later on will be solidly empirically tested.

In the following sections of this chapter I aim at illustrating this intrinsic character of abduction, which shows why we certainly can logically consider it a kind of ignorance-preserving cognition, but at the same time a cognitive process that can enhance knowledge at various level of human cognitive activities, even if the empirical evaluation lacks.

1.4.1 Why Does Abduction Enhance Knowledge? Instinct, Inference, and Synechism: Mind and Matter Intertwined

Peirce provides various justifications of the productive gnoseological role of abduction. They basically resort to the conceptual exploitation of evolutionary and metaphysical ideas, which clearly show that abduction is constitutively akin to truth, certainly ignorance-preserving—because the "absolute truth" is never reached through abduction—but also knowledge-enhancing. Peirce himself notes that abductive guesses are belief-inducing and truth making. Not only, it cannot be said that unevidenced belief is itself evidence of malfunction and disorder, and so source of falsification.

First of all Peirce considers hypothesis generation a largely instinctual endowment[24] of human beings given by God or related to a kind of Galilean "*lume naturale*": "It is a primary *hypothesis* underlying all abduction that the human mind is akin to the truth in the sense that in a finite number of guesses it will light upon the correct hypothesis" (Peirce 1931–1958, 7.220). Again, the example of the innate ideas of "every little chicken" is of help to describe this human instinctual endowment:

[24]Instinct is of course in part conscious: it is "always partially controlled by the deliberate exercise of imagination and reflection" (Peirce 1931–1958, 7.381).

> How was it that man was ever led to entertain that true theory? You cannot say that it happened by chance, because the possible theories, if not strictly innumerable, at any rate exceed a trillion – or the third power of a million; and therefore the chances are too overwhelmingly against the single true theory in the twenty or thirty thousand years during which man has been a thinking animal, ever having come into any man's head. Besides, you cannot seriously think that every little chicken, that is hatched, has to rummage through all possible theories until it lights upon the good idea of picking up something and eating it. On the contrary, you think the chicken has an innate idea of doing this; that is to say, that it can think of this, but has no faculty of thinking anything else. The chicken you say pecks by instinct. But if you are going to think every poor chicken endowed with an innate tendency toward a positive truth, why should you think that to man alone this gift is denied? (Peirce 1931–1958, 5.591).

The naturalistic view of instinct involves at least two aspects: *evolutionary/adaptive* and *perceptual*—as a "certain insight" (Peirce 1931–1958, 5.173): the instinctual insight that leads to a hypothesis is considered by Peirce to be of "the same general class of operations to which Perceptive Judgments belong"[25] (*ibid.*) Hence, Peirce considers the capacity to guess correct hypotheses as instinctive and enrooted in our evolution and from this perspective abduction is surely a property of naturally evolving organisms:

> If you carefully consider with an unbiased mind all the circumstances of the early history of science and all the other facts bearing on the question […] I am quite sure that you must be brought to acknowledge that man's mind has a natural adaptation to imagining correct theories of some kind, and in particular to correct theories about forces, without some glimmer of which he could not form social ties and consequently could not reproduce his kind (Peirce 1931–1958, 5.591).[26]

Peirce also says "Thought is not necessarily connected with brain. It appears in the work of bees, of crystals, and throughout the purely physical world; and one can no more deny that it is really there, than that the colours, the shapes, etc., of objects are really there" (Peirce 1931–1958, 4.551). It is vital to explain the meaning of this important statement.

First of all it has to be noted that instincts themselves can undergo modifications through evolution: they are "inherited habits, or in a more accurate language, inherited

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[25] I have described perception as abduction in the Sect. 1.2 above.

[26] Cognitive anthropologist Atran advocated a similar view about a century later, arguing in his *Cognitive Foundations of Natural History* that the evolution of religion and pre-scientific forms of knowledge into fully-blown science could be accounted for just recurring to the concepts of *culture* and *cognition*, understanding the latter as "the internal structure of ideas by which the world is conceptualized" (Atran 1990, p. 3). Peirce's philosophical speculations have been recently corroborated by a growing interest in *folk science*, that is in the study of uneducated expectations about natural aspects such as biology, mechanics, psychology, physiology and so on. Berlin and his colleagues pioneered the exploration of folkbiological expectations across different cultures (Berlin et al. 1973). The existence of folk science does not make the case for the actuality of a *lume naturale* predisposing humans towards Truth, but for the reality of a penchant (which is also at the level of perception) towards truthfulness: (Keil 2010) argues that the success of science partially comes from "the ways in which scientists learn to leverage understandings in other minds and to outsource explanatory work through sophisticated methods of deference and simplification of complex systems," (p. 826) but such ways of relying on other people's knowledge in order to achieve better approximations of the truth about a matter are actually preexistent in laypeople and children.

dispositions" (Peirce 1931–1958, 2.170). Elsewhere Peirce seems to maintain that instinct is not really relevant in scientific reasoning but that it is typical of just "the reasoning of practical men about every day affairs". So as to say, we can perform instinctive abduction (that is not controlled, not "reasoned") in practical reasoning, but this is not typical of scientific thinking:

> These two [practical and scientific reasoning] would be shown to be governed by somewhat different principles, inasmuch as the practical reasoning is forced to reach some definite conclusion promptly, while science can wait a century or five centuries, if need be, before coming to any conclusion at all. Another cause which acts still more strongly to differentiate the methodeutic of theoretical and practical reasoning is that the latter can be regulated by instinct acting in its natural way, while theory of how one should reason depends upon one's ultimate purpose and is modified with every modification of ethics. Theory is thus at a special disadvantage here; but instinct within its proper domain is generally far keener, and surer, and above all swifter, than any deduction from theory can be. Besides, logical instinct has, at all events, to be employed in applying the theory. On the other hand, the ultimate purpose of pure science, as such, is perfectly definite and simple; the theory of purely scientific reasoning can be worked out with mathematical certainty; and the application of the theory does not require the logical instinct to be strained beyond its natural function. On the other hand, if we attempt to apply natural logical instinct to purely scientific questions of any difficulty, it not only becomes uncertain, but if it is heeded, the voice of instinct itself is that objective considerations should be the decisive ones.[27]

I think that the considerations above do not mean, as some commentators seem to maintain (Rescher 1995; Hoffmann 1999; Paavola 2005), that instinct—as a kind of mysterious, not analyzed, guessing power—"does not" operate at the level of conscious inferences as in the case of scientific reasoning. I think a better interpretation is the following that I am proposing here: certainly instinct, which I consider a simple and not a mysterious endowment of human beings, is at the basis of both "practical" and scientific reasoning, in turn instinct shows the obvious origin of both in natural evolution. If every kind of cognitive activity is rooted in a hybrid interplay with external sources and representations, which exhibit their specific constraints and features, it does not appear surprising that "[…] the instincts conducive to assimilation of food, and the instincts conducive to reproduction, must have involved from the beginning certain tendencies to think truly about physics, on the one hand, and about psychics, on the other. It is somehow more than a *mere* figure of speech to say that nature fecundates the mind of man with ideas which, when those ideas grow up, will resemble their father, Nature" (Peirce 1931–1958, 5.591). Hence, from an evolutionary perspective instincts are rooted in humans in this interplay between internal and external aspects and so it is obvious to see that externalities ("Nature") "fecundate" the mind. In this perspective abduction represents the most interesting fruit of this "fecundated" mind.

Beyond the multifarious and sometimes contrasting Peircean intellectual strategies and steps in illustrating concepts like inference, abduction, perception and

[27] Cf. Arisbe Website, http://www.cspeirce.com/menu/library/bycsp/l75/ver1/l75v1-01.htm. The passage comes from MS L75 Logic, regarded as semeiotic (The Carnegie application of 1902).

instinct, which of course are of great interest for the historians of philosophy,[28] the perspective I am describing here seems able to clearly focus on some central recent cognitive issues which I contend also implicitly underlie Peircean thoughts: nature fecundates the mind because it is through a disembodiment and extension of the mind in nature that in turn nature affects the mind. If we contend a conception of mind as "extended", it is simple to grasp its instinctual part as shaped by evolution through the constraints found in nature itself. It is in this sense that the mind's abductive guesses—both instinctual and reasoned—can be classified as hypotheses "akin to the truth" concerning nature and the external world because the mind grows up together with the representational delegations[29] to that "nature" (external world) that the mind itself has made throughout the history of culture by constructing what some present-day biologists call cognitive niches. In this strict perspective hypotheses are not merely made by pure *unnatural* chance.[30]

Peirce says, in the framework of his *synechism* that "[…] the reaction between mind and matter would be of not essential different kind from the action between parts of mind that are in continuous union" (Peirce 1931–1958, 6.277). This is clearly seen if we notice that "[…] habit is by no means a mental fact. Empirically, we find that some plants take habits. The stream of water that wears a bed for itself is forming a habit" (Peirce 1931–1958, 5.492). Finally, here the passage we already quoted above, clearly establishing Peirce's concerns about the mind: "Thought is not necessarily connected with brain. It appears in the work of bees, of crystals, and throughout the purely physical world; and one can no more deny that it is really there, than that the colours, the shapes, etc., of objects are really there" (Peirce 1931–1958, 4.551).

To conclude, seeing abduction as rooted in instinct vs. in inference represents a conflict we can overcome, following Peirce, simply by observing that the work of abduction is partly explicable as an instinctual biological phenomenon and partly as a "logical" operation related to "plastic" cognitive endowments of all organisms. I entirely agree with Peirce: a guess in science, the appearance of a new hypothesis, is also[31] a biological phenomenon and so it is related to instinct: in the sense that first of all we can analogize the appearance of a new hypothesis to a "trustworthy" chance variation in biological evolution (Peirce 1931–1958, 7.38), even if of course the evolution—for example—of scientific guesses does not conform to the pattern of biological evolution (Colapietro 2005, p. 427). An abduced hypothesis introduces a change (and a chance) in the semiotic processes to advance new perspectives in the

[28] For example, in the latest writings at the beginning of XX century Peirce more clearly stresses the instinctual nature of abduction and at the same time its inferential nature (Paavola 2005, p. 150). On the various approaches regarding perception in Peircean texts cf. (Tiercelin 2005).

[29] Representational delegations are those cognitive acts that transform the natural environment in a cognitive one (a *cognitive niche*). Cf. (Laland et al. 2000, 2001; Odling-Smee et al. 2003). I have illustrated in detail the concept of cognitive niche in Chap. 6 of (Magnani 2009).

[30] This is not a view that conflicts with the idea of God's creation of human instinct: it is instead meant on this basis, that we can add, with Peirce, the theistic hypothesis, if desired.

[31] Of course this conclusion does not mean that artifacts like computers do not or cannot perform abductions. The recent history of artificial intelligence (AI) in building systems able to perform diagnoses and creativity clearly illustrates this point.

co-evolution of the organism and the environment: it is in this way that they find a continuous mutual variation. The organism modifies its character in order to reach better fitness; however, the environment (already artificially—culturally—modified, i.e. a cognitive niche), is equally continuously changing and very sensitive to every modification. In summary, the fact that abduction is akin to truth is guaranteed at both the metaphysical and evolutionary levels: the case of instinct and the case of perception described by Peirce are striking, both provide abductions that are immediately and spontaneously generated but at the same time activated and efficacious, certainly not "in sufferance" (as Woods would say, referring to the case of the standard activity of abducing hypotheses in natural science), and so in need of empirical evaluation.

1.5 Enhancing Knowledge through Reward and Punishment and the Inductive Risk

In the previous section I have contended that abduction represents a kind of non-monotonic reasoning, and in this perspective we even said that abduction interprets the "spirit" of modern science, where truths are never stable and absolute. Peirce also emphasized the "marvelous self-correcting property of reason" in general (Peirce 1931–1958, 5.579). So to say, abduction incarnates the human perennial search of new truths and the human Socratic awareness of a basic ignorance which can only be attenuated/mitigated: abduction always preserves ignorance because it reminds us we can reach truths that can always be withdrawn; ignorance removal is at the same time constitutively related to ignorance regaining. Moreover, even if ignorance is preserved in the sense I have just indicated, which coincides with the spirit of modern science, abduction is also knowledge-enhancing because new truths can be and "are" discovered which *are not necessarily best explanations intended as hypotheses which are accepted because empirically tested*.

Modern science acknowledges the fact that to produce knowledge a kind of process of reward and punishment is required: analogously to what happens in the case of morality. The spirit of modern science luckily distills and idealizes a moral conduct which inform a cognitive practice devoted to seeking truth. Already in Plato at the birth of western philosophy various virtuous cognitive conducts are stressed, which are transformed and reverberated in syllogism by Aristotle (a list of these conducts is given below in Chap. 6, Sect. 6.1.2). Among these behavioral traits "respect for the evidence" and "being willing to questions assumptions" transform in epistemic virtue the fact that acquired knowledge can be so to say "rewarded" or "punished", for example by the authority of empirical evidence. These traits reflect a change with respect to other areas of knowledge, such as metaphysics, religion, etc. which present "unpunishable" assertions, because granted by a moral authority which does

not consider the role of empirical evidence. They reflect what I call a "moral epistemology".[32]

1.5.1 Beneficial and Detrimental Dissent: Inductive Risk

A neglected but important issue refers to the problem of differentiating between epistemically beneficial and epistemically detrimental dissent. For example, when we object to an established scientific hypothesis, we can act by obeying to epistemic good standards and so the objection can become a "falsification" in Popperian sense, that is potentially beneficial for the growth of science. However, there are other cases in which dissent—often aggressive and repeated—can be negative to science and to rationality.[33] Examples include the tobacco industry's funding of some results that questioned the link between smoking and lung cancer, and the attempt by the petroleum industry and other groups to question the conclusion that human consumption of fossil fuels leads to global climate change (Biddle and Leuschner 2015). The problem of distinguishing between good and bad dissent in such "concrete" cases is of course important from the social and economical perspectives: indeed sometimes stakeholders attempt to delay political action by creating doubts.

Bad dissent is obviously related to the problem of evaluation of abductive hypotheses, which resorts to what Hempel (Hempel 1965) called *inductive risk*.[34] Jeffrey says that "accepting a hypothesis" is "a sort of inductive jump from high probability to certainty" and concludes "We seem to have been driven to the conclusion that the scientist's proper role is to provide the rational agents in the society which he represents with probabilities for the hypotheses which on the other account he simply accepts or rejects" (Jeffrey 1956, p. 238 and p. 245). Because no evidence seems to be able to establish a hypothesis (at least in the case the hypothesis is "empirical") with certainty (we know that abduction is a kind of presumptive cognitive process), inductive risk is the risk of error in accepting or rejecting hypotheses. Inductive risk regards the "unavoidable" role of value judgments—even ethical—in the evaluation of scientific hypotheses, and so to the well-known *presumptive* character of abduc-

[32] In (Magnani 2011, Sect. 6.5) I addressed the related problem of what I call "moral epistemology" (which comprehends the intrinsic "morality of sound reasoning" and is concerned with a somehow moral "commitment to the truth"), supposed to be clever in a pure way and able to foster good moral outcomes for everyone.

[33] When established hypotheses are attacked scientists are compelled to respond to an endless wave of unnecessary and unhelpful objections and demands and an atmosphere is created in which scientists fear to address certain topics and/or to defend hypotheses. In these cases they can unfortunately adopt a weaker epistemic attitude than the one they would have implemented in a more serene eco-cognitive environment: a situation of what I call *epistemic irresponsibility* can arise (cf. below Chap. 8 of this book)..

[34] At the time of this classical article on inductive risk the problem of abduction was relatively unknown and understudied, and induction dominated the studies regarding the process of generating hypotheses. On inductive risk cf. also (Rudner 1953; Jeffrey 1956; Douglas 2000; Wilholt 2009).

tive cognition, extensively treated in the present book.[35] Of course when there is a negligible uncertainty the chance of being wrong is so small that the chance of bad consequences becomes unimportant.

Obviously not all the areas of scientific research are affected by inductive risk: it is unlikely some errors in physics or in pure mathematics can have non-epistemic consequences, even if "[…] there are cases where the science will likely be useful but the potential consequences of error may be difficult to foresee. This gray area would have to be debated case by case, but the fact that such a gray area exists does not negate the basic argument: that when non-epistemic consequences of error can be foreseen, non-epistemic values are a necessary part of scientific reasoning" (Douglas 2000, p. 577). Studying the inductive risk also concerns the establishment of suitable and contextual conditions that make the agent—a scientist in our case —able to distinguish between epistemically good and epistemically problematic dissent, that is between acceptable value-influence cases and cases of illegitimate bias. Of course, when for example severe individual or public risk is at stake the problem of inductive risk is extremely important. In this sense the objective domain of policymaking in which actions—based on scientific chosen (and accepted) hypotheses—are performed as deeply related to non-epistemic values is clearly distinct from the cognitive domain of hypothesis generation and acceptation appropriate to scientific practice.

When a scientific hypothesis in publicly "asserted" this involves not only its communication but also undertaking the responsibility of its defense (Franco 2017): indeed, depending on the audience, some intended or unintended consequences derive, which are oriented by non-epistemic values, for example moral, that should be taken into account also by the scientific people who made the assertion. This means that a scientist can be influenced by some possible moral consequences she is able to predict and, accordingly, she can decide to avoid to assert her claim. Moreover she has to control the ways in which assertions are rendered available for use in contexts related to non-epistemic actions, especially considering that misfired (in the sense that they contain aspects unrelated to epistemic dimensions not simply detectable) or wrongful assertions turn out to have more or less easily foreseeable non-epistemic consequences.[36]

(Biddle and Leuschner 2015, p. 273) list a set of conditions that are sufficient for individuating epistemically detrimental dissent in general "1. The non-epistemic consequences of wrongly rejecting H are likely to be severe. 2. The dissenting research that constitutes the objection violates established conventional standards. 3. The dissenting research involves intolerance for producer risks at the expense of public risks.

[35] (Douglas 2000, p. 578) usefully adds that there is inductive risk not only in accepting a hypothesis but also a related risk when accepting methodologies, data, and interpretations.

[36] Scientists working on a particular program have moral reasons for taking into account the most relevant societal consequences of their research and for attempting to weaken the harmful outcomes that it might have. Moreover, scientists have to be aware of scientific situations in which available information and knowledge are too uncertain or insufficient. Of course, not always scientists can dominate the situation by themselves: in these cases it can be "harmful or impracticable for scientists to respond to this uncertainty by withholding their judgment or supplying only minimally interpreted data to decision makers"(Elliott 2010).

4. Producer risks and public risks fall largely upon different parties". Further, Biddle proposes the interesting concept of "epistemic risk", which is simply "the risk of being wrong. One can wrongly accept or reject a hypothesis given evidence that is taken to support that hypothesis—thus the concept of epistemic risk includes the concept of inductive risk—but one can also wrongly accept or reject many other things, including a methodology, a background assumption, a set of test subjects, a policy and, as I will argue, a definition" (Biddle 2016, p. 202). This problem touches aspects of the evaluations of abductive hypotheses that will be richly reconsidered below in Chap. 8: in the perspective of the present study on abduction epistemic risk resorts to the analysis of possible strong non epistemic values, which possible enter and infest the evaluation process, so altering—in the case of science—the "rational" decency of the final result, possibly originating high hazards for public safety.

In (Magnani 2011 Chap. 2) I have treated the problem of denialism as a form of *ad ignorantiam fallacy* as a semantic attack. Various aspects of ignorance related to dissent —and the fundamental problem of the possible bad consequences of "moral ignorance"—are illustrated by Proctor (Proctor and Schiebinger 2008), who stressed various aspects that link ignorance to both positive and negative (for example violent) outcomes: examples from the realms of global climate change, military secrecy, female orgasm, environmental *denialism*, Native American paleontology, theoretical archaeology, and racism are described, also with the aim of showing how ignorance can present a violent potential ("Doubt is our product" is the tobacco industry slogan).[37]

1.6 Tracking the External World: Enhancing Predictive Knowledge

I think that everyday, philosophical, and scientific knowledge about natural and artificial phenomena (as well as the technologies that relate to them) have allowed human beings a wide range of possibilities for choosing and acting: in many ways, the more one knows, the more options one has.

The evolution of knowledge and its externalization in objects and artifacts is directly related to our bodies' and brains' capacities for consciousness and free will and is directly related to the role of abduction. Indeed, knowledge sheds light on both natural and artificial external worlds, revealing two kinds of phenomena: (1) regular, foreseeable phenomena whose predictability makes possible a range of free choices and allows us to plan appropriate and effective responses and (2) unpredictable or unprecedented phenomena that cannot be altered by human intervention because

[37] On the several ways in which "the product defense industry" ambiguously exploits scientific (and pseudoscientific) arguments to undermine public health protections, corrupt the scientific record, and mislead the public cf. (Michaels 2008). More details about the current dangers which human creative abduction and scientific cognition are facing with are illustrated below in Chap. 8, this book.

we lack the knowledge to do so. Moreover, as we well know, this second sort of knowledge, because of its dynamics, does not involve "ontological" limitations: a phenomenon once considered beyond the reach of human action can, with new understanding, become easily manageable, a process that increases our options and, consequently, our free will. In the knowledge framework of some primitive people, for example, the course of a river was not considered modifiable, but new knowledge and new artifacts made it feasible to govern flowing water, allowing other ancient civilizations to "choose" between natural and artificial courses.

Dennett lists five different kinds of natural phenomena that relate to the "elbow room" he claims is the basic requirement for free will: those that are fixed, beneath notice, changing (and worth caring about),[38] trackable ("at least under some conditions—and hence efficiently and usefully predictable under those conditions"), and chaotic, that is (practically) unpredictable but still worth caring about). These categories of phenomena—which, I repeat, are dynamic products of human knowledge—provide us with what Dennett calls "epistemic possibilities", which are necessary for an agent to become a free deliberator. This variety encompasses everything that is "possible-for-all-the-deliberator-knows-or-cares" and ensures that every "deliberator-agent—a species, for instance—will always be equipped with a somewhat idiosyncratic way of gathering and partitioning information about its world so it can act effectively in it. […] It is this epistemic openness, this possibility-for-all-one-knows, that provides the elbow room required for deliberation". This epistemic openness also nullifies deterministic objections to free will (Dennett 1984, pp. 111 and 113). The tradition of western science maximizes the epistemic openness that provides the elbow room required for deliberation and so the chances of tracking the external world: in Chap. 7 I will illustrate that science is characterized by a maximization of abducibility, performed thanks to specific constraints and through a process in which affirming truths implies negating truths.

Two simple examples will clarify the problem of the choice and its "elbow room" one related to everyday situations, the other related to science (cf. the following section). It is supposed I have a normal brain endowed with normal consciousness. Phylogenesis and (my personal) epigenesis have provided me with "hardware," the physical equipment that can be described as having free will because it can adopt various cognitive approaches to decision making, strategies human beings are now also able to model through algorithms (in my case, the non-technical ones I acquired and refined especially during my childhood).

At this moment, I am in my hotel room writing on my laptop; later today, I plan to go to the Sun Yat-sen University, which is relatively close. My everyday knowledge of the city (Guangzhou) (some of it already stored in my memory) tells me that I can "choose" many routes to reach Sun Yat-sen University. I already have the mental representation of a possible route I used in the past, but I want to find a new one that is much shorter. All I need are new representations of the roads, which I can

[38](Dennett 1984, p. 109). Dennett also sees the chaotic systems as "the source of the 'practical' (but one might say infinitely practical) independence of things that shuffle the world and makes it a place of continual opportunity" (Dennett 1984, p. 152).

easily "pick up" from a map. Most of the world's information is stored in external "mediators"—it is not necessarily found only in brains!

At this point all the required elements for decision making are present: brain, consciousness, intentionality, free will, a reasoning mechanism guided by a system of values, and adequate knowledge about my goal and the possible routes I might take. Some aspects are internal and some are external. Some external ones-new data about possible routes, for example—become internal when they are put in memory and are therefore represented in my brain. I know there are routes I cannot choose because they involve loops or *cul de sac*. At this point, I can plan my route.

At this stage, I can do more: I can externalize some data that are internal by drawing a simple map for the brain of a friend who needs information about how to get to the park. To an observer of this hypothetical interaction—a third brain—all aspects of this exchange between my friend and me are "external", and even my brain is considered an external object by the observer. But that third brain easily hypothesizes that my drawings derive from my existing "internal" representations. Cognitive psychologists contend that human consciousness requires a capacity to infer others' mental states from their behavior (Wegner 2002). In turn, philosophers used those hypothesized mental states as evidence that being aware of our own internal representations derives from the immaterial Cartesian Cogito, that famous supplemental and embarrassing "ghost in the machine".

Let us come back to the problems of conscious free will and the role of knowledge, both internal and external. The simple example of my quest to reach Sun Yat-sen University has a clear epistemological significance; the new knowledge involved, both available and represented, indicates that based on the external mixture of natural things and artifacts that is my environment, "there are" various routes shorter than the one already stored in my mind. These shortcuts are then revealed and evaluated by the decision-making mechanisms operating in my brain. By picking up new knowledge from external devices (a map, for example) and re-representing it in my brain cells, I can enhance my range of possible choices and so gain more room to flex my free will.

As we can easily see, all the "characters" of this theater of consciousness are intertwined with one another (Seth and Baars 2005). Consciousness in human brains (and so "my" consciousness) has evolved in this way because human brains in turn have produced knowledge about the world that sanctioned as available and believable multiple representations, that, once re-represented in the brain, further expand our menu of possible choices, and vice versa. Consequently, I contend that consciousness and higher mechanism of knowledge (such as abduction) are very much interdependent.

1.7 Tracking the External World through Scientific Knowledge

It is not only everyday knowledge that helps us to track the external world; higher levels of knowledge, like that found in philosophy and science, multiply the options available to human beings for choosing and acting. Consider for a moment a set of external natural circumstances and/or lack of knowledge that renders voluntary choice impossible—volcanic eruption, for example. Stored in my brain, which is endowed with consciousness function etc., is enough general knowledge volcanology for me to understand that neither I nor any other human being can possibly predict the exact date of the next eruption of Vesuvius; even scientists who are experts in the field can only estimate that it will probably occur some time in the next two hundred years. Consequently, in the next two hundred years I cannot freely choose when to go to Naples and be certain I will avoid an eruption. Human beings currently have limited abilities to predict and thus to affect the impact of geological events in particular and of chaotic events in general-we cannot, therefore, reconfigure the Naples soccer team's schedule so a game does not coincide with the eruption. In this case, our capacity for free will is of no use: even with help from scientific models, computational devices, and complicated calculations, our brains are not able to pinpoint the precise day Vesuvius will erupt. Our best choice might be to postpone a trip to Naples until after 2217! Future improvements in volcanology, however, could allow more accurate predictions, even if we know that unpredictability is constitutive in chaotic phenomena.

If the world "out there" were always cognitively dark and homogeneous, free will would be impossible: free will and knowledge are two sides of the same coin. In recent human evolution, there has been a general increase in the human abductive production of philosophical and, subsequently, scientific knowledge (and in their systematic "externalization") as people have sought to free the human organism from its immediate environment. It is easy to imagine how many representations and inferential mechanisms can be stored in our brains and used at will: even those not already consigned to our brain memory exist over there, crystallized in various external mediators throughout the history of civilizations, ready to be "picked up" when needed. To that same end, human beings also participate in the reverse process by externalizing many techniques and technologies.

The roles of knowledge, however, extend beyond phenomena of the natural and artificial world, beyond settings like the streets of a city. In the external world there are also other human beings. What happens to our internal free will mechanisms when we are faced with the behavior of other human beings?

1.8 Tracking Human Behavior. Rendering Human Behavior Predictable through Ethics

In the previous two sections I contended that cognitively tracking the external natural and artificial world provides the "elbow room" necessary to build a free deliberative agent, and that, unfortunately, one of the main obstacles to free choice (and thus to making free will effective) is not only the lack of suitable predictive knowledge about the processes of the natural and artificial world, but also about the behavior of other human beings. From this perspective, other people are "natural things" whose behavior is a priori difficult to predict: how can we track human intentions? Consequently, human behavior poses a very different sort of challenge, with respect to the constitutive incompleteness or lack of trustworthiness of available knowledge about natural and artificial phenomena. Indeed, when we "morally" seek ownership of our own destinies we expect to be able to reach objectives through consciousness, free will and intentionality, thus undertaking a stand for the "best". We can only obtain the desired results if we can count on some consistency and predictability in the behavior of other human agents. If, in an attempt to "author" my destiny, I consider *merit* as a way to achieve a desired position, I must be able to assume that other human beings of my collectivity value it similarly. I contend that many objectified entities like common and religious morality, moral philosophy, human and social sciences, and of course all other kinds of ethical knowledge, are clearly connected to our existing need to operate at our highest level of conscious activity, as is the case when we seek to exercise free will and to claim ownership of our destinies.

How can I fruitfully employ my brain's free will mechanisms if I cannot trust other human beings? How can I work on a personal project or participate in a social project if not by relying on the commitment of other human agents? How may I "author" my life and reach my goals if I am unsure which actions to choose because I cannot be assured that others share my values and support my intentions? Religion, morality, moral knowledge and teaching enhance and permit free will because they impose order on the randomness of human behaviors, giving people a better chance of owning their destinies.

There are many human actions that affect others' free will and ownership of destiny; among them, as recently observed by some scholars, is the practice of gossiping. These authors affirm that the practice is not just an exchange of information about absent people, which can of course be a form of indirect aggression: it is also, they contend, a form of sociable interaction[39] processing others as "moral characters" (Yerkovich 1977). The narratives created by gossiping become a possible source of shared knowledge about evaluative categories concerning (moral) ways of acting and

[39]In my research I often emphasized the role of gossip. Dunbar (2004) originally gives scientific cognitive dignity to gossip explaining it in the framework of the so-called "social brain hypothesis". Posited in the late 1980s, this hypothesis contends that the relatively large brains of human beings and other primates reflect the computational demands of complex social systems and not just the need to process information of ecological relevance. Cf. also the recent (Magnani 2011) and (Bertolotti and Magnani 2014) .

interacting. Gossip need not be evaluative, but it is "moral" insofar as it describes behaviors and presents them as interesting and salient and, consequently, as potentially or *de facto* sanctionable. Gossiping could play an important role in morally—more or less violently—"policing free riders" (Dunbar 2004), that is, those who enjoy the benefits of sociality but refuse to pay their share of its costs. Commenting on the behavior of such people, or casting aspersions on their character, helps us to control their potentially destructive effect on societies.

I have contended above that moral practices protect the ownership of our destinies because ethics render human behavior more predictable, and when we can count on shared values in dealing with other "moral" human beings, we can better project our future. Consequently gossip helps safeguard the ownership of our destinies as it constantly shapes our narrative constructions of morality: empirical data have shown, for example, that gossip works as a form of low-cost (moral) social cognition that conveys valuable information about culture and society. The act of gossiping can allow us to recognize that others are at risk of exploitation by moral free riders even though we ourselves are not (Dunbar 2004, pp. 106–109). Kant said that the "Kingdom of Ends"—that is, the moral world—"is a practical Idea used to bring into existence what does not exist but can be made actual by our conduct—and indeed to bring it into existence in conformity with this Idea" (Kant 1964, p. 104).

Hence, the kingdom of ends is a kingdom of possible free choices created by (and contingent upon) human beings, for it is only their reliability that makes free will, and thus responsibility and freedom, possible. Dennett, when discussing the status of "self-made selves", makes the following comment: "Kant's famous claim in *Foundations of the Metaphysics of Morals* that the law we give ourselves does not bind us suggests that the selves we become in this process are not constrained by the law we promulgate because these selves are (partly) constituted by those very laws, partly created by a fiat that renders more articulate and definite something hitherto underdone or unformed" (Dennett 1984, p. 90). Moreover, human aspects that are the underpinnings of the kingdom of ends—such as religion, for example —must be successfully and appropriately activated; their being in good working order is a basic condition for exercising morality and allowing free will to become "good" will. As I have stressed in my book *Morality on a Technological World* (Magnani 2007), I am a sustainer of the importance of knowledge in constructing a new ethical commitment that embraces the idea of "respecting people as things",[40] and I always stressed the fact that particular kinds of technologies can threaten the growth—and even the existence—of freedom, responsibility, and the ownership of our destinies.

How could we use our free will without the constraints of objectified morality, religions, laws, and institutions that impose regularity and predictability on human behavior, and that, in turn, bolster people's trustworthiness? In this sense, we are responsible for our own free will (and, therefore, our freedom) because its exis-

[40]In essence, the idea holds that human beings often can and even should be treated as "things", and that in the process they become "respected as things" that had been ascribed more value than some people. We must reappropriate the instrumental and moral values that people have lavished on external things and objects, which I contend is central to reconfiguring human dignity in our technological world.

tence and its perpetuity seem not to be an inalienable given, but they depend on our intellectual and practical choices about knowledge, religions, scientific and moral institutions and the related techniques and technologies, and on their use in everyday settings, work environments, education, communication, and economic life. For example, environmental imperatives are matters of principle that cannot be economically bargained away because they represent a kind of paradox of liberalism. Indeed, in matters of conservation, one could maintain that neutrality is necessary to preserve the rights of the individuals involved, but this notion is obviously outweighed by the fact that the freedom to destroy natural goods and things today will, paradoxically, inhibit freedom in the future, when people will have as a result fewer options when choosing among competing ideas of the good life.

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Chapter 2
Distributed Model-Based Science

Scientific Models Are Not Fictions

In the current epistemological debate scientific models are not only considered as useful devices for explaining facts or discovering new entities, laws, and theories, but also rubricated under various new labels: from the classical ones, as abstract entities and idealizations, to the more recent, as fictions, surrogates, credible worlds, missing systems, make-believe, parables, functional, epistemic actions, revealing capacities. The chapter discusses these approaches showing some of their epistemological inadequacies, also taking advantage of recent results in cognitive science. The main aim is to revise and criticize scientific fictionalism, also reframing the received idea of abstractness and ideality of models with the help of recent results coming from the area of distributed cognition (common coding) and abductive cognition (manipulative). The chapter also introduces the concept of epistemic warfare, later on further studied in chapter four. It will be illustrated how 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. Finally a reference to new epistemological perspectives on the role of ignorance in model-based science is also provided.

2.1 Models and Fictions

Scientific models are now not only considered useful ways for explaining facts and/or discovering new entities, laws, and theories, but are also rubricated under various new labels: from the classical ones, abstract entities (Giere 1988, 2009, 2007) and idealizations (Portides 2007; Weisberg 2007; Mizrahi 2011), to the more recent, fictions (Fine 2009; Woods 2010; Woods and Rosales 2010b; Contessa 2010; Frigg

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2010a, b, c; Godfrey-Smith 2006, 2009; Woods and Rosales 2010a; Suárez 2009a, 2010), surrogates (Contessa 2007), credible worlds (Sugden 2000, 2009; Kuorikoski and Lehtinen 2009), missing systems (Mäki 2009; Thomson-Jones 2010), as make-believe (Frigg 2010a, b, c; Toon 2010), parables (Cartwright 2009b), as functional (Chakravartty 2010), as epistemic actions (Magnani 2004a, b), as revealing capacities (Cartwright 2009a). Some of the authors mentioned above are also engaged in a controversy about the legitimacy especially of speaking of fictions in the case of scientific models.

Even if the above studies have increased knowledge about some aspects of the role of models in science, I am convinced that sometimes they have also generated some philosophical puzzles and it seems to me correct (following the suggestion embedded in the title of a recent article) "to keep quiet on the ontology of models" (French 2010). Models are used in a variety of ways in scientific practice, they can also work as mediators between theory and experiment (Portides 2007), as pedagogical devices, for testing hypotheses, or for explanatory functions (Bokulich 2011), roles of models in science which are already relatively well-known in the epistemological literature. In this chapter I will concentrate on scientific models in creative abductive cognitive processes, which Hintikka considered the central problem of current epistemological research (Hintikka 1998).

I aim at substantiating my analysis of scientific models—so to speak—"in motion" also outlining the first features of my own approach in terms of what I call "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, etc.) weapons. 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.[1]

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 (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: Galileo's discussions of real experiments—in the *Dialogo* but also in the *Discorsi*—become rhetorical, to confound the opponents and persuade the readers, and also to fulfil didactic needs, as contended by (Naylor 1976).

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 will illustrate in this chapter, which for example directly govern the path to provide a new intelligibility

[1] In this perspective I basically agree with the distinction between epistemic and non-epistemic values as limpidly depicted in Steel (2010). In chapter eight I will illustrate how, in recent times, various kinds of what I call epistemic irresponsibility are precisely jeopardizing the efficiency of these "epistemic weapons".

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 sum, I will illustrate that there is no substantial need of reframing—in the new complicated lexicon of fictions (and of the related metaphors)—what is already well-known thanks to the tradition of philosophy of science. We have to remorselessly come back to Newton's famous motto "hypotheses non fingo", which has characterized for centuries the spirit of modern science: "I have not as yet been able to discover the reason for these properties of gravity from phenomena, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterwards rendered general by induction" (Newton 1999, p. 493).

2.2 Models Are Not Fictions. The Inconsistency of the Argument of Imperfect Fit

Should scientific models be regarded as works of fictions? At the beginning of the previous section I said that models, both in scientific reasoning and in human perception, are neither mere fictions, simple surrogates or make-believe, nor they are unproblematic idealizations; in particular, models are—when we adopt a perspective informed by the distributed cognition framework—never abstract, contrarily to the received view. Let us outline in this section the first problem, related to the *fictionalist* nature of models. I will return to this problem in Sect. 2.3, in which also the problem of the *abstractness* of models will be deeply illustrated: as for now we can note that, in a philosophical naturalistic framework, where all phenomena and thus also cognition, gain a fundamental eco-physical significance, models are always material objects, either when we are dealing with concrete diagrams, physical or computational models, or when we face human "mental models", which at the end "are" particular, unrepeatable, but ever-changing configurations and transformations of neural networks and chemical distributions at the level of human brains. Indeed, defending in this chapter an interdisciplinary approach we are simply re-engaged in one of the basic tenets of the philosophical mentality, now enriched by a naturalistic commitment, which acknowledges the relevance of scientific results of cognitive research.

If, ontologically, models are imaginary objects in the way objects of fictions are imaginary objects, I cannot see them as situated in any "location" different from the

brain, so that they are imaginary in so far as they are just "mental" models. As Giere contends:

> In spite of sharing an ontology as imagined objects, scientific models and works of fiction function in different cultural worlds. One indication of this difference is that, while works of fiction are typically a product of a single author's imagination, scientific models are typically the product of a collective effort. Scientists share preliminary descriptions of their models with colleagues near and far, and this sharing often leads to smaller or larger changes in the descriptions. The descriptions, then, are from the beginning intended to be public objects. Of course, authors of fiction may share their manuscripts with family and colleagues, but this is not part of the ethos of producing fiction. An author would not be professionally criticized for delivering an otherwise unread manuscript an editor. Scientists who keep everything to themselves before submitting a manuscript for publication are regarded as peculiar and may be criticized for being excessively secretive (Giere 2009, p. 251).

Moreover, to consider models as fictions would destroy the well regarded distinction between science and science fiction. This attitude can present cultural dangers: is science just a matter of fictions? Both kinds of fictions (scientific and literary) certainly provide insights on something "real", that is they aim at *representing* aspects of the world (for example *War and Peace*, Giere says, provides insight into the "human condition") but often various genres of literary fictions are simply finalized to entertain. Even if both contain imaginary objects, the processes that govern their formation and what from them is derived are very dissimilar, as I will further describe in Sect. 2.3. Representation in science is always related to criteria of scope, accuracy, precision and detail—Giere says—and further notes: "Remember the many models that were proposed and rejected in the race for the double helix because they failed adequately to represent the structure of DNA molecules. In the realm of fantasy, such criticisms are not appropriate. It is no criticism of the Harry Potter novels that there is no community of genuine wizards. Nor is it a criticism of War and Peace that its main characters did not exist" (Giere 2009, p. 252). The fact that a scientific model, relating to the "real" world, seems to be a fiction—that is to say, the fact it does not perfectly fit to any real system—does not authorize us to regard the overall model as a work of fiction, because it does not function like a work of fiction such as novels or so.

Finally, I strongly agree with Giere that "In fact, the argument from imperfect fit to a functionally fictional status for models proves far too much" (Giere 2009, p. 254), because it is typical of every cognition the involvement of ideal categorization and schematization, so that most of what everyone thinks and perceives should be regarded as fictional:

> It seems to me that the assimilation of scientific models to works of fiction presupposes an exaggerated conception of nonfiction. On this conception, a genuine work of nonfiction has to provide "the truth, the whole truth, and nothing but the truth". Thus, the realization that scientists are mostly in the business of constructing models that never provide a perfect fit to the world leads to the unwarranted conclusion that scientists are in the business of producing fictional accounts of the world (cit.)

Mizrahi (2011) seems to support—in the linguistic perspective about the role of "facticity" in scientific cognition—a similar point of view about the coherence of

seeing scientific "idealized" models as "quasi-factive": "[…] if [scientific] understanding is (quasi) factive, then we can attribute this sort of cognitive success to scientists when they employ idealizations, such as the Ideal Gas Law, precisely because they mirror the facts to some extent. That is to say, in the case of the Ideal Gas Law, it is precisely because of the agreement between the predictions of the gas laws and the behavior of gases (under specified conditions of temperature and pressure) that we attribute cognitive success to scientists in this case. Otherwise, it seems, we would say that scientists don't understand the behavior of gases at all".

The problem is that models help reach success in experimental outcomes, because they instead fit to designated aspects of the world:

> […] the view that scientific models are ontologically like works of fiction in being imaginary creations not only does not uniquely support fictionalism, but is compatible with a moderate realism. There is nothing in this notion of a scientific model that prevents identifying elements of models with things traditionally classified as "unobservable". On the other hand, as discussed earlier in this chapter, some elements of models may not be identified with anything in the world (cit., p. 256).

(Mizrahi 2011)

I confess that I would not encourage epistemologists to engage in debates about "realism" against "fictionalism", or about problems like "is fictionalism compatible with realism?" etc. (Suárez 2010), because the adoption of these old pre-Kantian categories is in my opinion philosophically sterile. After all, the same discussions about a privileged *level* of reality (able to demarcate everything else, for example "fictions") could be easily substituted by an equally coherent view about the consistency of various *levels* of reality, where the referents of fictions could be easily included.

It is not that "fictions provide inferential shortcuts in models; and the fact that this is the main or only reason for their use distinguishes them as fictional" (Suárez 2010, p. 239), even if Vaihinger would agree with this functionalist perspective on fictions.[2] Indeed, even if it is not decisive to say "that the inferential characterisation provides a way to distinguish precisely scientific from non-scientific uses of fiction", models used in non-scientific practices may also trigger inferences, and the problem here is more fundamental. In science, models are not used and intended as fictions, they are just labeled as fictions because of a juxtaposition of some recent philosophers of science, who certainly in this way render the scientific enterprise more similar to other more common modes of human cognition: after all fictions are ubiquitous in human cognition, and science is a cognitive activity like others. Unfortunately science never aimed to provide "fictions" at the basic levels of its activities, so that the recent fictionalism does not add new and fresh knowledge about the status of models in science, and tends to obfuscate the distinctions between different areas of human

[2] Suárez's approach to scientific models as fictions is actually more sophisticated than it may appear from my few notes. Basically, Suárez does not defend the view according to which models are fictions: even if he defends the view that models contain or lead to fictional assumptions, he explicitly rejects the identification of models and fictions, preferring instead to stay "quietist" about the ontology of models, and focusing rather on modeling as an activity—see in particular his introduction to the 2009 Routledge volume he edited entitled *Fictions in Science* (Suárez 2009b).

cognition, such as science, religion, arts, and philosophy. In the end, "epistemic fictionalism" tends to enforce a kind "epistemic concealment", which can obliterate the actual gnoseological finalities of science, shading in a kind of debate about entities and their classification that could remind of medieval scholasticism.[3]

2.3 Models Are Distributed

At the beginning of the previous section I advanced the hypothesis that models, both in scientific reasoning and in human perception, are neither mere fictions, simple surrogates or make-believe, nor they are unproblematic idealizations, and I also specifically contended that models are never *abstract* or *ideal*, contrarily to the received view: they do not live—so to say—in a kind of mysterious Popperian *World 3*. Let us deepen this second problem concerning the abstract and ideal nature of models in scientific reasoning.

First of all, within science the adopted models are certainly constructed on the basis of multiple constraints relating to the abstract laws, principles, and concepts, when clearly available at a certain moment of the development of a scientific discipline. At the same time we have to immediately stress that the same models are always *distributed* material entities, either when we are dealing with concrete diagrams or physical and computational models, or when we face human "mental models", which at the end are indeed particular, unrepeatable, and ever-changing configurations and transformations of neural networks and chemical distributions at the level of human brains. In this perspective we can say that models are "abstract" only in a special cognitive sense, that is as "mental models", shared to different extents by groups of scientists, depending on the type of research community at stake.

I contend that the so-called "abstract model" can be redescribed 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). Of course the internal representation presents slight differences in each individual's brain, but this does not impede that the various specific representations are clearly thought to be "abstract" insofar as they are at the same time "conceived" as referring to a unique model. This model, at a specific time, is considered "manifest", in an atmosphere of common understanding. Nevertheless, *new* insights/modifications in the internal manifest model usually occur at the individual level, even if the approach to solve a determinate problem through the model at stake is normally shared by a

[3] I will reconsider the demarcation problem in Sect. 3.2.1 of the following chapter.

specific scientific collective: the singular change can lead to the solution of the problems regarding the target system and so foster new understanding.[4] However, new insights/modifications can also lead to discard the model at stake and to build another one, which is expected to be more fruitful and which possibly can become the new manifest model. Moreover, some shared manifest models can reach a kind of stability across the centuries and the scientific and didactic communities, like in the case of the ideal pendulum, so that they optimally reverberate the idea of high "abstractness" of scientific models.

If we comply with a conception of the mind as "extended", 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[5] to the external world that the mind itself has made throughout the history of culture by constructing the so-called cognitive niches.[6] Consequently, as I have already anticipated few lines above scientific models 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 problem of the role of models in the dynamics of 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.[7] These models are clearly recognized as external systems—external artifacts more or less intentionally prepared and manipulated, exactly like concrete diagrams in the case of ancient geometry—interacting with the internal corresponding models of the researchers,

[4]The analytic literature on scientific models has recently clearly acknowledged both the role of scientific models in extended/distributed cognition but also their related capacity to favor "understanding". The increase of explanatory inferential ability—which favors understanding—can in turn be broken down along different dimensions of explanatory power: non-sensitivity, precision, factual accuracy, degree of integration, and cognitive salience: "The explanatory power of the model, and consequently the amount and type of understanding it can provide, amounts to the number and importance of these inferences it enables. […] Understanding the model and understanding with the model should be kept" (Kuorikoski and Ylikoski 2015, p. 3834). Toon (2015, p. 3874) too exploits extended cognition to propose a new gracious view of the nature of understanding: "Understanding is not always in the head. Instead, it involves brain, body and world". Finally, on the problem of degrees of understanding of phenomena and its relationship with explanationist and manipulationist interpretation cf. the rich (Kelp 2015, p. 3794).

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

[6]I introduced this concept in the previous chapter, Sect. 1.4.1.

[7]An analysis of the differences between models in biology and physics and of the distinction between natural, concrete, and abstract models from a traditional epistemological perspective is illustrated in Rowbottom (2009). A comparison between experiments as commonly thought to have epistemic privilege over simulations provided by models is given by Parke (2014). The importance of the different roles played in science by thought experiments, simulations, and computer simulations is further studied in El Skaf and Imbert (2013), taking advantage of a unique conceptual framework.

and they aim at generating new concepts and control structures regarding target systems.[8] I have to note that manipulative abduction—that is reasoning to hypotheses I have introduced in Sect. 1.3 of the previous chapter—also happens when we are more or less unintentionally *thinking through doing* (and not only, in a pragmatic sense, about doing). This kind of action-based cognition can hardly be intended as completely intentional and conscious.

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[9] (and the relative established conventionality) performed by the model builder(s): artificial languages, proofs, new figures, examples, computational simulations, and so new "affordances" etc. I have more deeply illustrated the concept of cognitive delegations to external artifacts in (Magnani 2009, chapter three, Sect. 3.6), stressing how formats also matter in the case of external hypothetical models and representations, and how they provide different affordances and inferential chances, cf. (Vorms 2010). Roughly speaking affordances—a concept famously introduced by Gibson (1979)—present to humans and animals various opportunities for action.[10]

It is obvious that the information (about 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 illustrated in my book on abductive cognition.[11] 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.[12] Moreover, given the fact that judgments in perception are fallible but

[8] Thomson-Jones (2012) too acknowledges, even if in the framework of an analytic scenario, not indebted to cognitive science, the importance of "concrete" models, and establishes a novel and useful distinction between mathematical and non-mathematical models together with the concept of "propositional model".

[9] The semiotic (iconic) status of models—in general—has also been extensively acknowledged by the recent analytic literature, cf. for example Kralemann and Lattmann (2013), who amply illustrate a Peircean-based approach. As also observed by the authors, the semiotic theory of models seems to contribute to the solution of the "ontological puzzle" of models.

[10] Actually the concept is much more complicated also illustrating its relationship with abductive cognition and cognitive niches..

[11] The complicated analysis of some seminal Peircean philosophical considerations concerning abduction (which refers to all the cognitive processes that lead to hypotheses), perception, inference, and instinct, which I consider are still important to current cognitive and epistemological research, is provided in Magnani (2009, Chap. 5).

[12] A detailed treatment of this issue is given in the article "Vision, thinking, and model-based inferences" Raftopoulos (2017), published in the *Handbook of Model-Based Science* (Magnani and Bertolotti (2017)).

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 perceptual 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 at p. 38), so that model-based cognition is in this case 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 2012, 2017), and (Bertolotti 2012)), such as scientists.[13] Finally, if perception cannot be wrong, given the fact that judgments in perception are fallible but indubitable abductions, as I have just illustrated, then these judgments should not be regarded as *fictional*.

2.4 Perception-Action Common Coding as an Example of "On-line" Manipulative Abduction

The cognitive mechanism carefully exploited and illustrated in (Chandrasekharan 2009) takes advantage of the notion of *common coding*,[14] 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 mechanism that coordinates action and movements in the world: we can see this process as an example of "on-line"—where the interplay between internal and external aspects is fundamental—manipulative abduction. Common coding hypothesizes

[13] 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).

[14] "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.

> […] 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 that shared "manifest model" I have illustrated above), 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. Not only both data and theoretical adopted hypotheses, but also the intermediate steps between them—i.e. for 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[15] 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. 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 I always made when speaking of the case of abduction: cognition is basically *multimodal*;

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.[16]

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 we can use "as they stand", which can be for example exemplified thanks to an analogy between models and externalized mathematical symbols and their so-called "semantic opacity": "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. Indeed 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

[15] 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.

[16] In a perspective that does not take into account the results of cognitive science but instead adopts the narrative/literary framework about models as make-believe, Toon (2010) too recognizes the role of external models in perturbing mental models to favor imagination: "Without taking a stance in the debate over proper names in fiction, I think we may use Walton's analysis to provide an account of our prepared description and equation of motion. We saw […] that these are not straightforward descriptions of the bouncing spring. Nevertheless, I believe, they do represent the spring, in Walton's sense: they represent the spring by prescribing imaginings about it. When we put forward our prepared description and equation of motion, I think, those who are familiar with the process of theoretical modelling understand that they are to imagine certain things about the bouncing spring. Specifically, they are required to imagine that the bob is a point mass, that the spring exerts a linear restoring force, and so on" (p. 306).

by Abraham Robinson (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.

De Cruz and De Smedt call this property of symbols that represent non-intuitive concepts and remain partially semantically inaccessible to us "semantic opacity". It renders them underdetermined, allowing further creative processes where those same symbols can be relatively freely exploited in novel contexts for multiple cognitive aims. Semantic opacity favors a kind of reasoning that is unbiased by those intuitive aspects that possibly involve stereotypes or intended uncontrolled interpretations, typical of other less opaque external models/representations.

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",[17] 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 at stake, 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).

2.5 Model-Based Ignorance

An interesting issue recently introduced in the epistemological debate is concerned with the role of ignorance in cognition and its relationship with scientific modeling.[18] Elliott (2012, p. 333) notes that Alfred North Whitehead (Whitehead 1925) was already completely aware of the abstracting role of scientific models generated by the need of focusing only on specific features of a phenomenon. Whitehead said that scientists and philosophers tend to assume that their simplified abstractions adequately capture all the nuances of the phenomenon and dubbed this mistake

[17] It is not surprising to find in recent analytic academic articles about models in science the reference to the concept of imagination: for example Levy nicely stresses that modeling is not only the representation of target phenomena, but is also intimately linked to the imagination, "[…] we utilize the imagination as a means of describing and reasoning about a real-world object. […] models are imaginative descriptions of real-world phenomena" (Levy 2015, pp. 791 and 797). Also Meynell (2014, p. 4149) stresses the imaginative role of those particular kinds of models that are the thought experiments.

[18] On ignorance and epistemic irresponsibility see Chap. 8, Sect. 8.5.

the "Fallacy of Misplaced Concreteness", because it is characterized by the false assumption that abstractions accurately mirror all the details of concrete phenomena.

Gross, treating the problem of modeling in multiple scales in biology usefully observes that

> The process of what I have called "selective ignorance" leads to decisions as to what is included in constructing or utilizing a model, and what is left out. Indeed, part of the art of modeling is choosing what to exclude and what to include. This art involves general decisions of model type: conceptual, quantitative, physical (e.g., real, such as a physical model for an animal to evaluate heat-loading), and biological (including animal models used for experiments, cell lines, and tissue cultures). The question focused upon here concerns whether there are some general methods to evaluate the utility of these quite different forms of models (Gross 2013, p. 74).

We know that scientific models are created *ad hoc* (that is they are creatively abduced) or simply chosen (through selective abduction) from an encyclopedia of pre-stored ones. Indeed it is important to note that this cognitive process is characterized by an activity of model evaluation that regards epistemological utility with respect to the scientific objectives of a model—and the criteria for model adoption and acceptance—which are not always explicit and may vary from highly quantitative to qualitative: "Models are constructed for a diverse array of objectives including: *descriptive*, in which the model is intended to summarize a set of observations; *mechanistic*, in which the model is intended to explicate patterns based upon hypothesized mechanisms; *predictive*, in which the model is applied to predict system response perhaps to alternative treatments; and *control*, in which the model is used to manage the system perhaps based upon some optimization criteria and constraints. These are often not independent since many models are hierarchical in structure, with some mechanistic components based upon descriptive submodels" (Gross 2013, p. 75).

Further, model evaluation can be characterized by some model *testing*, using statistics or comparison with other models, but also by model *flexibility* (how the model may be applied to disparate problems), *feasibility* (how model is easily available for the application at stake), and *applicability* (how the model parameters may be quickly estimated). Given the fact developing scientific models needs considerable effort, it is not frequent to see them criticized in scientific papers, also because this would be a threat to the cohesion of the collective of scientists that work in the lab; not only, many models are computational and their complexity is an obstacle to criticisms, because it is difficult to know or to detect their internal ways of functioning, also on the part of peers and reviewers.

What is important to note at the end of this chapter is that scientific models not only are ways of abstracting and idealizing. They are also triggers of selective ignorance: the abduction of a certain scientific model inclines research in a specific direction, they hide some aspects or prevent the acquisition of relevant information (a simple example is represented by their constraining data collection to guide theory development in a certain direction) (cf. (Elliot 2012)).

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Chapter 3
Not Everything in Scientific Cognition Is Evidence-Based

The Epistemology of Evidentially Inert Knowledge Enhancing

Peirce provides various justifications of the knowledge enhancing role of abduction, even when abduction is not considered an inference to the best explanation in the classical sense of the expression, that is an inference necessarily characterized by an empirical evaluation phase, or inductive phase. In Chap. 1 I have illustrated the justifications which basically resort to the conceptual exploitation of *evolutionary* and *metaphysical* ideas, which clearly show that abduction is constitutively akin to truth, even if certainly always ignorance-preserving or mitigating in the sense that the "absolute truth" is never reached through abduction. In this chapter other justifications are described: (1) in empirical science abducing *conventions* favors and increases knowledge even if these hypotheses remain evidentially inert—at least in the sense that it is not possible to empirically falsify them. Consequently abduced conventions are evidentially inert but knowledge enhancing at the rational level of science; (2) in science we do not have to confuse the process of abducing models with the process of abducing fictions: the recent epistemological conundrum concerning fictionalism helps us to see, on the contrary, that models abduced by scientists reveal themselves not to be "airy nothings" at all (cf. the epigraph I have added to the present book), and certainly different in their gnoseological status from literary fictions. Scientific models instead play fundamental "rational" knowledge enhancing roles: in a static perspective (for example when inserted in a textbook) scientific models can appear fictional to the epistemologist, but their fictional character disappears if a dynamic perspective is adopted, as I will further elaborate in the following chapter. Abduction in scientific model-based reasoning is not a suspicious process of guessing fictions.

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3.1 The Epistemology of Evidentially Inert Knowledge-Enhancing: Guessing Conventions in Science

After having illustrated in the previous chapter the philosophical and evolutionary justifications provided by Peirce to substantiate the truth-reliability of abductive cognition, some actual examples of knowledge-enhancing abductions active in science, that nevertheless are evidentially inert,[1] have to be exhibited. To this aim the epistemological problem of guessing conventions and of guessing models in science will be illustrated in this and in the following section.

We will now consider some aspects dealing with Poincaré's famous conventionalism of the principles of physics and the possibility of negating conventions. We will soon see that even if conventions in science are abduced and accepted, and their presence favors and increases knowledge, they are nevertheless not evidentially-sensitive, so to say—at least in the sense that it is not possible to empirically falsify them. Consequently abduced conventions are evidentially inert but knowledge-enhancing.

Gabbay and Woods maintain we can face a kind of abduction that, basically,

- is not plausibilist

at least in the sense of the word plausibilist indicated by the classical models provided in the literature. They say: "It is not uncommon for philosophers to speak of the contribution made by the hypothesis of action-at-a-distance as one of explaining otherwise unexplainable observational data. […] Like numerous instances of D-N explanation, Newtonian explanations need convey no elucidation of their explicanda. They need confer no jot of further intelligibility to them. The action at-a-distance equation serves Newton's theory in a wholly instrumental sense. It allows the gravitational theory to predict observations that it would not otherwise be able to predict" (Gabbay and Woods 2005, pp. 118–119). In my first book on abduction (Magnani 2001) I made some examples of abductive reasoning that basically are instrumental without clearly acknowledging it. Later on I have adopted this concept in (Magnani 2009, Chap. 2): in this book I noted that for example in this case Newtonian explanations are seen as epistemically agnostic conjectures, that is they lack the classical epistemic virtues envisaged by the neopositivistic tradition. These abductions are secured by instrumental considerations and accepted because doing so enables one's target to be hit. They cannot be discharged because of their possible implausibility, and on the basis of empirical disconfirmation.

From the point of view of a radical instrumental abduction this example is striking because it shows how these abduced principles fail all tests that would reveal them as having a traditional epistemic value, so that they are not subject to discharge except for their instrumental value. Again we are dealing with abductive cognitive fruits that are not strictly ignorance-preserving, and that not only mitigate ignorance but also provide further reliable knowledge.

[1] That is not inferences to the best explanation in the classical sense of the expression, involving an empirical evaluation phase.

An extension of Poincaré's so-called *geometric conventionalism*, according to which the choice of a geometry is only justified by considerations of simplicity, in a psychological and pragmatic sense ("commodisme"), is the *generalized conventionalism*, expressing the conventional character of the principles of physics:

> The principles of mathematical physics (for example, the principle of conservation of energy, Hamilton's principle in geometrical optics and in dynamics, etc.) systematize experimental results usually achieved on the basis of two (or more) rival theories, such as the emission and the undulation theory of light, or Fresnel's and Neumann's wave theories, or Fresnel's optics and Maxwell's electromagnetic theory, etc. They express the common empirical content as well as (at least part of) the mathematical structure of such rival theories and, therefore, can (but need not) be given alternative theoretical interpretations (Giedymin 1982, pp. 27–28).

From the epistemological point of view it is important to stress that these abductively hypothesized conventional principles usually survive the demise of theories and are therefore responsible for the continuity of scientific progress: in a sense they show a radical instrumental character. Evidence from history of science, for example in the case of Mayer's establishment of the principle of conservation of energy (Coopersmith 2010), shows that conventional principles are usually fruit of complicated abductive processes and not of simple inductive generalizations. Moreover, they are not empirically falsifiable; as stated by Poincaré in *Science and Hypothesis*.[2]

Poincaré says "we have a right to make" these conventions, and so their abduction is instantly knowledge-enhancing.

> The principles of mechanics are therefore presented to us under two different aspects. On the one hand, they are truths founded on experiment, and verified approximately as far as almost isolated systems are concerned; on the other hand they are postulates applicable to the whole of the universe and regarded as rigorously true. If these postulates possess a generality and a certainty which the experimental truths from which they were deduced lack, it is because they reduce in final analysis to a simple convention that we have a right to make, because we are certain beforehand that no experiment can contradict it. This convention, however, is not absolutely arbitrary; it is not the child of our caprice. We admit it because certain experiments have shown us that it will be convenient, and thus is explained how experiment has built up the principles of mechanics, and why, moreover, it cannot reverse them (Poincaré 1902, pp. 135–136).

Following Poincaré we can say that conventional principles of mechanics derive abductively from experience, as regards their "genesis", but cannot be falsified by experience because they contribute to "constitute" the experience itself, in a proper Kantian sense. The experience has only suggested their adoption because they are *convenient*: there is a precise analogy with the well-known case of geometrical conventions, but also many differences, which pertain the "objects" studied.

The conventional principles of mechanics should not be confused with geometrical conventions: "The experiments which have led us to adopt as more convenient the fundamental conventions of mechanics refer to bodies which have nothing in common with those that are studied by geometry. They refer to the properties of

[2]Poincaré says that these principles are "deduced" from experimental truths, but it is unlikely to think of them as fruit of deduction instead of abduction. I think that the use of the word deduction is just a way adopted by Poincaré to refer to a generic kind of scientific inference.

solid bodies and to the propagation of light in a straight line. These are mechanical, optical experiments" (Poincaré 1902, pp. 136–137) they are not, Poincaré immediately declares, "*des expériences de géométrie*" (ibid.): "And even the probable reason why our geometry seems convenient to us is, that our bodies, our hands, and our limbs enjoy the properties of solid bodies. Our fundamental experiments are preeminently physiological experiments which refer, not to the space which is the object that geometry must study, but to our body—that is to say, to the instrument which we use for that study. On the other hand, the fundamental conventions of mechanics and experiments which prove to us that they are convenient, certainly refer to the same objects or to analogous objects. Conventional and general principles are the natural and direct generalisations of experimental and particular principles" (ibid.)

Poincaré continues:

> Principles are conventions and definitions in disguise. They are, however, derived from experimental laws, and these laws have, so to speak, been erected into principles to which our mind attributes an absolute value. Some philosophers have generalized far too much. They have thought that the principles were the whole of science, and therefore that the whole of science was conventional. This paradoxical doctrine, which is called nominalism, cannot stand examination. How can a law become a principle? (Poincaré 1902, p. 138).

If the experimental laws of experimental physics are the source of the conventional principles themselves, conventionalism escapes nominalism.

As stated at the beginning of this section, conventional principles survive the demise (falsification) of theories in such a way that they underlie the incessant spectacle of scientific revolutions: "It is the mathematical physics of our fathers which has familiarized us little by little with these various principles; which has habituated us to recognize them under the different vestments in which they disguise themselves" (Poincaré 1905, p. 95). Underlying revolutions of physics, conventional principles guarantee the historicity and the growth of science itself. Moreover, the conventional principles surely imply "[…] *firstly*, that there has been a *growing tendency* in modern physics to *formulate and solve* physical problems *within powerful, and more abstract, mathematical systems of assumptions* […]; *secondly*, the role of conventional principles has been growing and *our ability to discriminate experimentally between alternative abstract systems* which, with a great approximation, save the phenomena *has been diminishing* (by comparison to the testing of simple conjunctions of empirical generalizations)" (Giedymin 1982, p. 28).

Moreover, as stated above, they are not empirically falsifiable: "The principles of mechanics […] reduce in final analysis to a simple convention that we have a right to make, because we are certain beforehand that no experiment can contradict it" (Poincaré 1902, p. 136).

Up to now I have considered in details how the conventional principles guarantee the revolutionary changes of physics and why they cannot be considered arbitrary, being motivated by—and abduced from—the *experimental laws* of the "experimental physics", that is by experience. Even if arbitrary and conventional, the conventional principles too can be substituted by others. This is the main problem treated by Poincaré in the last passages of Chap. 9, "The Future of Mathematical Physics", in *The Value of Science*. Already the simple case of "linguistic" changes in science

"[…] suffices to reveal generalizations not before suspected" (Poincaré 1905, p. 78). By means of the new abductive discoveries, scientists arrive at a point where they are able to "[…] admire the delicate harmony of numbers and forms; they marvel when a new discovery opens to them an unexpected perspective" (Poincaré 1905, p. 76) a new perspective that is always provisional, fallible, open to further confirmations or falsifications when compared to rival perspectives.

We have seen how the conventional principles of physics guarantee this continuous extension of experience thanks to the various perspectives and forms expressed by experimental physics. However, because conventional, "no experiment can contradict them". The experience only abductively suggested the principles, and they, since absolute, have become constitutive just of the empirical horizon common to rival experimental theories. These principles, even if abductively hypothesized just for strategic/instrumental reasons as important not ad hoc conventions, represent an interesting example of knowledge-enhancing abduction evidentially inert: we have seen how the conventional principles of physics guarantee the continuous extension of experience thanks to the various perspectives and forms expressed by experimental physics and they cannot be dismissed on the basis of experimental tests.

3.1.1 Dismissing Conventions

Poincaré observes:

> Have you not written, you might say if you wished to seek a quarrel with me – have you not written that the principles, though of experimental origin, are now unassailable by experiment because they have become conventions? And now you have just told us that the most recent conquests of experiment put these principles in danger. Well, formerly I was right and today I am not wrong. Formerly I was right, and what is now happening is a new proof of it (Poincaré 1905, p. 109).

Poincaré appeals to a form of weak negation. Let us follow the text. To pursue his point, Poincaré illustrates the attempts to reconcile the "calorimetric experiment of Curie" with the "principle of conservation of energy":

> This has been attempted in many ways; but there is among them one I should like you to notice; this is not the explanation which tends to-day to prevail, but it is one of those which have been proposed. It has been conjectured that radium was only an intermediary, that it only stored radiations of unknown nature which flashed through space in every direction, traversing all bodies, save radium, without being altered by this passage and without exercising any action upon them. Radium alone took from them a little of their energy and afterward gave it out to us in various forms (Poincaré 1905, pp. 109–110).

At this point Poincaré resolutely asserts: "What an advantageous explanation, and how convenient! First, it is unverifiable and thus irrefutable. Then again it will serve to account for any derogation whatever to Mayer's principle; it answers in advance not only the objection of Curie, but all the objections that future experimenters might accumulate. This new and unknown energy would serve for everything" (p. 110).

Now Poincaré can show how this ad hoc hypothesis can be identified with the non-falsifiability of the conventional principle of the conservation of energy:

> This is just what I said, and therewith we are shown that our principle is unassailable by experiment. But then, what have we gained by this stroke? The principle is intact, but thenceforth of what use is it? It enabled us to foresee that in such and such circumstance we could count on such total quantity of energy; it limited us; but now that this indefinite provision of new energy is placed at our disposal, we are no longer limited by anything (Poincaré 1905, p. 110).

Finally, Poincaré's argumentation ends by affirming negation as failure[3]: "[…] and, as I have written in 'Science and Hypothesis', if a principle ceases to be fecund, experiment without contradicting it directly will nevertheless have condemned it" (ibid.).

Let us now analyze this situation from the logico-epistemological point of view: the conventional principle has to be withdrawn when it "ceases to be fecund" and so because it is no longer endowed with an acceptable degree of *strategical plausibility*, or when it seems that we have failed to prove it. It is clear that the principle exhibits in this case a kind of strategic, rather than propositional, plausibility. Remember that for a logic database the assumption is that an atomic formula is false if we *fail* to prove that it is true. More clearly: as stated above, every conventional principle, suitably underlying some experimental laws, generates *expectations* with regard to the subsequent evidences of nature. I analogously consider as the proof of a conventional principle the fact that we can increasingly *extend* and complete the experimental laws related to it, adding the new (expected) evidence that "emerges" from the experimental research. If, after a finite period of time, nature does not provide this new "evidence" that is able to increase the fecundity of the conventional principle, this *failure* leads to its withdrawal: "[…] if a principle ceases to be fecund, experiment without contradicting it directly will nevertheless have condemned it". The "proof that a principle is not provable"[4] is the unsuccessful search for a proof of the principle itself. Here too, the logical symbol ¬ acquires the new meaning of "fail to prove" in the empirical sense.

Let us resume: if the old conventional principle does not produce new experimental "evidence" to underpin it, it is legitimate to abandon the principle, when convenient:

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[3]Computer and AI scientists have suggested an interesting technique for negating hypotheses and accessing new ones: negation as failure (Clark 1978). I consider this kind of logical account of negation, studied by researchers into logic programming, to be very important also from the epistemological point of view. Negation as failure is active as a "rational" process of withdrawing previously-abduced hypotheses in everyday life, but also in certain subtle kinds of diagnostic (analytic interpretations in psychoanalysis—cf. Chap. 4, Sect. 4.2, this book) and other epistemological settings. Contrasted with classical negation, with the double negation of intuitionistic logic, and with the philosophical concept of *Aufhebung* (Toth 1991), negation as failure shows how a subject can decide to withdraw her hypotheses, while maintaining the "rationality" of her argumentations, in contexts where it is impossible to find contradictions or falsifications. Negation as failure in query evaluation process for a logical database is more extensively illustrated in (Magnani 2009, Chap. 2).

[4]Please keep in mind I am making an analogy between "not provable" and "not empirically fecund".

the opportunity to reject the old principle will happen just by exploiting the experimental evidence which, even if not suitable for contradicting it (Poincaré says, it is "unassailable by experiment"), is nevertheless suitable as a basis for conceiving a new alternative principle, generated by new creative abductions.

We can now interpret Popper's ideas about conventionalism in a different way. Popper writes: "Thus, according to the conventionalist view, it is not possible to divide systems of theories into falsifiable and non-falsifiable ones; or rather, such a distinction could be ambiguous. As a consequence, our criterion of falsifiability must turn out to be useless as a criterion of demarcation" (Popper 1959, p. 81). In the light of Poincaré's theory of the principles of physics that we have just illustrated, the nominalistic interpretation of conventionalism given by Popper (see also Popper 1963) appears to be very reductive. Moreover, Popper's tendency to identify conventions with ad hoc hypotheses (a very bad kind of auxiliary hypotheses) is shown to be decidedly unilateral, since, as is demonstrated by the passages, immediately above, the *adhocness* is achieved only in a very special case, when the conventional principle is epistemologically exhausted.

In some sense Poincaré was already aware of the following fact, subsequently clearly acknowledged by Popper: the introduction of auxiliary hypotheses must not diminish the degree of falsifiability or testability (that will have to be performed by means of "severe tests") of the scientific theory in question, but, on the contrary, *should increase it* (Popper 1959, p. 83). The example of an unsatisfactory (ad hoc) auxiliary hypothesis given by Popper is the "[…] contraction hypothesis of Fitzgerald and Lorentz which had no falsifiable consequences but merely served to restore the agreement between theory and experiment—mainly the findings of Michelson and Morley" (Popper 1959, p. 83).

In turn Lakatos' revision of falsificationism in terms of the theory of research programs (Lakatos 1970) has definitely established that modified hypotheses (by means of auxiliary assumptions) have to be more falsifiable than the original versions, they have to lead to new testable consequences (and, moreover, independently testable, to use Popper's phrase—(Popper 1959, p. 193)); progress in "scientific programs" is heavily related to the existence of novel predictions: one program is superior to another insofar as it is a more successful predictor of novel phenomena.

Something analogous—but in a more *indirect* way—operates in the case of the conventional principles described by Poincaré: it seems that conventionalism, at least in the Poincaré's case, does not treat all conventional hypotheses like "stratagems", as maintained by Popper. Hypothetical conventional principles are unfalsifiable and should be withdrawn only when exhausted, when their indirect production of "novel" evidence is finished. Consequently, Poincaré's conventionalism is not simply a theory of *adhocness*, in the nominalistic Popperian sense.

As regards instrumental[5] abduction my example of the conventional principles of physics shows a cognitive situation that Gabbay and Woods synthetically illustrate in the following way: "Proposition 5.7 (Discharging radically instrumental hypotheses)

[5] See Chap. 1, footnote 14.

Since the hypothesis of a radically instrumental abduction fails all tests that would reveal it as having the requisite epistemic value, such hypotheses are not subject to discharge except for their instrumental value" (Gabbay and Woods 2005, p. 120).

3.2 The Epistemology of Evidentially Inert Knowledge-Enhancing: Abducing Scientific Models Versus Abducing Fictions

At the end of Sect. 1.4 above (Chap. 1) I have reminded that abduction is guessing and that human beings are very good at it. I also contended that it is in the case of empirical science that abduction seems to better exhibit its more representative epistemic virtues. Moreover, in Sect. 1.4.1 I have shown the classical Peircean philosophical and evolutionary justifications of that dominant character of abduction which is called "ampliative" in the standard literature. Finally, in the previous subsection, I have illustrated the case of conventions, extremely important in physics, evidentially inert fruits of abduction—at least from the point of view of their impossible falsification—but nevertheless knowledge-enhancing. I will further examine in the present section that in science we do not have to consider the process of abducing models as a process of abducing fictions[6]: as the reader can easily guess, this clarification will be intertwined with the aim of individuating other knowledge-enhancing functions of abduction, even when clearly and immediately seen as evidentially inert.

Let us start with an example provided by Woods, who illustrates the case of Planck's abduction as a case in which the epistemologist could see an active function of the so-called "fictions":

> When in his quest for a unified treatment of the laws of black body radiation, Planck thought up the quantum hypothesis, it was a proposition for which there wasn't a shred of antecedent evidence and none at all abduced by its presence as antecedent in the subjunctive conditional on which its provisional conjecture was based. Planck thought that the very idea of the quantum was bereft of physical meaning. It is no condition on abductive adequacy that abduced hypotheses turn out well at experimental trial. There are more things whose truth was a reasonable thing to conjecture than actually turn out to be true. […] In some sense, the quantum hypothesis was down to Planck. Planck was the one who thought it up. Planck was the one who selected it for provisional engagement in a suitably adjusted physics. Some philosophers might see in these involvements a case for fictionalism (Woods 2013, p. 32).

"Planck was the one who thought it up", in this important creative event of the history of science.

Not only in the case of key hypotheses like the one proposed by Planck, but also in the case of *models* that are built as "epistemic mediators" inside a more extended process of scientific cognition, it is unlikely to admit they are abduced fictions, surely not in the minimal unequivocal sense of the word as it is adopted in

[6] I have firstly introduced the problem of epistemological fictionalism in the previous chapter.

the literary/narrative frameworks. Indeed, as I have already illustrated in the previous chapter, current epistemological analysis of the role models in science is often philosophically unproblematic and misleading. Scientific models are now not only considered as useful ways for explaining facts or discovering new entities, laws, and theories, but are also rubricated under various new labels: from the classical ones, abstract entities and idealizations, to the more recent, fictions, credible worlds, missing systems, as make-believe, parables, as functional, as epistemic actions, as revealing capacities.

Even if evidentially inert in themselves, I think that the abduced models, both in scientific reasoning and in human perception (cf. Chap. 1, Sect. 1.4.1), cannot be considered as neither mere fictions, simple surrogates or make-believe, nor they are unproblematic idealizations. I am neither denying that models as idealizations and abstractions are a pervasive and permanent feature of science, nor that models, which are produced with the aim of finding the consequences of theories—often very smart and creative—are very important. I just stress that the "fundamental" role played by models in science is the one we find in the core abductive discovery processes, and that these kinds of models cannot be indicated as fictional at all, because they are *constitutive* of new scientific frameworks and new empirical domains.[7] The abduction of these models in science is epistemically productive, models are just inert in the perspective of a *direct* empirical significance but they play a "causal" role in generating it: scientific models can be empirically false, but they are not fictions, instead they are knowledge-enhancing devices, which play an important role in reaching empirically fecund knowledge. It is clear here we are dealing with cases in which abduction is not ignorance-preserving.

Suárez (Suárez 2009) provides some case studies, especially from astrophysics and concerning quantum model of measurement, emphasizing the inferential function of the supposed to be "fictional" assumptions in models: I deem this function to be usually ancillary in science, even if often highly innovative. Speaking of Thomson's plum pudding model, Suárez maintains that, basically "The model served an essential pragmatic purpose in generating quick and expedient inference at the theoretical level, and then in turn from the theoretical to the experimental level. It articulated a space of reasons, a background of assumptions against which the participants in the debates could sustain their arguments for and against these three hypotheses" (p. 163). In these cases the fact that various assumptions of the models are empirically false is pretty clear and so is the "improvement in the expediency of the inferences that can be drawn from the models to the observable quantities" (p. 165)[8]: the problem is that

[7] In this last sense the capacity of scientific models to constitute new empirical domains and so new *empirical knowability* is ideally related to the emphasis that epistemology, in the last century, put on the theory-ladenness of scientific facts (Hanson, Popper, Lakatos, Kuhn): in this light, the formulation of observation statements presupposes significant knowledge, and the search for new observability in science is guided by scientific modeling.

[8] It has to be added that Suárez does not conflate scientific modeling with literary fictionalizing. He distinguishes scientific fictions from other kinds of fictions—the scientific ones are constrained by both the logic of inference and, in particular, the requirement to fit in with the empirical domain

in these cases models, however, are not fictions—at least in the minimal unequivocal sense of the word as it is adopted in the literary/narrative frameworks—but just the usual idealizations or abstractions, already well-known and well studied, as devices, stratagems, and strategies that lead to efficient results and that are not discarded just because they are not fake chances from the perspective of scientific rationality.[9] Two consequences derive:

- the role of models as "expediency of the inferences" in peripheral aspects of scientific research, well-known from centuries in science, does not have to be confused with the *constitutive* role of modeling in the central *abductive* creative processes, when new conceptually more or less revolutionary perspectives are advanced;
- models are—so to say—just models that idealize and/or abstract, but these last two aspects have to be criticized in the light of recent epistemologico/cognitive literature as related to special kinds of epistemic actions: abstractness and ideality cannot be solely related to empirical inadequacy and/or to theoretical incoherence (Suárez 2009, p. 168), in a static view of the scientific enterprise.

The considerations I have just illustrated show that model-based abduction in science is not truth preserving. Nevertheless, even if the guessed scientific models seem left in epistemic sufferance, as indicated by (Woods and Rosales 2010, pp. 375–376) (see also the following chapter, Sect. 4.2), given they lack of empirical plausibility, scientific models cannot be considered works of fictions. At this point it can be said that one thing is to abduce fictions, like in the case of creations in literature, another thing is to abduce models in empirical science. Abducing fictions in literature is also certainly knowledge-enhancing—like it is the case of scientific models—because we cannot surely imagine that literature does not provide knowledge of some kind. Moreover, how ignorance-preservation is at stake in these two cases? In the first case ignorance preservation is related to an *esthetic* failure—a fictional character can be a literary failure, discarded by the author herself—in the second one to the possible experimental discredit, which would lead to the consequent lack of *rational* success of scientific enterprise. Again, no need of using in the second case the word fiction: scientific models cannot be fictions.

However, we have also to remember that—normally—abductive processes to new concepts and models in literature and in science can also be seen as a *continuum*—a sequence—of guessed hypotheses: in both cases if the production of an intermediate abductive hypothetical model fails (and so it is abandoned), this step *could still be seen as a significant cognitive achievement* if it is useful to provide some *crucial* new information later on, useful to produce further "successful" hypotheses (for example to provide, respectively, Anna Karenina or Bohr' planetary model of the interior of atom). In this light we can say that the failed abductions were not completely

(Footnote 8 continued)
(Suárez 2009, 2010)—in the framework of an envisaged compatibility of "scientific fiction" with realism. This epistemological acknowledgment is not often present in other followers of fictionalism.

[9] I discussed the role of chance-seeking in scientific discovery in (Magnani 2007).

esthetically or epistemically inert, because they facilitated the subsequent processes of hypothesis generation until the successful one.

3.2.1 Dynamic Versus Static View of Scientific Models and the Revival of the Demarcation Problem

We have to further analyze in detail the process of abducing a sequence of possible hypotheses in a segment of scientific reasoning. This kind of process is often considered a *heuristic strategy*. For example, Hintikka stresses the strategic nature of abductive adoption of hypotheses inside a cognitive process:

> […] a strategic justification does not provide a warrant for any one particular step in the process. Such a particular step may not in any obvious way aid and abet the overall aim of the inquiry. For instance, such a step might provide neither any new information relevant to the aim of the inquiry nor any new confirmation for what has already been established, and yet might serve *crucially* the inquiry – for instance, by opening up the possibility of a question whose answer does so. Furthermore, notwithstanding the views of reliabilists, the idea of a nonstrategic justification that they choose is not only mistaken but in the last analysis incoherent. From the theory of strategic processes misleadingly labeled game theory, it is known that what can be valuated (assigned "utilities" to) are in principle only strategies, not particular moves. Hence a theory of epistemic processes that operates with "warrants" for particular belief changes or other things that can be said of particular moves in our "games" of inquiry is inevitably going to be unsatisfactory in the long run. One of the many things that Peirce's use of the term "hypothesis" can serve to highlight is precisely the strategic character of any justification of abduction. Being strategic, such justification does not per se lend any reliability to the outcome of some particular abductive inference. This outcome has the status of a hypothesis. Whatever reliability it may possess has to be established by the inductive component of inquiry (Hintikka 2007, pp. 57–58).

We can agree with Hintikka that it is certainly true that we cannot have "warrants" at the level of strategic justification of particular steps in the process, and that it is also obviously true that the reliabilists are wrong suggesting the idea of a non-strategic justification. In my perspective it is the conclusion provided by Hintikka that is not satisfactory: "Being strategic, such justification does not per se lend any reliability to the outcome of some particular abductive inference. This outcome has the status of a hypothesis. Whatever reliability it may possess has to be established by the inductive component of inquiry". Hence, for example in the case of a scientific model abductively guessed, we would have to conclude—following Hintikka—that it is not reliable to the outcome of the cognitive process, indeed we have to wait for the empirical "judgment". Does this mean that every abductive guess is damned to be ignorance-preserving if evidentially inert? I do not think so.

To solve this problem a remark about the need of avoiding a confusion between a static and a dynamic view of scientific cognition has to be addressed. Indeed I think it is misleading to analyze the activity of abducing models in science by adopting a confounding and unclear mixture of static and dynamic aspects of the scientific

enterprise. Temporal features of cognition count in understanding abduction. Scientific abduced models in a static perspective (for example when inserted in a textbook or in a text concerning history of empirical science) certainly appear—but just appear—justified "by the inductive component of inquiry", that is only in the light of the successful empirical evaluation that has been finally performed: in this case the *instrumental*—and fruitful—character of the abduced models becomes manifest, but their *constitutive* function disappears.

Please imagine that you are isolating a single moment of a dynamic creative scientific process, forgetting to pay attention to what happened or will happen later on, in the last case for example as it is testified in a historical narrative or in a textbook. Contrarily to the previous static view, some—the creative ones—of the abduced scientific models, once seen inside the living dynamics of scientific cognition[10] actually appear to be *explicit*, *reproducible*, and *constitutive* machineries built and manipulated to the gnoseological aim of reaching a final overall scientific result empirically evaluated, a result *not yet available*: but we have a result, the only result we have is the intermediate one, the model. The final knowledge just results not yet available because the target system and its complicated experimental apparatuses have *not yet* been built. The problem is that our snapshot of the "single moment" shows to us that these final outcomes will be built *only* thanks to the gift in terms of subsequent *knowability* provided by the intermediate models themselves. In few words: the models at play are *creative*, because they positively "establish" the root that leads to the empirical success. In a sense, their creativity "is" their reliability, they do not need further strategic or not strategic justification or warrants. If we do not acknowledge this—Kantian, I would say—aspect, we are not able to befittingly and honestly understand what abduction is as a knowledge-enhancing cognitive device.

When Hintikka contends that the abductive steps which lead to intermediate models *cannot* have "warrants" at the level of strategic justification, and also at the level of non strategic justification, in my perspective we can relieve ourselves of this burden of epistemic sufferance just acknowledging we are dealing with *creative* models. If we only see models in empirical science in the light of the future achieved empirical success we obviously see them just as *provisional* guesses, *devoid* of justification and still and intrinsically looking for it. On the contrary, they are occasionally justified by themselves—abductively—just because creative, and so *constitutive* of a fruitful epistemic "cognitive travel". In sum, coming back to the main issue we are dealing with in this chapter, those models are sometimes knowledge-enhancing at their level, even if *locally* evidentially inert.

Let us reconsider in this perspective the problem of models as fictions. If we consider that the abduced models—in science—are fictions they are certainly evidentially inert; unfortunately they would be also ignorance preserving, because they will lack, as fictions, the capacity to produce a kind of intermediate knowledge endowed with the *epistemological virtue* of rationality. Woods furnishes a further crucial insight on the superfluity of speaking of fictions in science adopting a useful

[10] Which, by the way, is the key topic of epistemology at least since Karl Popper and Thomas Kuhn.

distinction between what he calls infinite (forlon) falsehoods and fictions. Given the fact that fictions detonate[11] and infinite falsehoods do not, infinite falsehoods cannot be fictions. At the same time his strict argumentation provides a further justification of the knowledge-enhancing status of scientific models. He thinks that the detonation question for infinite falsehoods (for example models that involve infinite populations in biology, that, as I have already said, many epistemologists consider fictions) is

> […] a trick question. It is a logical commonplace that, unlike truth, falsity is not preserved under consequence. How surprising can it be, then, that when $T \vdash O_i$ holds, the falsity embedded in T is not passed on to the O_i? The very fact of T's empirical adequacy precludes the detonation of its falsities. It is precisely here that fictionality's explosiveness achieves a grip. Since detonation is not a problem for falsely tinctured T_s, fictions are not required to fix it. Yet if fictions were called into play, they would create a detonation problem for T, and would guarantee that it could not be solved. For, again, detonation precludes empirical adequacy. I take this to be a serious discouragement of the fictionalist programme for science (Woods 2013, p. 29).

Again, if the O_i of an empirically adequate T are not derivable

> […] in the absence of $T's$ infinitely remote falsehoods, then $T's$ connection to those O_i cannot be grounding. T cannot be said to have demonstrated those consequences or to have provided a reason that supports them. This is a puzzle. But suppose, now, that fictions were called into play with a view to solving it. Then T wouldn't be empirically adequate. (Fictionality detonates.) The grounding question asks how T can be empirically adequate if it doesn't lend grounding support to the O_i in virtue of which this is so. But if fictions are let loose here, the empirical adequacy of T is lost. The grounding question wouldn't arise (ibid.)

Finally, a problem arises and concerns the old-fashioned demarcation problem, emphasized by Popper. It is certainly not decisive to say that the inferential characterization of models provides a way to distinguish precisely scientific from non-scientific uses of fiction: I have noted above that models used in non-scientific practices may also trigger inferences, but the problem here is more profound. I said that science never aimed at abducing "fictions" at the basic levels of its activities: on the contrary recent fictionalism tends to hide the distinctions between different areas of human cognition, such as science, religion, arts, and philosophy. In the end, "epistemic fictionalism" tends to enforce a kind "epistemic concealment", which can obliterate the actual cognitive finalities of science. Abduction is certainly a widespread cognitive activity, as many studies demonstrate, and so it is also embedded in the activity of abducing models in various areas of research, but this huge extension paradoxically

[11] It is worth mentioning that the metaphor of "detonation" originated as a characterization of what happens when in an inconsistent theory ex falso is true. "Detonation" is also a catching play on the words of Russell's famous 1905 paper "On denoting", published in *Mind*. The phrase derives from Schotch and Jennings' contribution to the paraconsistency volume of 1989, edited by Priest, Routley and Norman, as a paper entitled "On detonating" (Schotch and Jennings 1989). The point they were making (quite rightly) is that if ex falso is true then negation detonates in inconsistent theories; their every sentence has a validly derivable negation. In Woods' appropriation of it in the passages I am quoting, the property that detonates is the property of being fictional.

furnishes a further reason for the philosopher, the epistemologist, and the cognitive scientist to study, differentiate, and respect the various types of knowledge, beliefs, and levels of truth and/or rationality more or less involved.

3.3 Mathematics, Deduction, and Manipulative Abduction

In this section I plan to illustrate some arguments devoted to further substantiate my analysis of the limitations of the ignorance-preserving view of abduction. Abduction patently enhances knowledge also in mathematics, where it is completely manifest that every successful abductive process is evidentially inert. Still in this case my *eco-cognitive model* (EC-model) of abduction is useful (cf. above Chap. 1. Sect. 1.2, this book), because it aims at providing a concluding explanation of the cognitive machineries that can render abduction knowledge-enhancing even in the absence of empirical evaluation.

Mathematical discoveries are not empirically negotiable and also in the case of mathematics "models" are at play. I have called the external scientific models "mimetic" (Magnani 2009) (for example a geometrical diagram drawn on a blackboard or an in-vitro model of a neurobiological process),[12] 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 I described the centrality of the so called "disembodiment of the mind" in the case of semiotic cognitive processes occurring in science. Disembodiment of the mind refers to the fact the mind "disembodies" itself by projecting representations on the external environment, that is it refers to the cognitive interplay between internal and external representations, *mimetic* and, possibly, *creative* (in this last case they are not necessarily mimetic), where the problem of the continuous interaction between on-line and off-line (for example in inner rehearsal) intelligence can properly be addressed.[13]

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 our 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

[12] On the related problem of resemblance (similarity, isomorphism, homomorphism, etc.) in scientific modeling see Chap. 4, this book.

[13] In this eco-cognitive perspective we can even more strongly agree with Morrison's when she is pretty clear about the excessive habit of labeling fictional scientific models simply because they are superficially seen as "unrealistic": "Although there is a temptation to categorize any type of unrealistic representation as a 'fiction', I have argued that this would be a mistake, primarily because this way of categorizing the use of unrealistic representations tells us very little about the role those representations play in producing knowledge" (Morrison 2009, p. 133).

level of that continuous interaction between on-line and off-line intelligence that I underlined the importance of what I called *manipulative abduction*.[14]

Also Hintikka clearly shows the "embarrassing" presence of fruitful abductive creative moments in deduction, which are invaded by strategic hypothetical interventions crucial to proceed and reach the final results, and that of course are evidentially inert. Also in deduction, the presence of abductive events coincides with their knowledge-enhancing character: here too these strategic aspects reflect the pure—productive—conjectural element of abductive inference and its capacity to guessing right. Hintikka clearly points out the abductive nature of the inferential phase in which the existential quantifier is introduced. This case is in turn related to his emphasis on the *strategically* positing of the "right questions" which "depend on one's ability to anticipate their answers" (Hintikka 2007, p. 55):

> […] the very same sentence can serve as the presupposition of a question and as the premise of a deductive step. For instance, an existential sentence of the form
>
> (1) $(\exists x)S[x]$
>
> can serve either as the presupposition of the question
>
> (2) What (who, when, where,…), say x, is such that $S[x]$?
>
> or as the premise of an existential instantiation that introduces a John Doe—like "dummy name" of an "arbitrary name", say β. In the former case, the output of the relevant step is a sentence of the form
>
> (3) $S[b]$
>
> where b is a singular term—for instance, a proper name. In the latter case, the output is of the form
>
> (4) $S[\beta]$
>
> Here, (4) differs from (3) only by having a dummy name, whereas in (3) there was a real name.
>
> […] It seems to me that Peirce had an intuitive understanding of this type of similarity between abductive and deductive inferences. […] These similarities between questions (abductive steps) and logical inferences (deductive steps) are purely formal, however. An epistemological assimilation of the two to each other on the mere basis of such formal similarities would be irresponsible. The crucial insight here is that behind these formal similarities there lies a remarkable strategic similarity (Hintikka 2007, pp. 53–54).

The strategic similarity resorts to the need of the reasoner of using one of the propositions that are available to her as presuppositions or as premises, *both* in the case of abduction and of deduction:

> Which sentence or sentences should I use as the premise or as the premises of a deductive inference? It can be shown that the most sensitive strategic question in deduction is: Which sentence should I use first as the premise of an existential instantiation or its generalization, functional instantiation? […] If the inquirer is reasoning empirically (interrogatively), the next strategic question is: Which one of the available sentences should I use as the presupposition of a why question? These candidate sentences are the very same ones that could be used as premises of existential instantiations, suitably generalized. Neither question admits in general of a mechanical answer, in the sense that there is in neither case any recursive function that always specifies an optimal choice. […] In this sense, the strategic principles

[14] Cf. above, Chap. 1, Sect. 1.3, this book.

of abductive reasoning, interpreted as I have done, *are the same as the strategic principles governing deduction* (Hintikka 2007, p. 54) emphases added).

Taking advantage of the previous notes about the abductive aspect of mathematical reasoning (and discovery) and logical deduction let us come back to the problem of abduction and of its presumptive ignorance-preserving character. I have many times stressed in my works that manipulative abduction (I have just quoted few lines above), which is widespread in scientific reasoning, is a process in which a hypothesis is formed resorting to a basically extra-theoretical and extra-sentential behavior that aims at creating communicable accounts of new experiences to the final aim of integrating the successful results 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 for example in the neural engineering laboratory I have outlined in the previous chapter (Sects. 2.3 and 2.4), useful to make observations and "experiments" to transform one cognitive state into another to discover new properties of the target systems. Manipulative abduction refers to those more unplanned and unconscious action-based cognitive processes I have characterized as forms of "thinking through doing".[15] It is clear that manipulative abduction in science basically deals with the handling of external models in their intertwining with the internal ones. Consequently, even if related to experiments occasionally performed with the help of external models sometimes mediated by artifacts, manipulative abduction has to be considered—obviously in mathematics but also in the case of empirical science—evidentially inert, even if of course not necessarily ignorance-preserving, as I have tried to demonstrate in this chapter.

I have contended that manipulative abduction is also active in mathematics. For example, we have already seen that Peirce, in the case of mathematics, speaking of the model-based aspects of this kind of reasoning usually considered deductive, hypothesized there is an "experimenting upon this image [the external model/diagram] in the imagination", so showing how human geometrical imagination is always triggered by a kind of prosthesis, the external model as an "external imagination". Analogously, taking advantage of a fictional view on models and of the pretence theory Frigg (2010, p. 266 ff.) interestingly sees imagination as an authorized intersubjective game of make-believe sanctioned by the "prop" (an object, for example material models, movies, paintings, plays, etc.) and its rules of generation. This theory also works as a metaphor of abductive processes, in terms of some concepts taken from the theory of literary and artistic fictions: again, I think that it is neither necessary to adopt a fictionalist view in the case of science, nor the pretence theory adds something relevant to the issue and, moreover, this kind of fictionalism would obscure the knowledge-enhancing role of abduction we are describing in this book.

[15] Cf. also p. 38, Sect. 2.3 of the previous chapter of this book.

Analogously, in the example concerning the exploitation of concrete/external models (for example in-vitro or computational) in a scientific lab (cf. Chap. 4, Sect. 4.3, this book), scientists do not pretend anything and are not engaged in the relative make-believe process, if not in the trivial sense that almost every human intersubjective interplay can be seen as such. Just to make two different examples of models, the in-vitro networks of cultured neurons or the Peircean Euclidean diagram used by the ancient Greek geometers are just the opposite of a mere fiction or of a generic make-believe interplay, they are instead more or less mimetic (possibly creative and so enhancers of new knowledge not already available) external models—reached through manipulative abduction—which are expected to provide reliable information about the target system. They aim at abductively discovering some new representations about neurons in the first case and about pure concepts of geometry in the second.[16]

As I have anticipated, here we see that, even in the mathematical discovery processes, "on-line" manipulative abduction is based on the interplay between internal and external representations (not only diagrams, but also written proofs, etc.): the final result is an abductive hypothesis which assumes the clothes of a Kantian "stipulation", endowed with epistemic virtues, that same "productive" stipulation, squarely evidentially inert, we have seen at work in the case of conventions and models in empirical science.

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[16]The reason of my skepticism about the vision of models in terms of the pretence theory can be illustrated taking advantage of some classical but still astounding theses derived from Kantian philosophy and Thom's mathematical semiophysics, I will treat in the following chapter, Sect. 4.2.

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Chapter 4
Epistemic Warfare

Are Scientific Models Fictions or Epistemic Weapons?

In this chapter I will illustrate how 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. I will also further elaborate on a dynamic view of models, already introduced in the previous chapter: it is misleading to analyze models in science by adopting a confounding mixture of static and dynamic aspects of the scientific enterprise. Scientific models in a static perspective (for example when inserted in a textbook) certainly appear fictional to the epistemologist, but their fictional character disappears in case a dynamic perspective is adopted. Finally, a reference to the originative role of thought experiment in Galileo's discoveries and to the usefulness of Feyerabend's counterinduction in criticizing the role of resemblance in model-based cognition is also provided, to further corroborate the thesis indicated by the chapter title.

4.1 Are Scientific Models Fictions or Epistemic Weapons?

Thanks to the cognitive research concerning common coding I have illustrated in Sect. 2.4 of Chap. 2, we are faced with the modern awareness of what also implicitly underlies Peircean speculations: nature fecundates the mind because it is through a disembodiment and extension of the mind in nature (that becomes, so to say, "artificialized") that in turn nature affects the mind. In more modern words: models are built—for example—by the mind of the scientist, who first delegates "meanings" to external artifacts of various kinds; in this way the "internal" representations are "extended" in the environment, and later on they will be reshaped by processes that are occurring outside, also taking into account the constraints found in the external

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representation (for example a model). After having operated the manipulation of the external model resulting aspects of those modifications/movements are "picked up" and in turn re-represented in the human brain of the scientist.

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 coincide with (or lead to) new guesses—either instinctual or reasoned, depending on the brain areas involved—that is to plausible abductive hypotheses about the external extra-somatic world (the target systems). As I have already said in Chap. 2 (Sect. 2.3, p. 37), 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 the mind itself has made 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.

Even if Chandrasekharan and Nersessian's research deals with models which strongly incorporate a reference to movement, and so does not consider models that are not fundamentally based on it, it provides an useful example able to stress the distributed character of scientific models, and the true type of abstractness/ideality they possess, so refreshing these notions that come from the tradition of philosophy of science. The analysis of models as material, mathematical, and fictional—and as "abstract objects"—provided by Contessa (2010), where "a model is an actual abstract object that stands for one of the many possible concrete objects that fit the generative description of the model" (p. 228) would take advantage of being reframed in the present naturalistic perspective. The same in the case of Frigg (2010), who illustrates a fictionalist view and says "Yet, it is important to notice that the model-system is not the same as its [verbal] description; in fact, we can re-describe the same system in many different ways, possibly using different languages. I refer to descriptions of this kind as model-descriptions and the relation they bear to the model-system as *p*-representation" (pp. 257–258). Indeed, Contessa's reference to models as "actual abstract objects" and Frigg's reference to models as abstract "model-systems" would take advantage of the cognitive perspective I am presenting here, which can easily answer the question "where are models located, from a naturalistic point of view?"

In this perspective scientific models cannot be easily considered fictional: scientists—at least in the cognitive processes of scientific discovery—do not have any intention to propose fictions, instead they provide models as tools that reshape a generic cognitive niche as an epistemological niche to the aim of performing a genuine struggle for representing the external world. Models, the war machines used in this struggle, which I call *epistemic warfare*, to stress the determined—strictly epistemic—dynamism of the adopted tools that are at stake, are not casual illusional/imaginary fictions or stratagems used for example to cheat nature or swindle

human beings, but just concrete, unambiguous, and well disposed tactical intermediate weapons able to strategically "attack" nature (the target systems) to further unveil its structure. Contrarily, fictions in works of fictions are for example meant to unveil human life and characters in new esthetic perspectives and/or to criticize them through a moral teaching, while fictions and stratagems in wars are meant to trick the enemy and possibly destroy the eco-human targets.

I contend that epistemologists do not have to forget that various cognitive processes present a "military" nature, even if it is not evident in various aspects and uses of syntactilized human natural language and in abstract knowledge. It is hard to directly see this "military intelligence"[1] in the many *epistemic* functions of natural language, for example when it is simply employed to transmit scientific results in an academic laboratory situation, or when we gather information from the Internet—expressed in linguistic terms and numbers—about the weather. However, we cannot forget that even the more abstract character of knowledge packages embedded in certain uses of language (and in hybrid languages, like in the case of mathematics, which involves considerable symbolic parts) still plays a significant role in changing the moral behavior of human collectives. For example, the production and the transmission of new scientific knowledge in human social groups not only operates on information but also implements and distributes roles, capacities, constraints and possibilities of actions. This process is intrinsically moral because in turn it generates precise distinctions, powers, duties, and chances, which can create new between-groups and in-group violent (often) conflicts, or reshape older pre-existent ones.

Let me present and an example. New theoretical biomedical knowledge about pregnancy and fetuses usually has two contrasting moral/social effects, (1) a better social and medical management of childbirth and related diseases; (2) the potential extension or modification of conflicts surrounding the legitimacy of abortion, or of in-vitro fertilization, etc. In sum, even very abstract bodies of knowledge and more innocent pieces of information enter the semio/social process which governs the identity of groups and their aggressive potential as coalitions: deductive reasoning and declarative knowledge are far from being exempt from being accompanied by argumentative, deontological, rhetorical, and dialectic aspects. For example, it is hard to distinguish, in an eco-cognitive setting, between a kind of "pure" (for example deductive) inferential function of language and an argumentative or deontological one: the deductive one—for example—can obviously also play an associated argumentative role. However, it is in the arguments traditionally recognized as fallacious, that we can more clearly grasp the military nature of human language and especially of some hypotheses reached through fallacies.

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

[1] I am deriving this expression from René Thom (1988), who relates "military intelligence" to the role played by language and cognition in the so-called *coalition enforcement*, that is at the level of their complementary effects in the affirmation of moralities and related conducts, and the consequent perpetration of possible violent punishments. The adjective "military" is obviously used in a metaphorical sense.

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 (Feyerabend 1975), 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.

I am aware of the fact that epistemological fictionalism does not consider fictions forgery or fake, that is something "far from being execrable", instead, something "we cherish" (Frigg 2010, p. 249), but to say that scientific and literary fictions are both "good" fictions is a bit of a theoretical oversemplification, because it is science that created, beyond literature and poetry, *new* kinds of models committed to a specific production of a rational truth, constitutively aiming at not being fictional. I confess I cannot see how we can speak of the ideal pendulum in the same way we speak of Anna Karenina: it seems to me that we are running the risk of inadvertently opening the gates of epistemology to a kind of relativistic post-modernism *à la mode*, even if fictionalists seem to avoid this possible confusion by producing—often useful—taxonomies about the slight differences between fictions in science and in other cognitive practices.

An extended article about models and representations is (Frigg and Nguyen 2017), published in the recent *Handbook of Model-Based Science* (Magnani and Bertolotti 2017). The authors extensively illustrate the various conceptions of scientific models (structuralist, inferential, fictionalist, representational, in terms of stipulative fiat or of similarity). When dealing with fictionalism and after having quoted my article (Magnani 2012), they observe that I dismiss the fiction view because it misconstrues the role of models in the process of scientific discovery and that I say these kinds of models cannot be indicated as fictional at all, because they are constitutive of new scientific frameworks and new empirical domains. They contend that my criticism seems to be based on an understanding of fiction as falsity, because falsities cannot play a constitutive role in the establishment of new empirical domains. In conclusion they reply that the fiction view is not committed to the "fiction as falsity" account and hence is not open to my objection. I can agree that falsity is not a defining feature of fiction,[2] and that in literary frameworks fictions can just be seen as imaginations and not as falsities (so carrying, I guess, some kind of truth or at least of potential truth), but this is exactly the problem, I am still convinced that there is a clear

[2]However, on this issue it is mandatory to see the fundamental observation given by Woods on the detonating role of fictions, I have illustrated in Sect. 3.2.1 of Chap. 3, this book.

distinction between the so-called works of fiction (for example literature) and non-fiction (for example science), and that even if we want to attribute to both some positive cognitive functions we are dealing with very different kinds of knowledge that cannot absolutely be confused.[3]

Anna Karenina and the in-vitro model are very different.[4] In actual scientific practice, a model becomes fictional only *after* the community of researchers has recognized it as such, *because* it has *failed* in fruitfully representing the target systems. In these cases a model is simply discarded, in the framework of the dynamic life of scientific enterprise. On the contrary, Tolstoy might have discarded the character of Anna Karenina as an inappropriate fiction for some contemporary esthetic—not scientific—purpose (for instance, had she failed, in her author's opinion, to veraciously represent a female member of Russia's high society at the end of XIX century), but he would have substituted her with yet another—just as fictional—character, doomed to *remain* fictional for ever.[5]

4.2 Scientific Models as Fictions in a Dynamic Perspective and Fictions as "*Façons de Parler*"

As I was saying few lines above, a scientific model can be discarded when it has *failed* in fruitfully representing the target systems and in playing a productive role in scientific cognitive processes. Indeed, by adopting the dynamic perspective I have already delineated in the previous chapter it is easier to see that a scientific model can be more correctly recognized as "fictional" in a cognitive (often creative) process when it is assessed to be unfruitful, by applying the *negation as failure* (Clark 1978; Magnani 2001a)[6]: it becomes fictional in the mere sense that it is falsified (even if "weakly" falsified, by failure) and consequently it does not play anymore a role in

[3]Moreover, I also read the recent ample Bokulich's (Bokulich 2017) article "Models and explanation" published in the quoted *Handbook of Model-Based Science*, in which so many cases of positive and also ineliminable roles of idealizations (but also of the supposed to be "fictions") in science are illustrated, not only in cognitive creative processes. She argues that some of the so-called fictions are able to capture in their fictional representation real patterns of structural dependencies in the world and so they are genuinely explanatory and yield real scientific understanding. I again concluded that it appears weird to preserve the word fiction in epistemology. The reader should refer to this text for a clear and articulated answer to the following other questions: do some highly abstract and mathematical models exhibit a non-causal form of scientific explanation? How can one distinguish an exploratory "how-possibly" model explanation from a "how-actually" model explanation? Do modelers face tradeoffs such that a model that is optimized for yielding explanatory outcome, for example, might fail to be the most predictively precise, and vice versa?

[4]In the recent epistemological debate about fictions, even the whole "experimental systems" are reframed as "materialized fictional 'worlds'" (Rouse 2009, p. 51)!

[5]Giere usefully notes that "Tolstoy did not intend to represent actual people except in general terms" and that, on the contrary, a "primary function [of models in science], of course, is to represent physical processes in the real world" (Giere 2007, p. 279).

[6]I have introduced this logical concept in the previous chapter, Sect. 3.1.1.

the "rational" life of scientific cognition.[7] Methodologically, negation as failure is a process of elimination that parallels what Freud describes in the case of constructions (the narratives the analyst builds about patient's past psychic life) abandoned because they do not help to proceed in the therapeutic psychoanalytic process: if the patient does not provide new "material" which extends the proposed construction, "if", as Freud declares, "[…] nothing further develops we may conclude that we have made a mistake and we shall admit as much to the patient at some suitable opportunity without sacrificing any of our authority". The "opportunity" of rejecting the proposed construction "will arise" just "[…] when some new material has come to light which allows us to make a better construction and so to correct our error. In this way the false construction drops out, as if it has never been made; and indeed, we often get an impression as though, to borrow the words of Polonius, our bait of falsehood had taken a carp of truth" (Freud 1974, vol, 23, 1937, p. 262).

Similarly, for example in a scientific discovery process, the scientific model is simply eliminated and labeled as "false", because "new material has come to light" to provide a better model which in turn will lead to a new knowledge that supersedes or refines the previous one, and so the old model is buried in the necropolis of the no longer fruitful—dead—models. Still, similarly, in the whole scientific enterprise, also a successful scientific model is sometimes simply eliminated (for example the ether model) together with the theory to which that model belonged, and so the old model is buried in yet another necropolis, that of the abandoned "historical" models, and yes, in this case, it can be plausibly relabeled as a fiction.[8]

A conclusion in tune with my suspects concerning the fictional character of scientific models is reached by Woods and Rosales (2010), who offer a deep and compelling logico-philosophical analysis of the problem at stake. They contend that it is extremely puzzling to extend the theory of literary and artistic fictions to science and other areas of cognition. Whatever we say of the fictions of mathematics and science, there is "nothing true of them in virtue of which they are *literary fictions*" (p. 375). They correctly note that "Saying that scientific stipulation is subject to normative constraints is already saying something quite different from what should be said about literary stipulation":

> We also see that scientific stipulation is subject to a *sufferance* constraint, and with it to factors of timely goodness. A scientist is free to insert on his own sayso a sentence ϕ in T's model of M on the expectation that T with it in will do better than T with it not in, and

[7] On the powerful and unifying analysis of inter-theory relationships, which involves the problem of misrepresenting models—and their substitution/adjustment—and of incompleteness of scientific representation, in terms of partial structural similarity, cf. (Bueno and French 2011) and the classic (da Costa and French 2003).

[8] In the recent literature this problem is also linked to the role of "understanding" in science. The puzzling interplay between scientific understanding, false models, and realism is treated in (de Regt 2015, pp. 3782), who maintains that "The practice and history of science reveal that understanding can be—and is in fact often—achieved through models that are unrealistic, highly idealized representations of the target system, or on the basis of theories that are strictly speaking false" or through models and theories that are now considered false because superseded, but this does not mean that they were not able to provide understanding of phenomena.

> subject in turn to its removal in the face of a subsequently disappointing performance by T. This is a point to make something of. Here is what we make of it:
>
> - The extent to which a stipulation is held to the sufferance condition, the more it resembles a *working hypothesis*.
> - The more a sentence operates as a working hypothesis, the more its introduction into a scientific theory is conditioned by *abductive considerations*.
>
> Accordingly, despite its free standing in M, a stipulationist's ϕ in T is bound by, as we may now say, *book-end* conditions, that is to say, conditions on *admittance* into T in the first place, and conditions on its *staying* in T thereafter. The conditions on going in are broadly abductive in character. The conditions on *staying in* are broadly – sometimes very broadly – confirmational in character. Since there is nothing remotely abductive or confirmational in virtue of which a sentence is an $\mathcal{F}$-truth [fictive truth] on its author's sayso, radical pluralism must be our verdict here (Woods and Rosales 2010, pp. 375–376).

In conclusion, after having proposed a distinction between predicates that are load-bearing in a theory and those that are not, Woods and Rosales maintain that a predicate that is not load-bearing in a theory is a *façon de parler*: "For example, everyone will agree that the predicate 'is a set' is load-bearing in the mathematical theory of sets and that 'is an abstract object', if it occurs there at all, is a *façon de parler*. 'Is an abstract object' may well be load-bearing in the philosophy of mathematics, but no work-a-day mathematician need trouble with it. It generates no new theorems for him. Similarly, 'reduces to logic' is not load-bearing in number theory, notwithstanding the conviction among logicists that it is load-bearing in mathematical epistemology" (Woods and Rosales 2010, pp. 377–378). Unfortunately the predicate "is a fiction" is non-load-bearing, or at best a *façon de parler*, in any scientific theory. At this point the conclusion is obvious, and I agree with it, since there is no concept of scientific fiction, the question of whether it is assimilable to or in some other way unifiable with the concept of literary fiction does not arise.

I have said in the previous chapter (Sect. 3.3) that I call the external scientific models "mimetic" to stress the fact the mind disembodies itself, in the case of semiotic cognitive processes occurring in science, performing a cognitive interplay between internal and external representations, *mimetic* and, possibly, *creative* (in this last case they are not necessarily mimetic). In the Sect. 4.4 below, we will see that this distinction parallels the one illustrated by Morrison between models which idealize (mirroring the target systems) and abstract models (more creative and finalized to establish new scientific intelligibility).

As I am trying to show in this book with the description of the above eco-cognitive view of models, which considers them material and distributed (cf. Sect. 2.3, of Chap. 2), I find 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 on-line and off-line intelligence that I underline the importance of what I called *manipulative abduction*.

As I have described in Chap. 1 (Sect. 1.3) and in the previous chapter (Sect. 3.3) manipulative abduction, which is widespread in scientific reasoning 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. I have said that 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 to the aim of making observations and "experiments" able to transform one cognitive state into another to unveil new properties of the target systems. I added that manipulative abduction also refers to those more unplanned and unconscious action-based cognitive processes I have characterized as forms of "thinking through doing".[9]

4.3 Are the In-Vitro Model or a Geometrical Diagram Fictions?

In Sect. 2.4 of Chap. 2 I have contended that Peirce, speaking of the model-based aspects of deductive reasoning, hypothesized there is an "experimenting upon this image [the external model/diagram] in the imagination", so indicating how human geometrical imagination is always triggered by a kind of prosthesis, the external model as an "external imagination". I also said that, taking advantage of a fictional view on models and of the pretence theory, Frigg (2010, p. 266 ff.) interestingly sees imagination as an intersubjective game of make-believe ratified by the "prop" (an object, for example material models, movies, paintings, plays, etc.) and its rules of generation. I already anticipated that the in-vitro networks of cultured neurons described in Chap. 2 or the Peircean Euclidean diagram used by the ancient Greek geometers are not fictions or parts of generic make-believe interplay, they are external models which are expected to provide *reliable* information about the target system.

The reason of my skepticism can be illustrated taking advantage of some theses derived from classical Kantian philosophy and Thom's mathematical semiophysics. Immanuel Kant was clearly aware of the interplay between internal and external models, exemplified in the case of a formal science like mathematics. In his transcendental terms, Kant says that in geometrical construction "[…] I must not restrict my attention to what I am actually thinking in my concept of a triangle (this is nothing more than the mere definition); I must pass beyond it to properties which are not contained in this concept, but yet belong to it" (Kant 1929, A718–B746, p. 580). Hence,

[9] Cf. also p. 38 above.

for Kant models in science (in this case, of geometry) are first of all *constructions* that go beyond what the researcher simply "thinks". We have seen that manipulative abduction is a kind of, usually model-based, abduction that exploits external models endowed with delegated (and often implicit) cognitive roles and attributes: 1. The model is external and the strategy that organizes the manipulations is unknown a priori. 2. The result achieved is new (if we, for instance in this geometrical case, refer to the constructions of the first creators of geometry), and adds properties not contained before in the concept (the Kantian to "pass beyond" or "advance beyond" the given concept (Kant 1929, A154–B194, p. 192)).[10]

"Iconicity" is central for Peirce, who analogously to Kant, maintains that "[…] philosophical reasoning is reasoning with words; while theorematic reasoning, or mathematical reasoning is reasoning with specially constructed schemata" (Peirce 1958, 4.233); moreover, he uses diagrammatic and schematic as synonyms, thus relating his considerations to the Kantian tradition where schemata mediate between intellect and phenomena.[11] The following is the famous related passage in the *Critique of Pure Reason* ("Transcendental Doctrine of Method"), in which the process that leads to the "discovery" of the sum of the internal angles of a triangle (axiomatically reframed as the Theorem 32 of the first book of Euclid's *Elements*) is illustrated:

> Suppose a philosopher be given the concept of a triangle and he be left to find out, in his own way, what relation the sum of its angles bears to a right angle. He has nothing but the concept of a figure enclosed by three straight lines, and possessing three angles. However long he meditates on this concept, he will never produce anything new. He can analyse and clarify the concept of a straight line or of an angle or of the number three, but he can never arrive at any properties not already contained in these concepts. Now let the geometrician take up these questions. He at once begins by constructing a triangle. Since he knows that the sum of two right angles is exactly equal to the sum of all the adjacent angles which can be constructed from a single point on a straight line, he prolongs one side of his triangle and obtains two adjacent angles, which together are equal to two right angles. He then divides the external angle by drawing a line parallel to the opposite side of the triangle, and observes that he has thus obtained an external adjacent angle which is equal to an internal angle – and so on. In this fashion, through a chain of inferences guided throughout by intuition, he arrives at a fully evident and universally valid solution of the problem (Kant 1929, A716–B744, pp. 578–579).

Here "intuition" is the Kantian word that expresses our present reference to what we call "external model".

We can depict the situation of the philosopher described by Kant at the beginning of the previous passage taking advantage of some ideas coming from the catastrophe

[10] Of course in the case we are using diagrams to demonstrate already known theorems (for instance in didactic settings), the strategy of manipulations is often already available and the result is not new.

[11] Schematism, a fruit of the imagination is, according to Kant, "[…] an art concealed in the depths of the human soul, whose real modes of activity nature is hardly likely ever to allow us to discover, and to have open to our gaze" (Kant 1929, A141–B181, p. 183). Now we have at our disposal, thanks to epistemology and cognitive science, a lot of knowledge about the cognitive processes which correspond to Kantian schematism. On models as epistemic mediators in mathematics cf. (Boumans 2012).

theory. As a human being who is not able to produce anything new relating to the angles of the triangle, the philosopher experiences a feeling of frustration (just like the Kölher's monkey which cannot keep the banana out of reach). The bad affective experience "deforms" the organism's regulatory structure by complicating it and the cognitive process stops altogether. The geometer instead "at once constructs the triangle" [the scientist constructs the model] that is, he makes an external representation of a triangle and acts on it with suitable manipulations. Thom thinks that this action is triggered by a "sleeping phase" generated by possible previous frustrations which then change the cognitive status of the geometer's available and correct internal idea of triangle (like the philosopher, he "has nothing but the concept of a figure enclosed by three straight lines, and possessing three angles", but his action is triggered by a sleeping phase). Here the idea of the triangle is no longer the occasion for "meditation", "analysis" and "clarification" of the "concepts" at play, like in the case of the "philosopher". Here the inner concept of triangle—symbolized as insufficient—is amplified and transformed thanks to the sleeping phase (a kind of Kantian imagination active through schematization) in a prosthetic triangle to be put outside, in some external support. The instrument (here an external diagram) becomes the extension of an organ:

> What is strictly speaking the end […] [in our case, to find the sum of the internal angles of a triangle] must be set aside in order to concentrate on the means of getting there. Thus the problem arises, a sort of vague notion altogether suggested by the state of privation. […] As a science, heuristics does not exist. There is only one possible explanation: the affective trauma of privation leads to a folding of the regulation figure. But if it is to be stabilized, there must be some exterior form to hold on to. So this anchorage problem remains whole and the above considerations provide no answer as to why the folding is stabilized in certain animals or certain human beings whilst in others (the majority of cases, needless to say!) it fails (Thom 1988, pp. 63–64).[12]

4.4 Confounding Static and Dynamic Aspects of the Scientific Enterprise

Taking advantage of Thom's considerations, we can clearly see that the constructed external scientific model in the case of creative processes is exactly the opposite both of a fiction and of a generic process of make-believe (neither is a mere surrogate (Contessa 2007) or a bare credible world (Sugden 2000, 2009)).[13] It is instead a

[12] A full analysis of the Kölher's chimpanzee getting hold of a stick to knock a banana hanging out of reach in terms of the mathematical models of the perception and the capture catastrophes is given in (Thom 1988, pp. 62–64). On the role of emotions, for example frustration, in scientific discovery cf. (Thagard 2002).

[13] Mizrahi (Mizrahi 2011) seems to support—in the linguistic perspective about the role of "facticity" in scientific cognition—a similar point of view about the coherence of seeing scientific "idealized" models as "quasi-factive": "[…] if [scientific] understanding is (quasi) factive, then we can attribute this sort of cognitive success to scientists when they employ idealizations, such as the Ideal Gas Law, precisely because they mirror the facts to some extent. That is to say, in the case of the Ideal

regulatory tool *stabilized* in "some exterior form", a kind of a reliable anchorage, not intentionally established as fiction, as a romance writer could intentionally do, assessing the character of Harry Potter. In the epistemological fictionalism about models the use of the label "fiction" is usually legitimated by the fact that there are no empirical systems corresponding for example to the ideal pendulum (and its equation).

However, the label sets up a paradox we can clearly see taking advantage of the case of scientific models seen as "missing systems", another new metaphor that echoes the fictional one—indeed the description of a missing system might be a fiction. Thomson-Jones (2010) emphasizes that science is full of "descriptions of missing systems", that at the end are thought as abstract models.[14] Further, Mäki (2009) usefully acknowledges that scientific models are "pragmatically and ontologically constrained representations", and elaborates on the missing systems framework adding a supplementary metaphoric conceptual apparatus: missing systems are also "surrogate" systems expressed as credible worlds, as models. Similar arguments are advanced by Godfrey-Smith (2009, pp. 114): "To say that talk of model systems is a psychologically exotic way of investigating conditionals (and the like) is not itself to solve the problem. It is natural to think that the useable output we get from modeling is generally a conditional—a claim that if such-and such a configuration existed, it would behave in a certain way. The configurations in question, however, are usually known *not* to exist, so the problem of explaining the empirical usefulness of this kind of knowledge reappears".

I contend that, at least in a very innovative and revolutionary discovery cognitive process, the missing system (Thomson-Jones) is not the one represented by the "model", but instead the target system itself, still more or less largely unknown and un-schematized, which will instead appear as "known" in a new way only after the acceptation of the research process results, thus admitted into the theory T and considered worth to *staying* in T thereafter.[15] The same can be said of models as configurations (Godfrey-Smith), which certainly are conditional, but at the same time do not have to be considered as "known *not* to exist", in Godfrey-Smith's sense, because simply in the moment in which a scientific model is introduced in a discovery process it is instead exactly the only object we plausibly *know* to exist (for example a diagram in a blackboard, or a in-vitro artifact, or a mental imagery). Once a final scientific result has been achieved, together with the description of the related experimental side, everything that does not fit that final structure is a fiction, and so models that helped reach that result itself. This is an exaggeration which

(Footnote 13 continued)
Gas Law, it is precisely because of the agreement between the predictions of the gas laws and the behavior of gases (under specified conditions of temperature and pressure) that we attribute cognitive success to scientists in this case. Otherwise, it seems, we would say that scientists don't understand the behavior of gases at all".

[14]Cartwright (1983), more classically, speaks of "prepared description" of the system in order to make it amenable to mathematical treatment.

[15]Cf. the previous Sect. 4.2, on the problem of scientific model stipulation as subject to a *sufferance* constraint.

Morrison corrects when she is pretty clear about the excessive habit of labeling fictional scientific models simply because they are superficially seen as "unrealistic": "Although there is a temptation to categorize any type of unrealistic representation as a 'fiction', I have argued that this would be a mistake, primarily because this way of categorizing the use of unrealistic representations tells us very little about the role those representations play in producing knowledge" (Morrison 2009, p. 133).

In the framework of an account of scientific representation in terms of partial structures and partial morphisms Bueno and French (2011, p. 27) admit that they agree in fact that an important role for models in science is to allow scientists to perform the so-called "surrogative" reasoning, but they add the following constraint: "Indeed, we would claim that representing the 'surrogative' nature of this reasoning effectively rides on the back of the relevant partial isomorphisms, since it is through these that we can straightforwardly capture the kinds of idealizations, abstractions, and inconsistencies that we find in scientific models". So to say, we can speak of surrogates, fictions, credible worlds, etc., but it is only through the suitable partial isomorphism we can detect after a success of the model, that we can be assured to be in presence of a "scientific" representation or model.

Further, Kuorikoski and Lehtinen (2009, p. 121) contend that: "The epistemic problem in modelling arises from the fact that models always include false assumptions, and because of this, even though the derivation within the model is usually deductively valid, we do not know whether our model-based inferences reliably lead to true conclusions". However, the false premises (also due to the presence in models of both substantive and auxiliary assumptions) are not exploited in the cognitive process, because, in various heuristic processes, only the *co-exact* ones are exploited.

The notion of co-exact properties, introduced by Manders (2008), is worth to be further studied in fields that go beyond the realm of discovery processes of classical geometry, in which it has been nicely underscored. Mumma (Mumma 2010, p. 264) illustrates that Euclid's diagrams contribute to proofs only through their co-exact properties. Indeed

> Euclid never infers an exact property from a diagram unless it follows directly from a co-exact property. Exact relations between magnitudes which are not exhibited as a containment are either assumed from the outset or are proved via a chain of inferences in the text. It is not difficult to hypothesize why Euclid would have restricted himself in such a way. Any proof, diagrammatic or otherwise, ought to be reproducible. Generating the symbols which comprise it ought to be straightforward and unproblematic. Yet there seems to be room for doubt whether one has succeeded in constructing a diagram according to its exact specifications perfectly. The compass may have slipped slightly, or the ruler may have taken a tiny nudge. In constraining himself to the co-exact properties of diagrams, Euclid is constraining himself to those properties stable under such perturbations.

In sum, I think it is misleading to analyze models in science by adopting a confounding mixture of static and dynamic aspects of the scientific enterprise. Scientific models in a static perspective (for example when inserted in a textbook) certainly appear—but just appear—fictional, because they are immediately compared with the target systems and their complicated experimental apparatuses: in this case also the *ideal* character of models becomes manifest and so the *explanatory* function of them

(cf. (Weisberg 2007)). Contrarily, scientific models seen inside the living dynamics of scientific creativity, which is the key topic of epistemology at least since Karl Popper and Thomas Kuhn, appear *explicit* and *reproducible* machineries intentionally built and manipulated to the gnoseological aims of increasing scientific knowledge *not yet available*.[16]

Morrison (2009) is certainly not inclined to see models as fictions because she emphasizes that in science they are specifically related to ("finer graded") ways of understanding and explaining "real systems", far beyond their more collateral predictive capabilities and their virtues in approximating. She indeed further clarifies that the models which is appropriate to label as *abstract* resist—in the so-called process of de-idealization—corrections or relaxing of the unrealistic assumptions (such as in the case of mathematical abstractions or when models furnish the sudden chance for the applicability of equations), because they are "necessary" to arrive to certain results. The fact that in these models "relevant features" are subtracted to focus on a single—and so isolated—set of properties or laws, as stressed by Cartwright (1989), is not their central quality, because what is at stake is their capacity to furnish an overall new depiction of an empirical (and/or theoretical, like in case of mathematics or logic) framework: "[…] We have a description of a physically unrealizable situation that is required to explain a physically realizable one" (p. 130). In a similar vein Woods nicely concludes that a dominant role for empirically forlorn representations in model-based science is the establishment of non-probative premiss-conclusion links in ways that set up their conclusions for empirical negotiation at the checkout counter (Woods 2013).

Other models, easier to define, which is better to classify as *idealizations*, allow "[…] for the addition of correction factors that bring the model system closer (in representational terms) to the physical system being modelled or described" (Morrison 2009, p. 111). It is for example the case of simple pendulum, where we know how to add corrections to deal with concrete phenomena. Idealizations distort or omit properties, instead abstractions introduce a specific kind of representation "that is not amenable to correction and is necessary for explation/prediction of the target system" (p. 112), and which provides information and transfer of knowledge. Morrison's characterization of scientific models as abstract is in tune with my emphasis on models as *constitutive*, beyond the mere role played by models as idealizations, which instead allow corrections and refinements (cf. below, Sect. 4.6).[17] In this perspective, "abstract" models, either related to prepare and favor mathematization or directly involving mathematical tools, have to be intended as poietic ways of producing new intelligibility of the essential features of the target systems phenomena, and not mere expedients for facilitating calculations. If idealization *resembles* the

[16]Taking advantage of the perspective on models in terms of "points of view" (Vázquez and Liz 2011), in which models can be directly identified by their role and they can solely be understood as ways of accessing the world that bring some kind of perspective about it, an interesting logic that aims at treating both static and dynamic aspects is proposed (Charro and Colomina 2014; Hautamäki 2016).

[17]On the constitutive versus descriptive role of models cf. also (Stefanov 2012).

phenomena to be better understood, abstract models can *constitute* the resemblance itself, as I will illustrate in the following section.

When Mäki (2009, p. 31) contends that "It may appear that a fantastically unreal feature is added to the model world, but again, what happens is that one thereby removes a real-world feature from the model world, namely the process of adjustment", I have to note that, at least in various creative processes, the adopted model (for example in the case of creative thought experiments) is not necessarily implemented through "removal" or "neutralization" of real-world features, because some features of the target system—that is the supposed to be real world—have simply not been discovered yet, and so, paradoxically, they are the ones still "missing". Consequently it is impossible to imagine that some aspects of the model derive from a removal of features of the real world, that can just be those features that will derive later on exactly thanks to that cognitive process that constructed the model itself to reach that objective. At the same time, and for the same reason, it is difficult to always state that models depict a "surrogate" systems, because the systems we want to subrogate *are largely not yet known*.

4.5 Resemblance and Feyerabend's Counterinduction

Even the concept of resemblance (similarity, isomorphism, homomorphism, etc.)[18] as it is employed in the epistemological framework of missing systems (and related topics, fictions, surrogate systems, credible world, make-believe models, etc.) is disputable. "*M* resembles, or corresponds to, the target system *R* in suitable respects and sufficient degrees. This second aspect of representation enables models to serve a useful purpose as representatives: by examining them as surrogate systems one can learn about the systems they represent" (Mäki 2009, p. 32): I contend that resemblance, at least in scientific discovery processes, is constitutively partial *also* because it is basically impossible to appropriately resemble things that are not yet known.[19]

Actually it is just the work of models that of creating, in a poietic way, the "resemblance" to the target system. Some discovered features of the target system resemble the model not because the model resembled them a priori but only post hoc, once discovered thanks to the modeling activity itself: the new features appear well-defined only in the static analysis of the final developed theory. Morrison too contends that "To say that fictional models are important sources of knowledge in virtue of a particular kind of similarity that they bear to concrete cases or systems is to say virtually nothing about how they do that. Instead what is required is a careful analysis of the model itself to uncover the kind of information it yields and the ways in which that information can be used to develop physical hypotheses" (Morrison 2009, p. 123).

[18] On the so-called Received View and Semantic View of scientific theories and their relationship with the problems of models cf. the exhaustive (Portides 2017).

[19] On the puzzling relationships between similarity and representations, in the framework of intentionality, cf. (Giere 2007).

In this perspective we paradoxically face the opposite of the received view, we could say that it is the newly known target system that resembles the model, which itself originated that resemblance.[20] Often models are useful to discover new knowledge just because they do not—or scarcely—resemble the target system to be studied, and are instead built to the aim of finding a new general capacity to make "the world intelligible".[21]

As I have aready illustrated in Chap. 1, in *Against Method* (Feyerabend 1975), Feyerabend attributes a great importance to the role of contradiction, against the role of similarity. He establishes a "counterrule" which is the opposite of the neopositivistic one that it is "experience" (or "experimental results") which measures the success of our theories, a rule that constitutes an important part of all theories of corroboration and confirmation. The counterrule "[…] advises us to introduce and elaborate hypotheses which are inconsistent with well-established theories and/or well-established facts. Feyerabend stresses the role of "dreaming", but these dreams are Galileo's dreams, they are not fictions: as I have already pointed out Feyerabend clearly distinguished between scientific dreams (as modeling) and propaganda, that can instead be organized thanks to fictions, inconsistent thought experiments, mistakes, aggressive fallacies, and so on, but that do not play any epistemic role in the restricted cognitive process of scientific discovery, I have called "epistemic" warfare.[22]

Coming back to the problem of models as surrogates, Mäki (2009, p. 35) says:

> The model functions as a surrogate system: it is construed and examined with a desire to learn about the secrets of the real world. One yearns for such learning and sets out to build a model in an attempt to satisfy the desire. Surrogate models are intended, or can be employed to serve, as bridges to the world.

First, I would add some auxiliary notes to the expression "secrets of the real world". I would warn about the preferability of being post-Kantian by admitting that, through science, we are *constructing* our rational knowledge of the world, which consequently is still an objective world independent of us, but constructed. If we say we build surrogate systems to learn about the secret of nature, a disputable realist assumption seems to be presupposed: the models would be surrogates because they are not "reliably reflecting the true reality of the world we are discovering". We rejoin Giere's observation I already quoted above in Chap. 2 (Sect. 2.2) who suspects fictionalists are paradoxically obsessed by "the truth, the whole truth, and nothing but the truth": theories would reflect this hyper-truth that in turn would

[20] I endorse many of the considerations by Chakravartty (2010), who stresses the unwelcome division between informational and functional perspective on models and representations in science, which negatively affects the epistemology of scientific modeling.

[21] I am convinced that knowledge about concepts such as resemblance, imaginability, conceivability, plausibility, persuasiveness, credit worthiness (Mäki 2009, pp. 39–40) would take advantage of being studied in the framework of the rigorous and interdisciplinary field of abductive cognition, which is forgotten in the studies of the "friends of fiction", with the exception of Sugden (2000, 2009).

[22] On Galileo's mental imagery, cf. the following Sect. 4.6.

reflect true reality (curious! Is not science the realm or self-correcting truths?)[23] In this way it becomes easy to say that everything else in science different from complete established true theories—which would reflect "real world"—is fiction, surrogate, belief, mere credible world, etc.

I would reserve the label of surrogate models to those models employed in some "sciences" that fail in providing satisfactory knowledge about target systems. "There is a long tradition in economics of blaming economists for failing in just this way: giving all their attention to the properties of models and paying none to the relations of the model worlds to the real world" (Mäki 2009, p. 36). Mäki calls the systems described by such models "substitute systems": I will just reserve for them the expression "surrogate systems", because they fake a scientific knowledge that is not satisfactorily achieved, from various perspectives.

I argued above about the epistemological problems of the concept of model as make-believe: indeed I have already said that make believe processes occur in almost every human intersubjective interplay. Here I can further stress that the idea of credible world is very wide: every cognitive process that aims at providing scientific—but also non scientific—knowledge aims at the same time at providing credible worlds. The problem in science is how to construct the subclass of *epistemologically* credible worlds, that is, also *scientific* models, which successfully lead to scientific theories. In this spirit Sugden (2009, p. 10) usefully suggests that an epistemologically "good" credible world would have to be provided by models that are able to trigger hypotheses about the "causation of actual events", that is in cases in which "the fictional world of the model is one that *could* be real". Cartwright's classical perspective (Cartwright 2009) concerning capacities is fruitfully adopted:

> For her, the function of a model is to *demonstrate the reality* of a capacity by isolating it – just as Galileo's experiment demonstrates the constancy of the vertical component of the acceleration of a body acted on by gravity. Notice how Cartwright speaks of *showing that C* has the capacity to produce *E*, and of deriving this conclusion from *accepted principles*. A satisfactory isolation, then, allows a real relationship of cause and effect to be demonstrated in an environment in which this relationship is stable. In more natural conditions, this relationship is only a latent capacity which may be switched on or off by other factors; but the capacity itself is stable across a range of possible circumstances. Thus, the model provides a "theoretical grounding" for a general hypothesis about the world (Sugden 2009, p. 20)).

Sugden prudently considers too strong these perspectives on models as tools for *isolating* the "capacities" of causal factors in the real world, and provides other conceptual devices to save various aspects of epistemological—supposed to be weak—"sciences", for example some parts of biology, psychology, or economics, which

[23] We should not forget what Morrison reminds us: "Laws are constantly being revised and rejected; consequently, we can never claim that they are true or false" (Morrison 2009, p. 128).

not ever fulfill the target of revealing capacities. To save these sciences he says that models can simply provide "conceptual explorations", which ultimately contribute to the development of genuinely explanatory theories or credible counterfactual worlds which can trigger inductive (or "abductive") inferences to explain the target systems. I think that it is virtuous to be prudent about strong methodological claims such as the ones advanced by Cartwright, but the epistemological problem remains open: in the cases of models as conceptual exploration are they used to depict credible worlds able to reach satisfactory theorization of target systems, or are they just providing ambitious but unjustified hypotheses, devoid of various good epistemological requisites?

Adopting Cartwright's rigid demarcation criterium clearly restated in "If no capacities then no credible worlds" (Cartwright 2009), it would seem that no more citizenship is allowed to some post-modern exaggeration in attributing the label "scientific" to various proliferating areas of academic production of knowledge, from (parts of) psychology to (parts of) economics, and so on, areas which do not—or scarcely—accomplish the most common received epistemological standards, for example, the *predictivity* of the phenomena that pertain the explained systems. Are we sure that this demarcation is too rigid or it is time to criticize some excess in the proliferation of models supposed to be "scientific"? It is in this perspective that the epistemological use of the so-called credible worlds appears theoretically suspect, but ideologically clear, if seen in the "military" framework of the academic struggle between disciplines, dominated—at least in my opinion—by a patent proliferation of "scientific" activities that just produce bare "credible" or "surrogate" models, looking aggressively for scientificity, when they actually are, at the best, fragments of *bad philosophy*.

An example is furnished by the precarious condition of various parts of psychological research. Miller (2010, p. 716) explores three contentions: "[…] that the dominant discourse in modern cognitive, affective, and clinical neuroscience assumes that we know how psychology/biology causation works when we do not; that there are serious intellectual, clinical, and policy costs to pretending we do know; and that crucial scientific and clinical progress will be stymied as long as we frame psychology, biology, and their relationship in currently dominant ways". He further rigorously illustrates the misguided or epistemological puzzling attempts[24] to localize psychological functions via neuroimaging and the misunderstandings about the role of genetics in psychopathology, sadly intertwined with untoward constraints on health-care policy and clinical service delivery.

[24]Cf. for example the recent (Glymour and Hanson 2016).

4.6 Galileo's Modeling Vindicated

Weisberg (2007, p. 642)[25] maintains that "Galilean idealization is the practice of introducing distortions into theories with the goal of simplifying theories in order to make them computationally tractable. One starts with some idea of what a non-idealized theory would look like. Then one mentally and mathematically creates a simplified model of the target". I would like to advance a suspect about this canonical treatment of Galileo's idealizations, and provide some reasons that explain my perplexity: this image does not cover all the ways adopted by Galileo's modeling activity.

When Galileo illustrates an imaginary model concerning the problem of falling bodies, he provides a kind of smart mental modeling. Let us religiously follow the text of the creator of modern science on this subject:

> SALV. But, even without further experiment, it is possible to prove clearly, by means of a short and conclusive argument, that a heavier body does not move more rapidly than a lighter one provided both bodies are of the same material and in short such as those mentioned by Aristotle. But tell me, Simplicio, whether you admit that each falling body acquires a definite speed fixed by nature, a velocity which cannot be increased or diminished except by the use of force [violenza] or resistance.
>
> SIMP. There can be no doubt but that one and the same body moving in a single medium has a fixed velocity which is determined by nature and which cannot be increased except by the addition of momentum [impeto] or diminished except by some resistance which retards it.
>
> SALV. If then we take two bodies whose natural speeds are different, it is clear that on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. Do you not agree with me in this opinion?
>
> SIMP. You are unquestionably right.
>
> SALV. But if this is true, and if a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, then when they are united, the system will move with a speed less than eight; but the two stones when tied together make a stone larger than that which before moved with a speed of eight. Hence the heavier body moves with less speed than the lighter; an effect which is contrary to your supposition. Thus you see how, from your assumption that the heavier body moves more rapidly than the lighter one, I infer that the heavier body moves more slowly.
>
> SIMP. I am all at sea because it appears to me that the smaller stone when added to the larger increases its weight and by adding weight I do not see how it can fail to increase its speed or, at least, not to diminish it.
>
> SALV. Here again you are in error, Simplicio, because it is not true that the smaller stone adds weight to the larger.
>
> SIMP. This is, indeed, quite beyond my comprehension. (Galilei 1914, pp. 62–63).

Gendler nicely summarizes this kind of Galilean mental modeling stressing that we are dealing with an admirable example of *Gedankenexperiment* (thought experiment) in which we imagine that a heavy and a light body are strapped together and dropped from a significant height:

[25] Weisberg distinguished between various kinds of idealization: Galilean, minimalist (still devoted to reveal the most important causal powers at stake), and multiple-models (devoid of a single representation ideal, widespread for example in biology and social science).

> What would the Aristotelian expect to be the natural speed of their combination? On the one hand, the lighter body should slow down the heavier one while the heavier body speeds up the lighter one, so their combination should fall with a speed that lies between the natural speeds of its components. (That is, if the heavy body falls at a rate of 8, and the light body at a rate of 4, then their combination should fall at a rate between the two […]. On the other hand, since the weight of the two bodies combined is greater than the weight of the heavy body alone, their combination should fall with a natural speed greater than that of the heavy body. (That is, if the heavy body falls at a rate of 8 and the light body with a rate of 4, their combination should fall at a rate greater than 8.) But then the combined body is predicted to fall both more quickly, and more slowly, than the heavy body alone. The way out of this paradox is to assume that the natural speed with which a body falls is independent of its weight: "both great and small bodies […] are moved with like speeds" (Gendler 1998, p. 403).

Is this modeling a fiction, a surrogate, an idealization, an abstraction, a credible world of the target system? Surely these attributes do not appropriately characterize this Galileo's epistemic act, which cognitively attacks the Aristotelian views on motion. Let us explain why. For the Aristotelian, the daily experience seems to confirm that heavier bodies fall faster than the lighter ones. Nevertheless, when the Aristotelian sees two stones of different weights fall the ground with similar speeds, this requires an explanation.[26] Two auxiliary assumptions can be provided, the Galilean one in terms of air resistance, the Aristotelian one which complains that the bodies have not been dropped from a height sufficiently great. What the Galilean thought experiment provides to the Aristotelian is not a new empirical knowledge of the external world but a sudden new belief, or a "conceptual reconfiguration", concerning the independency between speed and weight of falling bodies, and the *kind of thing* natural speed might be as a new *physical property*, as Gendler says (Gendler 1998, pp. 408–409).

Given the fact the modeling activity provided by this thought experiment is not posterior to the conceptual "reconfiguration" of the empirical data, it could hardly be classified as fictional or as a surrogate of them, it is instead *constitutive* of the possible reconfiguration itself: "Prior to contemplation of the case, there was no room on the Aristotelian picture for the thought that natural speed might be constant, not varying—that it might be dependent not on some specific features of the body in question, but only on the fact that it is a body at all" (Gendler 1998, p. 412). The old Aristotelian idea of natural speed does not make sense anymore "like phlogiston, it disappears into the ether of abandoned concepts" (cit.) The model provided by the thought experiment is not a simple way of modifying the Aristotelian perception of falling bodies, but a transformation of the "schematization" of the percepts themselves, to use the Kantian efficacious word, which makes them intelligible in a novel way. And, like experiments in science, this good thought experiment is not evanescent and fuzzy, but clear, *repeatable*, and *sharable*, in so far as it can involve unambiguous constructive representations in various human agents.

[26] Philosophy of science has often stressed that theories are undetermined by evidence, such as in the case of the conventionalist tradition (Magnani 2001b, Chap. 5).

In this case the model is "crucial": "There will, no doubt, be many cases where the role of the imagery is simply heuristic. But there will also be cases where the role of the imagery is […] epistemically crucial" (Gendler 2004, p. 1161).[27] This "crucial" creative role is also stressed by Nersessian (1993, p. 292) who, describing Mach's seminal ideas on the *Gedankenexperiment*, reminds us that "[…] while thought experimenting is a truly creative part of scientific practice, the basic ability to construct and execute a thought experiment is not exceptional. The practice is highly refined extension of a common form of reasoning […] by which we grasp alternatives, make predictions, and draw conclusions about potential real-world situations" (Nersessian 1993, p. 292).

Instead of seeing Galilean model as a fiction, it has to be considered an *actual* representation,[28] which helps discover—and justify—in this case in a precise *model-based* non-propositional way, what sorts of motions (and objects) we think plausible in the world. The door that provides access to further mathematical refinement and experimental research concerning the target system is finally opened. It will be only after having fruitfully built the complete Galilean mathematized theory of motion that the mental model provided by the thought experiment in question can appear, bit just appear, fictional, a surrogate, and so on. Moreover, it is only at this later stage that also a clear concept of approximation (and, in turn, of de-idealization) of related models will acquire a rigorous and complete sense.[29] No distortions are present in the presupposed "idealization" of this Galilean thought experiment, simply because the new schematization of the target is the fruit itself of the modeling activity, and we cannot provide a distortion of objects/targets that are not yet available. If still we want to say that the model shows itself as an idealization, this is simply because it belongs to modern physics, which on the whole, Galileo teaches us, idealizes.

A further remark which takes advantage of Cartwright's epistemology of models and capacities can be useful to grasp the point about Galilean mental modeling. Treating Sugden's problem of models as credible worlds (that I have quoted above

[27] The basic epistemological and cognitive aspects of thought experiments are nicely illustrated by Arcangeli (2010), who stresses their role in producing new knowledge and the useful distinction between their icastic or recreative character.

[28] "[…] the person conducting the experiment asks herself: 'What would I say/judge/expect were I to encounter circumstances XYZ?' and then finds out the (apparent) answer. This technique is common in linguistics, where the methodology is used to ascertain the grammaticality of sentences, the meanings of phrases, the taxonomic categories of words, and so on. And it is, on one view at least, a central element of moral reasoning: we think about particular imaginary cases, observe the judgements that they evoke in us, and use these judgements as fixed points in developing our moral theories" (Gendler 1998, p. 414).

[29] A deep analysis of the relationships between idealization, approximation (and de-idealization), which is also in part in tune with my observations above, is provided by Portides (2007, p. 708): "I employ this analysis of the process of construction of representational models to demonstrate that idealisation, and its converse process of de-idealisation, is present at every level of scientific theorising whereas the concept of approximation becomes methodologically valuable, and epistemically significant, either when a tractable mathematical description of a de-idealising factor is needed or after a certain point in the process is reached when a given theoretical construct (i.e. a scientific model) may be proposed for the representation of a physical system".

in Sect. 4.4), Cartwright contends that "[…] the license to move from the results in the model about what happens when a cause is exercised without impediment to a contribution that the cause will make in all situations of some designated category depends on the assumption that the cause has a stable contribution to make, and that assumption must be supported by evidence from elsewhere. This is part of the way in which Sugden's own view relies on the logic of capacities" (Cartwright 2009, pp. 53–54). It is very easy for Cartwright to add that capacities in science are characterized by some additional "premises": (1) "stable contribution" of the envisaged cause (eventually to be measured) in the real-world situation is not necessarily the same it does in the model, when we know that some other cause can have generated the effect in question; (2) the contribution the capacity makes in the model, the result "is exported to understand or predict in real-world situations where the cause that carries that capacity operates even when we do not expect the overall results to be the same in those situations that have results similar to those situations as they are in the models" (p. 54).

This is an important point, Cartwright says, because Sugden's account based on credible worlds simply looks at the real-world situation that presents results similar to those in the model and then infers by "abduction" that the causes are the same. Here a *bad example* of the fallacy of affirming the consequent (abduction) is committed: we face the cognitive activity of inferring from the same effect to the same cause (pp. 54–55) and not, on the contrary, the fact that "whenever the same cause appears as in the model, the same effect will appear", because we can do this given the fact the model is based on a robust hypothesis about the complex relationships between cause and effect. Indeed, in this case, the abduction as "inferring from same effect to same cause" is highly uncertain, and it does not tell us that the model furnishes a stable contribution, which instead should only be related to the level of abstraction at which to describe the cause and the effect. It is the presence of more abstract concepts which describe the causes and effects that characterizes the epistemological quality of the model.

In the Galilean thought experiment I have illustrated above the bodies are envisaged as masses, and gravity is implied: this is exactly what is at the basis of the fertile exportation of conclusions from the model to the world, and of the possibility of finding a suitable schematization through mathematization. Indeed, Cartwright observes "Say we have a model about the planetary system. In the model we deduce that planets are caused by gravitational attraction to accelerate towards the sun. Is the motion of cannonballs towards the earth a similar effect so that we might do an abduction to similar causes? It is if we describe both the cannonballs and the planets as compact masses. Otherwise the abduction is farfetched" (p. 57). I must note that in the perspective of this important distinction the epistemological divergence between static and dynamic aspects of science is still at stake. In the Galilean case, and by adopting a dynamic perspective on science, abduction at stake is good and "creative" *because* we deal with the abductive process that concerns the *first* construction of modern physics. Otherwise, if we already possess the complete laws of Galilean physics—by adopting in this case a static perspective—the related model is seen exporting to the real situation thanks to a causal explanation through de-idealization.

In the case discussed above, of the model as a generic "credible world", the model is instead "shallow"—as it happens in the case of simple analogue economic models—because it does not lead to discover proper capacities—in Cartwright's sense—and unfortunately basic principles are neither available nor "foreseeable" through a working discovering modeling process, to which the model itself eventually strategically belongs. In the case of these shallow models Cartwright nicely concludes "the worry is not just that the assumptions are unrealistic; rather, they are unrealistic in just the wrong way" (p. 57). In this case models certainly are isolating devices, but they isolate in the wrong way, and induction[30]—in Sugden'sense, even if cautious—from the model to a real situation results to be a clear hasty generalization. This does not mean that these shallow models do not provide knowledge about target systems, but this knowledge is very limited and unsatisfactory in the light of the decent epistemological standards in terms of Cartwright's capacities.

To conclude, coming back to the problem of fictionalism and its discontents, Galileo is explicitly clear about the distinction between science (he calls "philosophy" in the following celebrated passage) and literary fiction:

> In Sarsi[31] I seem to discern the firm belief that in philosophizing one must support oneself upon the opinion of some celebrated author, as if our minds ought to remain completely sterile and barren unless wedded to the reasoning of some other person. Possibly he thinks that philosophy is a book of fiction by some writer, like the Iliad or Orlando Furioso, productions in which the least important thing is whether what is written there is true. Well, Sarsi, that is not how matters stand. Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth (Galilei 1957, pp. 237–238).[32]

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[30] Cartwright would say—and I agree with her—we are dealing in this case with an abduction and not with an induction.

[31] Lothario Sarsi of Siguenza is the pseudonym of the Jesuit Orazio Grassi, author of *The Astronomical and Philosophical Balance*. In *The Assayer*, Galileo weighs the astronomical views of Orazio Grassi about the nature of the comets, and finds them wanting (Galilei 1957, p. 231).

[32] As Bertolotti (2012) observes, the quotation obviously should not be used as an authority weapon against those who advocate the fictional nature of scientific models, because we would commit a fallacy, given the fact that to affirm that scientific models are fictions does not coincide with saying that the whole scientific endeavor has a fictional nature. Thus, the use of this quotation does not aim at getting definitively rid of fictionalism through the authority of one of the founding fathers of modern science.

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Chapter 5
The Genealogy of Abduction

᾽Απαγωγή Geometry, and Logic Intertwined

To further deepen the eco-cognitive character of abduction and hypothetical cognition in science a simple genealogy of logic is provided. Aristotle clearly states that in syllogistic theory local/environmental cognitive factors—external to that peculiar inferential process, for example regarding users/reasoners—are given up. At the same time in chapter B25 of the *Prior Analytics* Aristotle presents a seminal perspective on abduction: I contend that some of the current well-known distinctive characters of abductive cognition, and of abductive cognition in science, are already expressed, which are in tune with the EC-Model. By referring to the role of the method of analysis and of the middle terms in Plato's dialectic argumentation, considered as related to the diorismic/poristic process in ancient geometry, Aristotle is still pointing to the fundamental inferential and "distributed" role in reasoning of those externalities that substantiate the process of "leading away" (an expression which also translates what Aristotle calls ἀπαγωγή, that is "abduction").

5.1 Naïve Genealogy of Logic: Abduction and *Arche*-Validity

In Chap. 1 I have contended that, thanks to the so-called knowledge-enhancing abduction, truth can be attained in the absence of evidence; there are ideas, thoughts, and propositions about the world which turn to be true by virtue of considerations that lend them no evidential/empirical weight. They are truths that are not justified on the basis of evidence. We have to note that in this case we are not dealing with abduction or creative abduction in general, but with a specific creative process that *directly* leads to new knowledge, in the absence of empirical justification. This kind of abduction represents a special process of getting new true knowledge, which

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certainly and especially astonished our ancestors: even when not immediately subjectively recognized as true, soon the new hypothesis was often acknowledged and accepted as such, objectively and naturally, in the eco-cognitive dimension of the involved human collective. Obviously, a *new* truth of this type, is such because it is at the same time a truth considered *good* and *interesting*.

Let us create a naïve imaginary brief story referred to the cognitive past of our ancestors. We can simply guess that, as soon as they experienced that starting from some sensible or imaginary data, established as true, our ancestors were able to perform various cognitive processes—which we currently call abductive—to new "good" and "interesting" truths, they rapidly conceived the possibility of finding—starting from true and reliable data—objective, stable, learnable, and repeatable ways of getting other (eventually new) true results. In this perspective we can consider their first knowledge-enhancing abductions as related to the origin of what we can call *arche*-validity: a considerable part of creative abductions was seen as related to the non-arbitrary transition from reliable truths to interesting and new truths. So to speak, in their creative abductions our current validity was manifest as a much richer arche-validity, "materially" at work and stupefyingly—when shared and accepted—out there, reliable and destined to furnish non-fugitive truths, but truths endowed with various degrees of duration, stability, and goodness.

I have to stress the attention of the reader to the fact in the case of arche-validity I am not referring to abduction or creative abduction in general, but to those specific creative processes that abductively *directly* lead to new knowledge, in the absence of empirical justification (that is to knowledge-enhancing abductions, I have described in detail in Sect. 1.4 of Chap. 1). Of course if I would have stressed the attention to all those cases of ignorance-preserving abduction (see above, Chap. 1, Sect. 1.1), in which their *presumptive* character is at stake—that is in which presumptive results are looking for further "active" (for example empirical) evaluation—it would have been inconsistent to speak of truth generation and truth preservation as the dominant characters of arche-validity. Indeed, in our case of knowledge enhancing abduction "truth generation" is also, intrinsically and obviously, "truth preservation"; the material arche-validity of our imaginary ancestors certainly appeared as a form of truth preservation, but entangled with the relevance of the originality and goodness of the reached truths: that is, exactly, something in tune with the main cognitive virtues of what we now call creative abduction, which provides "new" (good and reliable) truths.

In summary, it seems likely that that kind of material validity[1] (I called arche-validity) exhibited by the first creative knowledge-enhancing abductions was obviously the condition of possibility of building later on the standard concept of valid-

[1]I am using here the jargon of mainstream logic—validity, etc.—applying it to this imaginary genealogical story of deduction: the standard concept of material validity is illustrated in Brandom (2000), as a case of a semantically valid inference, which instantiates an invalid syntactic form. I adopt the same term slightly modifying its meaning.

ity, rigorously established by the mainstream "logical" tradition.[2] After all, to preserve the reached truth and to derive from it other truths—by that "necessity" of reasoning which syllogisity imposes—first of all we certainly needed the reliable true knowledge contents themselves, already available, as the starting point, but also the establishment of some explicit and stable inferential rules and procedures. It is plausible to imagine that some inferential rules and procedures, even if hidden, were working in our archetypical abductive processes, when various human cognitive devices made possible the use of the first inferential mechanisms (propositional, model-based, manipulative, etc.) for reaching new truths of various type. For example, this is the case of the first religious, moral, or mathematical frameworks, immediately experienced as fruitful tools for making the world intelligible and manageable in a reliable and productive way. Probably, the first target was soon the one of possibly extracting and making explicit the cognitive/inferential tools, expressed thanks to oral and written language, which would have made humans able to reach other *new* truths starting from the already acquired ones: a very difficult task, unfortunately, which all researchers on creative abduction currently know.

5.1.1 Knowledge-Enhancing Abduction and Arche-Validity

As I have already said, when—for example taking advantage of the resources of natural language—I start from true assumptions and abductively arrive to a new true knowledge-enhancing result, I have created a first striking inferential example, objective and material, not only of the generation of new interesting truths (available out there, accepted as new truths by the human collective at stake) but also of truth preservation, that is—partially—of what we now could call *validity*. Currently, we know that validity does not suffice for premiss-conclusion argumental goodness, although it does suffice for truth-preservation. Logicians like their arguments to be sound—valid with only true premisses.[3] Others ask that premisses be at least well-backed. Soundness is also asked for or at least well-based premisses.[4] Unfortunately, we can also guess human beings soon realized that enhancing knowledge through what we now call "creative abduction" is due to processes that are contingent, and that cannot easily be made explicit and repeated. This is a kind of paradox: human beings abductively created new truths, interesting new truths, but soon realized it was very difficult to *explicitly* establish methods and abductive inferential routines

[2] We have to anticipate that the current notion of deduction or deductive validity is not what Aristotle meant by "syllogismos" (cf. below, Sect. 5.2). I am following Woods in contending that Aristotle considers validity a necessary condition of syllogismos and enlists it for that purpose as an undefined primitive of his logic. Syllogisity, therefore, is a proper subproperty of validity (Woods 2014).

[3] Soundness assures truth preservation, not truth. That is, sound: valid when premisses are assumed to be true.

[4] In the Sect. 5.1.2 below I will stress that Aristotle still draws an important distinction between a simple valid argument as an *anagkion*, and a *syllogismos* as a special case of it.

able to warrant—by that "necessity" advocated by Aristotle in the case of syllogisms[5]—the reaching of other *new* truths. Indeed, we have to acknowledge what I am illustrating in this chapter, that is that abduction is related to local, pragmatic, user-sensitive factors associated to situatedness, that is to factors that are subject to the influence of strong eco-cognitive constraints and chances. The paradox resorts to the fact that in the genealogy of the logical notion of validity there is the truth-creativity typical of arche-validity, that instead is expunged in the modern concept: so to speak, arche-validity is obliterated and basically lost by mainstream logical tradition.

In summary, the first knowledge-enhancing abductions probably were the ancient fathers of validity: but those cases (characterized by the reaching of interesting "new" truths from old truths) resulted contingent, material, and "rare". Better to pay attention to something certainly suggested by those striking events of truth production and truth preservation, but restricting the target of study to more manageable aspects. The end of this story as it occurred in ancient Greece is conventionally well-known: the idea of establishing syntactic, stable, and explicit rules for reaching new truths was abandoned and, thanks to Aristotle, syllogism definitely referred to the task of passing—by necessity—from available truths to other not available truths, and not to the task of extracting "creative" contingent and local ways of getting new interesting truths.

The issue of the origin of the more interesting truths, that, as we perfectly know, at least since Charles Sanders Peirce, is rubricated under the concept of abduction, was soon disregarded and removed,[6] certainly beyond Aristotle's intentions: the new invented Aristotelian *syllogistic* validity was seen as something related to idealized and universal features, scarcely *eco-cognitively* conditioned, where creativity is not at stake, and truth preservation guided by syntactic rules necessity-based is fundamental.

Indeed, even if present in Aristotle's *Prior Analytics* (cf. the following sections), the concept of abduction, as related to *creative* hypothetical cognition, at last is disregarded (almost removed) and substituted with the much more simple—and unsatisfactory from many perspectives—one of *induction* (ἐπαγωγή), also translated in English, in the case of ancient Greek texts, with the expression"leading in",[7] more appropriate to illustrate in universal and idealized explicit terms the inferential processes to new truths. Aristotle explicitly takes up the question of those states of knowing that are concerned with true, universal and necessary propositions (Aris-

[5]Of course, necessity is just only one criterion which can characterize the solution of an inferential problem. Also plausibility, probability, possibility, sufficiency, defeasibility are obviously legitimate (Woods 2013c, Chap. 8). On this point cf. the Sect. 6.2 of Chap. 6, this book.

[6]Bybee, dealing with abduction and rhetoric, ironically says: "One might claim [...] that if logic cannot adequately capture such legitimate inferences [abductions], then so much the worse for logic. [...] a theory ignoring inferential elements in discourse fails to account for our human ability (and our practice) to infer something we do not know on the basis of something we do know" (Bybee 1991, p. 283 and p. 298).

[7]We will soon see that the word abduction in ancient Greek texts, ἀπαγωγή, is usually translated as "leading away" or "reduction", and will explain their meaning.

totle 1993, A 33, 88b, 30ff., p. 45), and strongly suggests that *epagōgē*, made possible by the activity of *nous*, is sufficient for achieving *archai*, that is the firm starting points of syllogistic reasoning, and that indeed *archai* are achievable (Upton 1981, p. 174). In sum, Aristotle thinks that *epagōgē* and *nous* could achieve all true and necessary universal premisses that could function as the *archai* of demonstration/deduction.

In the *Posterior Analytics* Aristotle contends that "you cannot understand anything through a demonstration unless you know the primitive immediate principles", reached through induction, obviously (Aristotle 1993, B, 19, 99b, 20–22, p. 72).[8] We learn about properties of particular things through perception and we understand universals (which are imperceptible) through induction: induction as a method of grasping universals is closely related to sense-perception, which is not sufficient to reach them. Aristotle is pretty clear, induction and deduction govern the main characters of high-level "intellectual" reasoning, but are privileged even in the case of rhetoric:

> All teaching and all learning of an intellectual kind proceed from pre-existent knowledge. This will be clear if we study all the cases: the mathematical sciences are acquired in this way, and so is each of the other arts. Similarly with arguments, both deductive and inductive: they effect their teaching through what we already know, the former assuming items which we are presumed to grasp, the latter proving something universal by way of the fact that the particular cases are plain. (Rhetorical arguments too persuade in the same way – either through examples, which is induction, or through enthymemes, which is deduction) (Aristotle 1993, A, 1, 71a, 1–11,p. 2).

5.1.2 *Deduction as Eco-Cognitive Immunization: Removing the Origins of Truths*

To further deepenmy simple and abstract genealogy of logic it is very useful to quote Aristotle's passage below, who clearly states that in syllogistic theory local/environmental cognitive factors—external to the inferential process, regarding users/reasoners, are given up. Indeed, to define syllogism[9] Aristotle himself expressly contends that the *necessity* of this kind of reasoning is related to the circumstance that "no further term from outside (ἔξωθεν) is needed", in sum syllogism is the fruit of a kind of eco-cognitive *immunization*:

> A deduction (συλλογισμὸς) is a discourse (λόγος) in which, certain things having been supposed, something different from the things supposed results of necessity because these things are so. By "because these things are so", I mean "resulting through them," and by "resulting through them" I mean "needing no further term from outside (ἔξωθεν) in order for the necessity to come about" (Aristotle 1989, A1 24, 20–25, p. 2).

[8] On Aristotle's induction, a good relatively recent summary is contained in Gálik (2006).

[9] Aristotle insists that all syllogisms are valid (by definition) (Woods 2014), there is no such thing as an invalid syllogism. We know the syllogistic tradition began to relax this requirement quite early on.

Contemporary logicians as Gabbay and Woods clearly echo Aristotle's contention, when they say:

> From its inception, logic has sought to serve two masters. One is to specify and characterize sets of intuitively logical properties and relations that are definable for propositional structures or for these in relation to abstractively set-theoretic structures. Here the main goal is to get these target notions right, where the question of rightness is intimately bound up with the issue of rightness for. Accordingly, a logic gets consequence right if it is right for sets of sentences taken without reference to *factors of speaker-use and other pragmatic considerations* (Gabbay and Woods 2005, p. 241, emphasis added).

The canons of strict reasoning are the focus of the new Aristotelian syllogistic logic and of the subsequent developments, that is the extraction and clarification of the inference-rules: truth conditions are guaranteed by appropriate syntactic inference rules. Aristotle favors an intrinsic view of the rules which govern good arguments, to create those constraints that depict classical validity, thought in terms of "necessitation". A good syllogism is a valid argument whose premisses are *non-redundant*, whose conclusion *repeats no premiss*, and whose conclusion is *non-ambiguously multiple* [also, premisses do not have to contain a proposition and its contradictory]. Reasoning by strict (or truth-preserving) consequence "is always a matter of evacuating information already present in premisses. [...] Under Aristotle's constraints every piece of archeological reasoning evacuates its premisses of their total syllogistic information, which is then repackaged in the single proposition that serves as the reasoning's conclusion" (ibid.)

As indicated above, it seems that Aristotle is operating with a twofold conception of logic: a general theory of two-person argument, and an account of the syllogism, considered as a context-free sequence of (on most accounts) three categorical propositions, of which the terminal member is the conclusion and the other two are premisses. Aristotle did not expressly draw the dynamic argument vs. static argument distinction, that is Woods' distinction between syllogisms-as-such and syllogisms-in-use (this last ones considered embedded in a dialectic cognitive environment). As far as I can understand, I agree with Woods that, even so, it is clear that these are distinctions that Aristotle honors in a systematic way. Based on this assumption, Woods contends that

> At *Prior Analytics* A32, 47a 33–35,[10] Aristotle draws an important distinction. He says that a valid argument is an *anagkion*, and a *syllogismos* is a special case of it. We find in this distinction two notions of following from, one which I'll call "straight necessitation" and the other "syllogistic necessitation". Corresponding is the distinction between straight consequence and syllogistic consequence. In Aristotle's earlier logic, straight consequence is a theoretical primitive. These contrasts are instructive in a number of ways. Since Aristotle doesn't define it, it may be impossible to say with certainty whether straight consequence is monotonic. But it is clear that syllogistic consequence is not. If an argument is a syllogism, its conclusion is a syllogistic consequence of its premisses. If a new premiss is added, then

[10] "We are misled in cases like these by the fact that something necessary results from what is supposed, because a deduction is also necessary. But 'necessary' is more extensive than 'deduction': for every deduction is necessary, but not everything necessary is a deduction" (Aristotle 1989, A32 47a, 33–35, p. 51).

> by the requirement that syllogisms not have redundant premisses, the conclusion may still be a straight consequence of those premisses, but it cannot be a syllogistic consequence of them. [...] Thus neither the notion of nonmonotonicity nor its tie to monotonic consequence is new or even recent. Each arose with the very founding of systematic logic (Woods 2013c, p. 257).[11]

I have to provide some conclusive considerations regarding the interplay between arche-validity, I have at least linked in the previous subsection to knowledge-enhancing creative abduction, and syllogistic validity, in the light of the Aristotelian perspectives. If we acknowledge that Aristotle explicitly recognizes a distinction between what we now call validity and what he would insist is a proper subproperty of it, namely, syllogisity (the property of being a syllogism), obviously the conditions on syllogisity include very tight conditions on premiss-selection. It is patent that in the perspective of syllogisms Aristotle's conditions are not remotely close to Peirce's conditions on abduction. Furthermore, on Woods' reading of Aristotle, one apprehension of first principles arises causally from substantial disciplined empirical investigation of what would turn out to be the causally triggering data of their apprehension. There is room here for a Peircean story, in answer to the question "What would occasion those causal devices to fire?", for example taking advantage of the Peircean treatment of perception as abduction, I have introduced above in Sect. 1.2 of Chap. 1, this book.

Also, still following Woods, Aristotle seems to draw (or at least implicitly honors) a distinction, between concretely dynamic arguments, which are social events subject to situatedness and all the rest (I will work on this issue in the next sections), and arguments in the abstract and static sense, in which agents, agendas, and context, have no appearance whatever. These latter are syllogisms. The former include, among others, refutation arguments. Aristotle's whole point in *On Sophistical Refutations* is that we cannot get the logic of dynamic arguments right unless we find a load-bearing role for syllogisms. There arises, therefore, a distinction unannounced by Aristotle, between syllogisms-as-such and syllogisms-in-use, either as would-be refutations or would-be scientific demonstrations. There are no abductive constraints on premiss-selection for as-such syllogisms. There are plenty of in-use constraints on premisses for syllogisms-in-use, some of which admit—or at least leave room for—Peircean abductive interpretation.

In summary, in this section on "The Genealogy of Logic" I wanted first of all to alert the reader to the fact that even the founder of deductive logic is vastly open to the necessity of "third way considerations"[12] in the generation of premisses eligible for syllogisms-in-use. Not even Aristotle thinks—contrary to occasional assurance otherwise—that the principles that drive the almost valid perfectibility proof of *Prior Analytics* are syllogistic in character, notwithstanding that some of them are rule-counterparts of syllogisms in the first figure. But let us not forget that the logic of syllogisms-in-use and as-such are logics that pivot on a truth-preserving conse-

[11] Not only, Woods and other authors also think Aristotle considered possible an extension of syllogistic logic to modal contexts.

[12] I am adopting Woods' lexicon (Woods 2013c). Cf. also below, this subsection.

quence relation. So, at best, the closeness to Peirce's implied relation of abductive consequence to Aristotle's syllogistic consequence is slight, at least if we restrict our reference to the presumptive ignorance-preserving cases of abduction. In this last case better is the suggestion that Peirce's abductive conclusion relation is not really a relation of logical consequence. Of course, this is not to overlook, by the way, Aristotle's ready embrace of at least the idea of systematic accounts of non-truth-preserving premiss-conclusion reasoning. Second, I also wanted to stress that the founder of logic's expansive research program has no time for the idea that in inferential contexts validity *suffices* for the goodness of premiss-conclusion reasoning.

What happened to abduction, so clearly depicted by Aristotle, as we will soon see in the following sections? Killed by induction and by deductions as valid syllogisms, beyond Aristotle, *abduction (ἀπαγωγή)* will be definitely buried in the necropolis of inauspicious concepts, but only provisionally, until its resurgence during the XIX century, thanks to Peirce, and later on, in the second part of XX century, thanks to the birth of artificial intelligence (AI) and to renovated studies in semiotics and non-standard logic. Currently the revival of studies on abduction can further benefit from recent explicit Woods' claim about the need of a *naturalized* logic of the so-called *third-way reasoning*, I have just quoted above,[13] which refers to those kinds of inference that owe their "rightness to the meeting of standards other than deductive validity and inductive strength", certainly overworked and overvalued by logicians, and that instead show the capacity to reach good and reliable results. Third-way reasoning refers to those cases of human reasoning such as abduction, but also to many other kinds of the so-called fallacies, disregarded or simply considered irremediable errors by logic since its ancient and modern beginnings. The study of third-way reasoning aims at going beyond the logical obsession for *consequence-having*, opening to the analysis of the structure of the so-called *consequence-drawing* (eventually truth-preserving or truth-generating), typical of various actual human performances (Woods 2013c, pp. 3, 24, 293, and 518). Woods' recovering of the cognitive and inferential positive value of fallacies basically concerns: *ad hominem*, *ad populum*, *ad verecundiam*, *ad ignorantiam*, affirming the consequent (abduction), denying the antecedent, begging the question (and circularity), many questions, hasty generalization, equivocation, gambler's fallacy, base rate, and *post hoc, ergo propter hoc* (including false cause).

5.2 Aristotle's ἀπαγωγή and Its Eco-Cognitive Openness

I have illustrated in the previous section that the theory of syllogism is related to a kind of eco-cognitive immunization. At the same time I have anticipated that Aristotle presents a seminal perspective on abduction, which is instead in tune with my EC-Model: indeed Aristotle's ἀπαγωγή exhibits a clear eco-cognitive openness.

[13] On this issue cf. also the recent (Magnani 2015).

In the following sections I will describe the role of the method of analysis and of the middle terms in Plato's dialectic argumentation, considered as related to the diorismic/poristic process in ancient geometry, showing it as a theoretical heritage which informs Aristotle's chapter B25 of *Prior Analytics*, concerning abduction, introduced in this section. Thanks to Aristotle we can gain a new positive perspective about the "constitutive" eco-cognitive character of abduction.

It seems Peirce was not satisfied with the possible Apellicon's correction of Aristotle's text about abduction: "Indeed, I suppose that the three [abduction, induction, deduction] were given by Aristotle in the *Prior Analytics*, although the unfortunate illegibility of a single word in his MS, and its replacement by a wrong word by his first editor, the 'stupid' [Apellicon],[14] has completely altered the sense of the chapter on Abduction. At any rate, even if my conjecture is wrong, and the text must stand as it is, still Aristotle, in that chapter on Abduction, was even in that case evidently groping for that mode of inference which I call by the otherwise quite useless name of Abduction—a word which is only employed in logic to translate the ἀπαγωγή of that chapter" (Peirce 1931–1958, 5.144–145, *Harvard Lectures on Pragmatism*, 1903).

At this point I invite the reader to carefully follow Aristotle's chapter from the *Prior Analytics* quoted by Peirce. In this case the discussion turns arguments that transmit the uncertainty of the minor premiss to the conclusion, rather than the certainty of the major premiss. If we regard uncertainty as an epistemic property, then it is reasonably sound also to say that this transmission can be effected by truth-preserving arguments: by the way, it has to be said that this is not at all shared by the overall Peirce's view on abduction, which is not considered as truth preserving (with the exception of the knowledge-enhancing case—see above, Sect. 1.4, Chap. 1 of this book—which instead depicts a kind of "casual" truth preserving character).

I want first of all to alert the reader that in the case of the Aristotelian chapter, abduction does not have to be discussed keeping in mind the schema of the fallacy of affirming the consequent. What is at stake is abduction considered either (1) the classification of a certain "unclear" dynamic argument in a *context-free* sequence of three propositions; or (2) the introduction in a similar "unclear" dynamic three-propositions argument (in this case no longer *context-free*) of few new middle terms. Hence, ἀπαγωγή —leading away (abduction)—is, exactly (in the Aristotelian words we will soon entirely report below)

1. the feature of an argument in which "it is clear (δῆλον) that the first term belongs to the middle and unclear (ἄδηλον) that the middle belongs to the third, though nevertheless equally convincing (πιστόν) as the conclusion, or more so" (Aristotle 1989, B25, 69a, 20–22, p. 100);
2. the introduction of suitable middle terms able to make the argument capable of guiding reasoning to substantiate an already available conclusion in a more plausible way: Aristotle says in this way we "are closer to scientific understanding": "if the middles between the last term and the middle are few (ὀλίγα)

[14] Apellicon was the ancient editor of Aristotle's works. Amazingly, Peirce considers him, in other passages from his writings, "stupid" but also "blundering" and "scamp" (Kraus 2003, p. 248).

(for in all these ways it happens that we are closer to scientific understanding (πάντως γάρ ἐγγύτερον εἶναι συμβαίνει τῆς ἐπιστήμης))" (Aristotle 1989, B25, 69a, 22–24, p. 100).

It is clear that the first case merely indicates a certain status of the uncertainty of the minor premiss and of the conclusion and of the related argument; the second case, from the perspective of the eco-cognitive model of abduction, is much more interesting, because directly refers to the need, so to speak, of "additional/external" interventions in reasoning. It has to be said that Aristotle does not consider the case of the creative reaching of a *new* conclusion (that is of a creative abductive reasoning, instantly knowledge-enhancing or simply presumptive): however, I will illustrate in the following subsections that this case appears evident if we consider the method of analysis in ancient geometry, as a mathematical argument which mirrors the propositional argument given by Aristotle, provided we consider it in the following way: *we do not know the conclusion/hypothesis, but we aim at finding one thanks to the introduction of further "few" suitable middle terms*.

The following is the celebrated Chapter B25 of the *Prior Analytics* concerning abduction. The translator usefully avoids the use of the common English word *reduction* (for ἀπαγωγή): some confusion in the literature, also remarked by Otte (Otte 2006, p. 131), derives from the fact reduction is often rigidly referred to the hypothetical deductive reasoning called *reductio ad absurdum*, unrelated to abduction, at least if intended in Peircean sense. Indeed, the translator chooses the bewitching expression "leading away".

> XXV. It isleading away (ἀπαγωγή) when it is clear (δῆλον) that the first term belongs to the middle and unclear (ἄδηλον) that the middle belongs to the third, though nevertheless equally convincing (πιστόν) as the conclusion, or more so; or, next, if the middles between the last term and the middle are few (ὀλίγα) (for in all these ways it happens that we are closer to scientific understanding (πάντως γάρ ἐγγύτερον εἶναι συμβαίνει τῆς ἐπιστήμης)). For example, let A be teachable, B stand for science [otherwise translated as "knowledge"], and C justice [otherwise translated as "virtue"]. That science is teachable, then, is obvious, but it is unclear whether virtue is a science. If, therefore, BC is equally convincing (πιστόν) as AC, or more so, it is a leading away (ἀπαγωγή) (for it is closer to scientific understanding (ἐγγύτερον γάρ του ἐπίστασθαι) because of taking something in addition, as we previously did not have scientific understanding (ἐπιστήμη) of AC). Or next, it is leading away (ἀπαγωγή) if the middle terms between B and C are few (ὀλίγα) (for in this way also it is closer to scientific understanding (εἰδέναι)). For instance, if D should be "to be squared," E stands for rectilinear figure, F stands for circle. If there should only be one middle term of E and F, to wit, for a rectilinear figure together with lunes to become equal to a circle, then it would be close to knowing (ἐγγύσάν εἴη τοῦ εἰδέναι). But when BC is not more convincing (πιστότερον) than AC and the middles are not few (ὀλίγα) either, then I do not call it leading away (ἀπαγωγή). And neither when BC is unmiddled: for this sort of case is scientific understanding (ἐπιστήμη) (Aristotle 1989, B25, 69a, 20–36, pp. 100–101).

This passage is very complicated and difficult. I have indicated words and expressions in ancient Greek because they stress, better than in English, some of the received distinctive characters of abductive cognition:

1. ἄδηλον [unclear] refers to the lack of clarity we are dealing with in this kind of reasoning; furthermore, it is manifest that we face with a situation of ignorance—something is not known—to be solved, that kind of ignorance I have already fully illustrated in Chap. 1 of this book;
2. πιστόν [convincing, credible] indicates that degrees of uncertainty pervade a great part of the argumentation;
3. the expression "then it would be close to knowing (ἐγγύσάν εἴη τοῦ εἰδέναι)", which indicates the end of the conclusion of the syllogism,[15] clearly relates to the fact we can only reach credible/plausible results and not ἐπιστήμη; Peirce will say, similarly, that abduction reaches plausible results and/or that is "akin to the truth";
4. the adjective ὀλίγα [few] dominates the passage: for example, Aristotle says, by referring to the hypotheses/terms that have to be added—thanks to the process of leading away—to the syllogism: "Or next, it is leading away (ἀπαγωγή) if the middle terms between B and C are few (ὀλίγα) (for in this way also it is closer to scientific understanding (εἰδέναι))". The term ὀλίγα certainly resonates with the insistence on minimality that dominates the AKM model of abduction I have illustrated above, Sect. 1.1.

I favor the following interpretation (Phillips 1992, p. 173): abduction denotes "the method of argument whereby in order to explain an obscure or ungrounded proposition one can lead the argument away from the subject to one more readily acceptable".

In the passage above Aristotle gives the example of the three terms "science" [knowledge], "is teachable", and "justice" [virtue], to exhibit that justice [virtue] is teachable: Aristotle is able to conclude that justice [virtue], is teachable, on the basis of an abductive reasoning, that is ἀπαγωγή. A second example of *leading away* is also presented, which illustrates that in order to make a rectilinear figure equal to a circle only one additional middle term is required; that is the addition of half circles to the rectilinear figure.

I do not think appropriate to consider, following Kraus (2003, p. 247), the adumbrated syllogism (first Aristotelian example in the passage above)

AB Whatever is knowledge, can be taught
BC Virtue (e.g., justice) is knowledge
AC Therefore virtue can be taught

just an example of a valid deduction, so insinuating Peirce's interpretation failure. Indeed, it seems vacuous to elaborate on the syntactic structure of the involved syllogism, as Kraus does: the problem of abduction in Chapter B25 is embedded in the activity of the inferential mechanism of "leading away" performed thanks to the introduction of new terms, as I explained above. He also says that the second Aristotelian example

[15] I have already said above that Aristotle insists that all syllogisms are valid; there is no such thing as an invalid syllogism. The syllogistic tradition began to relax this requirement: here, and in the following sections, I will use the term syllogism in this modern not strictly Aristotelian sense.

Whatever is rectilinear, can be squared
A circle can be transformed into a rectilinear figure by the intermediate of lunes
Therefore, a circle can be squared

still a simple deduction, was questionably supposed by Peirce to be fruit of the correction of Aristotle's original text due to the "stupid" Apellicon, considered responsible of blurring Aristotle's reference to abduction. Indeed, Kraus suggests that, following Peirce, the original text would have to be the following:

Whatever is equal to a constructible rectilinear figure, is equal to a sum of lunes
The circle is equal to a sum of lunes
Therefore, the circle is equal to a constructible rectilinear figure

which indeed fits the Peircean abductive schema. At this point Kraus (Kraus 2003, p. 248) ungenerously—and, in my opinion, erroneously, as I have already said—concludes "Peirce's argument surely is bad. It begs the question". I disagree with this skeptical conclusion.

We need a deeper and better interpretation of Aristotle's passage. To this aim we need analyze some aspects of Plato's dialectic,[16] ancient geometrical cognition, and the role of middle terms: I am convinced we will gain a new positive perspective about the constitutive eco-cognitive character of abduction, just thanks to Aristotle himself.

5.3 Geometry and Logic: The Role of Constructions and Middle Terms in Abduction

Many researchers (for example Faller (2000); Karasmanis (2011)) contend that Aristotle's passage above reworks two examples already given by Plato in the *Meno* dialogue (Plato 1977). The interpretative conundrum is related to the role played by the middle term: first of all Aristotle points out that abduction is such "when it is clear (δῆλον) that the first term belongs to the middle and unclear (ἄδηλον) that the middle belongs to the third, though nevertheless equally convincing (πιστόν) as the conclusion, or more so". This good situation does not always hold. In this last case, Aristotle says that to have an abduction an act of *introducing* "something in addition" is necessary, and the addition can also be characterized by more middle terms: "That science is teachable, then, is obvious, but it is unclear whether virtue is a science. If, therefore, BC is equally convincing (πιστόν) as AC, or more so, it is a leading away (ἀπαγωγή) (for it is closer to scientific understanding (ἐγγύτερον γάρ του ἐπίστασθαι) because of taking something in addition, as we previously did not have scientific understanding (ἐπιστήμη) of AC). Or next, it is leading away

[16] I agree with the following claim by Woods: "Whatever else it is, a dialectical logic is a logic of consequence-drawing" (Woods 2013a, p. 31), that is not merely a logic of "consequence-having" (on these concepts cf. above the last paragraph of Sect. 5.1).

(ἀπαγωγή) if the middle terms between B and C are few (ὀλίγα) (for in this way also it is closer to scientific understanding (εἰδέναι)).”

A more careful analysis of the passage requires a reference to some central Plato’s ideas about dialectic argumentation. Already in the *Meno* dialogue Socrates “dialectically” reflects upon the various relationships between virtue, knowledge, and teachability and also furnishes the example of a geometrical “analysis” (or “method of hypothesis”), so-called in the literature pertaining ancient mathematics.[17]

5.3.1 Ἀπαγωγή *and Geometry*

The method of analysis in geometry, already employed by Hippocrates of Chios, can involve, to creatively solve the problem at hand, (1) a *diorism*, which resorts to the finding of the definite conditions under which one construction might be inscribed within another, and (2) a *porism*, which refers to direct or intentional discovery through suitable higher constructions related to the finding of indefinite cases, eventually capable of innumerable solutions, so looking for a higher unifying solution. What is important to note is that in the method of analysis new strategic constructions have to be found: translated in syllogistics terms, this means it is necessary “taking something in addition”, as Aristotle says in the passage above, that is a new “middle” (or new “middles”).[18]

The activity of finding new geometrical constructions (or new middle terms) is clearly a heuristic process[19]—based on a dynamics of subsequent steps—aiming at discovering new geometrical truths, a process which is a case of ἀπαγωγή, that is of *abduction*, also in the modern sense of the word.[20] In a syllogistic perspective, which

[17] Cf. for example (Hintikka and Remes 1974).

[18] Porism is usually translated as lemma or corollary. I am referring here to another meaning that goes deeper into the philosophy of ancient Greek mathematics. In this case porisms are active in solving problems in which it is necessary to adopt new suitable constructions. The most famous collection of porisms of ancient times was the book *The Porisms* of Euclid. This work is lost: the trace survived thanks to the *Collection* of Pappus. Playfair noted that, thanks to porisms, the analysis of all possible particular cases of a proposition would establish that: (1) under some conditions a problem becomes impossible; (2) under some other conditions, indeterminate or related to an infinite number of solutions the problem can be solved. Classical works on porisms are (Playfair 1882; Simson 1777). The concept is controversial and still subjected to studies and interpretations provided by researchers in ancient philosophy: a rich reference to the literature available is given in (Karasmanis 2011, pp. 39–40).

[19] I have provided an analysis of heuristics in the light of abductive cognition in Magnani (2014). Heuristics, in so far they can be algorithmically rendered, are still rules-based, even if these rules are weaker from the normative point of view, when compared with the logical rules, and typically closer to what actual human reasoners do.

[20] In (Magnani 2009, Chaps. 2 and 3), I illustrate how abductive cognition is characteristically also related to various examples of diagrammatic reasoning (based on porisms, we can say), for example in the case of the discovery of the first non-Euclidean geometries.

regards arguments in general, not necessarily geometrical, the method of analysis still resorts to the activity performed for finding the suitable middle term(s) able to substantiate the reasoning at play.

It is absolutely important to note that in Plato the *logico-dialectical* anticipation of the Aristotelian syllogistic relationship between virtue, knowledge, and teachability is directly derived from the geometrical example, as Socrates expressly says in the *Meno* dialogue (see below, the following subsection). From Hippocrates of Chios to Proclus, ἀπαγωγή is the fundamental pre-Euclidean method for solving problems, as a method of discovery, and at the same time also for proving theorems (Karasmanis 2011), no surprise that it is implicitly central in Plato and still explicitly present in Aristotle's *Prior Analytics*. In this perspective, we will soon see, the English translations "reduction" and "leading away" both stress the fact that the process involves a transition from a problem or theorem to another, which, if known or constructed, will make the original problem or theorem evident and solved (or potentially solved).

5.3.2 Ἀπαγωγή, *Dialectics, and Logic*

Socrates and Meno, by constructing the arguments on whether virtue is teachable are engaged in clarifying the following syllogism (obviously valid, but where both the second premiss and the conclusion are far from being reliable)

AB Whatever is knowledge, can be taught
BC Virtue (e.g., justice) is knowledge
AC Therefore virtue can be taught

Faller (2003a, b) explains that Socrates, exactly thanks to what Aristotle calls a "leading away" (ἀπαγωγή) argument—that is the introduction of new middles—, had established that since virtue is "good" and "there is nothing good that is not embraced by knowledge, our suspicion that virtue is a kind of knowledge would be well founded" (Plato 1977, 87d), consequently, Meno can say: "We must now conclude, I think, that it is; and plainly, Socrates, on our hypothesis that virtue is knowledge, it must be taught" (89c). In the Aristotelian terms exploited in Chapter B25:

AB Whatever is knowledge, can be taught
BC Virtue (e.g., justice) is knowledge

MC Virtue is good[21]
BM Good is knowledge

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[21] Karasmanis usefully notes that the term "good" is not given in the analogous Aristotelian example I have illustrated in the previous subsection. Aristotle only says that an intermediate term is introduced (Karasmanis 2011, p. 37).

AC Therefore virtue can be taught

The first premiss is evident, the second uncertain, and the conclusion is even more uncertain. We can arrive—using the Aristotelian words—"closer to scientific understanding (ἐγγύτερον γάρ του ἐπίστασθαι)", with the introduction of a new term "good" and the propositions "virtue is good" and "good is knowledge", which can *possibly* support the second premiss of the original syllogism.

Plato starts from AC, which reflects a situation of ignorance, a hypothesis *to be justified*, instead of its contrary; BC would guarantee the result but it has to be supported. MC, the "leading away" at stake, is the further hypothesis chosen to perform this task: MC results obvious and true.[22] Then Plato establishes that "good is knowledge" (BM) and concludes that "virtue is knowledge". Through this process (dialectical) AC is rendered—again, using the Aristotelian words—"closer to scientific understanding (ἐγγύτερον γάρ του ἐπίστασθαι)".

Meno accepts this conclusion but Socrates is not satisfied: to solve the problem we need—still in Aristotelian words—another "leading away". Indeed Socrates initiates a second argument consisting of a further hypothesis, that "if virtue is teachable, then there would be teachers of it". Unfortunately, because of the empirical fact that there are no teachers of virtue, virtue is not teachable, a conclusion which conflicts with the previous one about teachability. In sum, to prove that virtue is teachable it has been necessary to analyze its nature: "what is virtue"; it has been necessary this method of hypothesis to examine the features of an obscure subject.

First of all we have to note and remember that (1) in the example about virtue Plato adopts exactly the same method used in geometrical "analysis". We also have to stress that (2) we reached two conflicting conclusions (already available, one statement and its negation) and further steps would have to be performed to execute the *cutdown* process (cf. above, Sect. 1.2), to arrive to be "closer to scientific understanding (πάντως γάρ ἐγγύτερον εἶναι συμβαίνει τῆς ἐπιστήμης)", that is to a unique conclusion (the best result, which echoes abduction as the best explanation). Exactly in the spirit of Peircean original perspective on abduction, we have to select (and so to prefer) one of the two conflicting conclusions.

Again, let me stress that Plato's argumentation about virtue is the dialectic analogue of a diorismic/poristic geometrical process, which in turn substantiates the Aristotelian "taking something in addition", where various strategies can be activated: various kinds of arguments (for example the reaching of evident higher hypotheses from which the initial one can be deduced), considerations of simplicity, looking for consequences, (for example in terms of empirical ascertainments and testing), which are able not only to create new cognitive perspectives (fill-up aspect) but also to select (cutdown aspect) the multiple or conflicting flow of results.

[22]This proposition corresponds to that *arche* (ἀρχή) which was so called, in the case of the geometrical analysis, by Hippocrates of Chios (cf. Magnani 2001, Chap. 4).

5.3.3 *Geometry and Logic Intertwined:* ᾽Απαγωγή *and Its Eco-Cognitive Openness*

Geometrical analysis initially transforms a given problem into one that is more abstract and general: even if there are conflicting views in the available literature on the subject,[23] we can say that diorisms and porisms (often consisting in the depicting of locus[24] problems) favor a form of further geometrical cognition devoted—thanks to the study of auxiliary objects—to finding the conditions of possibility of an actual process of subsequent diagrammatic constructions, in turn finalized to solve the problem. Diorisms aim at determining the overall properties of the solutions, and so represent a wide range of mathematical activities, which "lead away" from the problem at hand to other unexplored porismic territories (diagrams and sentential proofs for example, but, for the sake of generality of various cognitive processes, we can also add other model-based or manipulatory activities totally eco-cognitively open). In the diorismic/poristic stage, the geometrician exploits the adopted auxiliary objects to show that a single solution is always possible, or if not, the limitations of the process or how many solutions there may be and how they are arranged (Saito and Sidoli 2010).

The process performs a *reduction* of the problem— caused by the hypothetical question to be solved—to another one (again, it is the Aristotelian syllogistic "leading away"), which we expect will enable us to solve the original problem (I have already said that in the Aristotelian passage above the word ἀπαγωγή is often translated with "reduction", and that we need interpret reduction as the transition to another cognitive sub-process and not as the *reduction ad absurdum*).

In the case of Plato's second problem—the geometrical one—we are to determine whether a certain rectilinear figure could be constructed along the diameter of a circle examining it by means of "a certain helpful hypothesis" (that is by means of an additional term, in Aristotelian terms), expressed in the following passage (see the emphasis I have added), where a state of ignorance is immediately declared". [I have already stressed in the previous subsection that it is important to note that in Plato it is just the "clarification" of the dialectic relationship between virtue, knowledge, and teachability, which is directly derived from the geometrical example, as Socrates expressly says]:

> So it seems we are to consider what sort of thing it is of which we do not yet know what it is! Well, the least you can do is to relax just a little of your authority, and allow the question – whether virtue comes by teaching or some other way – to be examined by means of hypothesis. I mean by hypothesis what the geometricians often do in dealing with a question put to them; for example, (86e) whether a certain area is capable of being inscribed as a triangular space in a given circle: they reply – "*I cannot yet tell whether it has that capability; but I think, if I may put it so, that I have a certain helpful hypothesis for the problem, and it is as follows: If this area is such that when you apply it to the given line [as a rectangle of equal area] of the circle you find it falls short by a space similar to that*

[23] Cf. above, footnote 18 at p. 101.

[24] It is interesting to note that the term *topoi* (in Latin *loci*) migrates to Aristotle's rhetoric and later rhetoricians' studies, probably parasitic of its origin in geometrical analysis (Faller 2003b).

which you have just applied, then I take it you have one consequence, and if it is impossible for it to fall so, then some other. Accordingly I wish to put a hypothesis, before I state our conclusion as regards inscribing this figure in the circle by saying whether it is impossible or not" (Plato 1977, 86e,87a).

Let me reiterate that Socrates explicitly analogizes his reasoning about virtue to the one used in the geometrical example, and we can reasonably guess that the source of the analogy is exactly the just illustrated geometrical example[25]:

> In the same way with regard to our question about virtue, since we do not know either what it is or what kind of thing it may be, we had best make use of a hypothesis in considering whether it can be taught or not, as thus: what kind of thing must virtue be in the class of mental properties, so as to be teachable or not? In the first place, if it is something dissimilar or similar to knowledge, is it taught or not – or, as we were saying just now, remembered? (cit., 87b).

To determine whether a certain rectilinear figure could be constructed along the diameter of a circle Socrates establishes the hypothesis which I have emphasized in the first passage above from the *Meno* dialogue: the hypothesis needs be worked thanks to a diagrammatic process, a "leading away", which opens up the reasoning to an eco-cognitive dimension, which in our case corresponds to the ἀπαγωγή: an abduction, endowed with its degrees of uncertainty. The echo of this reference to the importance of diagrams in analyzing reasoning is still vivid in Peirce: "I said, Abduction, or the suggestion of an explanatory theory, is inference through an Icon" Peirce (1997, p. 276).

A brief note on recent cognitive rich research on diagrammatic geometrical reasoning has to be introduced. Fresh studies have shown that false premisses (also due to the presence in models/diagrams of both substantive and auxiliary assumptions, indeed spurious problematic sub-diagrams and new "individuals" can pop-up at any step of geometric constructions Crippa (2009, p. 105)) are not exploited in the cognitive abductive process, because, in the various heuristics, only the *co-exact* properties are exploited. As I have described in the previous chapter (Sect. 4.4) the notion of co-exact properties, introduced by Manders (2008), is worth to be further studied in fields that go beyond the realm of deductive processes of classical geometry, in which it has been nicely underscored, so usefully touching various discovery cognitive processes.[26] Mumma illustrates that in Euclid's deductive framework diagrams contribute to proofs only through their co-exact properties: I suggest that this

[25] A strict relationship between geometry and dialectics stills echoes in Proclus: "[. . .] mathematics reaches some of its results with analysis, others by synthesis, expounds some matters by division, others by definition, and some of its discoveries binds fast by demonstration, adapting these methods to its subjects and employing each of them for gaining insight into mediating ideas. Thus its analyses are under the control of dialectic, and its definitions, divisions, and demonstrations are of the same family and unfold in conformity with the way of mathematical understanding. It is reasonable, then, to say that dialectic is the capstone of the mathematical sciences" (Proclus Diadochus 1873, 43, p. 35).

[26] Manders' definition describes the co-exact properties "as those conditions unaffected by some range of every continuous variation of the diagram" and the exact ones as "those which, for at least some continuous variation of the diagram, obtain only in isolated cases" (Manders 2008). "Diagrams of a single triangle, for instance, vary with respect to their exact properties. That is,

is also typical of diorismic/porismic processes and of their creative counterparts, exactly endowed with an objection-refuting role.

In the Aristotelian (and Platonic) perspective (see Chapter B25 of the *Prior Analytics*) I have delineated in this section we can definitely conclude that the general concept of abduction must be seen as constitutively and widely *eco-cognitive-based*. Indeed, by contrast, we have to remember that Aristotle says, in the passage I have already quoted and that I am reporting again, that a valid syllogism—by necessity—is instead not at all open to something "external": "A deduction (συλλογισμὸς) is a discourse (λόγος) in which, certain things having been supposed, something different from the things supposed results of necessity because these things are so. By 'because these things are so'. I mean 'resulting through them,' and by 'resulting through them' I mean '*needing no further term from outside* (ἔξωθεν) *in order for the necessity to come about*' " (Aristotle 1989, A1 24, 20–25, p. 2) (emphasis added).

Even if in this chapter I cannot illustrate in detail the diagrammatic constructions, which make possible to afford the geometrical problem illustrated by Plato-Socrates,[27] it is clear that, in syllogistic terms, the geometrical diagrammatic process, as well as the analogue argumentation about virtue, are ways of finding a "middle" ground that solves the problems at hand. Aristotle concludes, in *Posterior Analytics* "Thus it results that in all our searches we seek either if there is a middle term or what the middle term is. For the middle term is the explanation, and in all cases it is the explanation which is being sought" (Aristotle 1993, B, 90a, 5, p. 48).

At this point there is clear evidence that both Socrates' examples are recalled, with slight differences, in Aristotle's celebrated passage about abduction from Chapter B25 of *Prior Analytics*.

Let us come back to the geometrically puzzling example present in the Aristotelian passage, already reported above, involving the effort to square the circle through the lunes, a problem typical, together with the one related to the reduction of the famous Delian problem, of the geometrical research deriving from Hippocrates of Chios

DE Whatever is rectilinear, can be squared
EF A circle can be transformed into a rectilinear figure by the intermediate of lunes
DF Therefore, a circle can be squared

[D = square, E = rectilinear figure, F = circle]

The first premiss is known and true, the second is uncertain, the conclusion even more uncertain: a "leading away", towards the lunes, has to start. In the above syllogism we introduce a new term (N = lune) and two new premisses "EN = the lunes

(Footnote 26 continued)
the lengths of the sides, the size of the angles, the area enclosed, vary. Yet with respect to their co-exact properties the diagrams are all the same. Each consists of three bounded linear regions, which together define an area" (Mumma 2010, p. 264).

[27] An interesting reconstruction is given in Faller (2003b).

become rectilinear" and "NF = the circle is a sum of lunes": *thanks to and together with* the related diagrammatic constructions, the schema becomes

DE Whatever is rectilinear, can be squared
EF A circle can be transformed into a rectilinear figure by the intermediate of lunes

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EN The lunes become rectilinear
NF The circle is a sum of lunes

DF Therefore, a circle can be squared

The new additional premiss, fruit of a "leading away", aims at supporting the second uncertain premiss EF to approximate knowledge and so to solve the problem (Karasmanis 2011, p. 27). Moreover, Aristotle clearly notes, we have to deal with one or few new intermediate terms: the importance of minimality of abductive cognition is prefigured. The concept of abduction is finally established: it is leading away (ἀπαγωγή), Aristotle concludes, if the middle terms between B and C are few (ὀλίγα) (for in this way we are also closer to scientific understanding (εἰδέναι)). The efficacy of the abductive procedure is thus dependent on a minimum of middle terms, because too many moves will generate excessive distance for the argument to be convincing. In case of multiple kinds of middle additional terms which lead to different conclusions we still have to select/discriminate both the appropriate/productive additional middles and the and best related final result (cut/down problem).

5.4 Dialectics, Rules of Interrogation, Syllogisms: Dialectical Logic Versus Syllogistic Logic?

We know that in the light of classical logic abduction is the fallacy of the affirming the consequent. As I have already illustrated in Sect. 5.2, in the case of the Aristotelian chapter B25, abduction does not have to be discussed keeping in mind this fallacious schema. What is at stake in chapter B25 of *Prior Analytics*, in which Peirce envisages the first appearance of abduction, is abduction considered either 1) the classification of a certain "unclear" dynamic argument in a *context-free* sequence of three propositions; or 2) the introduction in a similar "unclear" dynamic three-propositions argument (in this case no longer *context-free*) of few new middle terms. Indeed, chapter B25 is built taking advantage of the examples provided by Plato. These examples are usually seen in a "dialectic" perspective, where both propositional and geometrical aspects are illustrated. It is important to note that Aristotle seems to sterilize the dialectic background pointing to the general and abstract role of those "propositional" externalities which are represented by the additional middle terms that substantiate the process of "leading away".

To try to clarify the above difficulties we can report a dispute about the status of the Aristotelian view of logic and fallacies, which might also acquire some further light thanks to the study illustrated in the present chapter. The dispute is due to Hintikka and Woods. Hintikka (1987) contends that in the *Topics* and *On Sophistical Refutations* the aim was practical: "Aristotle did not only want to study knowledge-seeking interrogative games for abstract theoretical purposes. He wanted to show how to win in such games" (Hintikka 1997, p. 242), and "Aristotle is still in the two *Analytics* thinking of logical inferences as steps in a questioning process" (cit., p. 243). I think that this perspective on logical inferences in terms of interrogative games favors a reading of Aristotle under the dialectic lens of Plato and overlooks the syllogistic spirit which pervades the study of arguments: in sum, Hintikka thinks that Aristotle treats the whole inquiry as an interrogative process and is looking for a theory of interrogative dialectical reasoning intended as a theory of ampliative reasoning, where what we now call deductive routines are just part and parcel of the dialectical/interrogative process. Following Hintikka, fallacies (for instance begging the question and many questions) are just considered by Aristotle violations of rules of interrogation.

It is interesting to note, by the way, that Hintikka's early (indeed foundational) attachment to a game-theoretic approach to logic involved the idea that dialectical interrogation rules are essential to the definition of logical particles ("all", "some") and logical relations (entailment, proof). Some scholars attribute this view to Aristotle (cf. Marion 2009 and Woods 2014, Chap. 3). The big difference between Hintikka et al. and Woods' approach seems to resort to the fact that Woods sees Aristotle as presenting two logics—one for syllogisms-as-such, in which nothing dialectical occurs, and another for syllogisms-in-use, in which dialectical considerations are sometimes vitally involved. Hintikka, on the other hand, thinks that dialectical factors are of central concern throughout.

Indeed, (Woods (2013b)) favors a reading of Aristotle, which attributes proper value to his invention of syllogism, contending that he clearly distinguished syllogism from dialectics: "Arguments in the narrow sense [not dialectical] stand starkly apart. They are not social events. They are not events of any kind. They are finite sequences of linguistic objects which Aristotle calls propositions. When they meet certain conditions, they are *syllogisms*", so "there is no great harm in distinguishing between Aristotles *dialectical logic* and his *syllogistic logic*. But we should not lose sight of the point that these are disjoint conceptions of logic": the logic of syllogism is the theoretical core of a successful dialectic in the broad sense, but we need to establish the distinction. In sum Woods objects that Aristotle develops both a theory of two-person argument (that is a theory about rules of interrogation in Hintikka's sense, where an interrogative dialectical argument is a series of alternating speech acts between opponents, questioner and respondent), *and* a theory of syllogism, intended as a context free sequence of three categorical propositions. Woods concludes "Certainly Aristotle would allow that these [begging the question and many questions] are interrogative rule-violations, but it is not this that makes them fallacies" (Woods 2013c, pp. 497–498). I think that this perspective helps us to read Aristotle's chapter B25 on ἀπαγωγή as a chapter which certainly reverberates some

aspects of dialectics but in the sense of syllogistic logic, where abduction is just characterized by the breaking of high degrees of certainty. In sum, Aristotle takes pains to strip away all strict dialectical considerations.

Leaving asidethe interesting *querelle* about the status of fallacies in Aristotle, we can nevertheless say that the study of Aristotelian ἀπαγωγή illustrated above provides support to Woods' conviction about a theory of syllogism "as a context free sequence of three categorial propositions": indeed it clearly results that in valid syllogisms there is no room for broad eco-cognitive acts of "leading away", such as the ones that are instead illustrated in chapter B25 of the *Prior Analytics*. At this point there is clear evidence that both Socrates examples are recalled, with slight differences, in Aristotles celebrated passage about abduction from the *Prior Analytics*, but they are embedded in a very different theoretical framework, in which the classification of certain "unclear" dynamic arguments in both *context-free* and *non context-free* sequences of three propositions dominates.

5.5 Abduction and Aristotelian Enthymeme from Signs

In the previous Sect. 5.1, I have quoted a passage (Aristotle 1993, A, 71a1–11) in which Aristotle classically says (and the conventional interpretive tradition repeats) that also rhetorical arguments optimally persuade through induction or enthymemes (that is deductions). This restricted view on good rhetoric arguments is corrected and extended thanks to the illustration of the so-called enthymemes from signs, described in the *Rhetoric* and at the end of the first book of *Prior Analytics*. It seems Peirce did not notice these Aristotelian themes (even if, paradoxically, he was the inventor of modern semiotics), instead only focusing on chapter B25 of *Prior Analytics*, I have extensively commented in the previous sections. Enthymemes from signs—if intended as rhetorical counterparts of syllogism—would have reasonably strengthened his contention about a parallel between inquiry of persuasion and abduction.

Kraus too, after having indicated that the word enthymeme is rarely present in Peircean writings, also observes that this fact is all the more surprising as Peirce is famous "[...] for basing his logic in general and especially his theory of arguments on an elaborate theory of signs [...]. And as for rhetoric, he even assigns the highest rank within the whole field of semiotics to a discipline he calls speculative rhetoric or methodeutic, whose principal task is to be the methodical study of methods of discovery and argumentation [...]. Any type of argument from signs should thus have appeared to him as a godsend. But even when he interprets arguments themselves as special kinds of signs, he associates abduction with icons rather than indexes" (Kraus 2003, p. 251). I can object to Kraus that too much interest in the Aristotelian enthymemes from signs, as related to their actual and strong rhetorical/persuasive characters (abductive arguments are often much more persuasive than the classical

deductive ones)[28] would have probably impeded to him to vindicate abduction from its proscription from the perimeter of rationality, a proscription I have stressed above in this chapter.[29]

Aristotle defines: "An enthymeme is a syllogism from likelihoods or signs" (Aristotle 1989, B29, 70a, 10, p. 136).[30] Paying attention to the case of the syllogism of the "middle figure", which yields results of certain plausibility, enthymematically expressed as

(Pregnant women are pale)
This woman is pale
This woman is pregnant

It is easy to see that Aristotle depicts abduction (in this case we are implicitly dealing with "selective" abduction—I call this kind of abduction "selective" in the present chapter and in all my studies on abduction) coherently with the famous syllogistic framework provided by Peirce: (emphasis is added to stress the case of the syllogism of "the middle figure")[31]

> A sign may be taken in three ways, corresponding to the ways the middle term in the figures is taken: for it is taken either as in the first figure, or as in the middle, or as in the third. For instance, proving that a woman is pregnant because she has milk is from the first figure, for the middle term is having milk (let A stand for being pregnant, B having milk, C for a woman). But "The wise are good, for Pittakos was good" is through the last figure. A stands for good, B stands for the wise, C stands for Pittakos. So it is true to predicate both A and B of C, except that people do not state the latter premiss because they know it, though they do take the former. *And "She is pregnant because she is pale" is intended to be through the middle figure: for since paleness follows pregnant women and also follows this woman, people think it has been proved that she is pregnant. A stands for pale, B stands for being pregnant, C stands for a woman. If one premise alone is stated, then, it is only a sign, but if the other premise is also taken in addition, it is a deduction.*[...] For instance, "Pittakos is generous, for the ambitious are generous, and Pittakos is ambitious". *And the deduction through the middle figure is always and in all ways nonbinding*, for a deduction never comes about when the terms are related in this way. For it is not the case that if a pregnant woman is pale and this woman here is also pale, then it is necessary for this woman to be pregnant. The truth, then, can occur in all signs, but they have the differences stated (Aristotle 1989, B27, 70a, 3–39 pp. 102–103).

The main uncertain character of selective abduction is stated, and usefully described in the following passage:

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[28] I have myself stressed the pragmatic (and rhetorical) role of abduction in moral and violent behavior in (Magnani 2011, Chap. 3, Sect. 3.2).

[29] I think Kraus' hypothesis that Peirce was conditioned by the XIX century widespread definition of enthymeme as a truncated syllogism is plausible, but I am still convinced that it was better Peirce had focused on chapter B25 of *Prior Analytics*, which more or less explicitly embeds the more interesting and wide aspects of the EC-Model of abduction, as I have tried to illustrate.

[30] Cf. Kraus (2003), also containing a reference to the most important scholarly contributions to understand Aristotelian enthymeme. On the particular problem of abduction and enthymemes see also Bybee (1991); Lanigan (1995); Sabre (1990).

[31] I kindly ask the reader the permission to extensively quote Aristotle.

> Therefore, it will have the sign, for we assumed there was one sign of one affection. Consequently, if these things are so, and we are able to collect such signs from those animals which have only some one peculiar affection (and each has a sign, since it must have a single sign), then we will be able to recognize natures. But if the whole kind has two peculiar affections (as, for example, the lion is courageous and generous), then how can we tell which one of the signs that follow peculiarly is the sign of which affection? Perhaps if both belong to something else but not as a whole, and among those cases in which each belongs to something but not entirely, some have one sign and not the other (for if something is courageous but not generous and possesses a certain one of the two signs, then it is clear that this is also the sign of courage in the case of the lion) (Aristotle 1989, B27, 70b, 21–32 pp. 102–103).

In conclusion, enthymeme from sign through the third figure is certainly less interesting, in the light of the defense of the eco-cognitive character of abduction, than the concept of ἀπαγωγή illustrated in chapter B25 of the *Prior Analytics*. Nevertheless, enthymeme from signs tells us something more about the objective banishment of the concept of abduction from the area of studies about rational ways of reasoning.

I have contended that *creative abduction* was, in some sense, killed by Aristotle's concepts of deduction and induction, which paradoxically obscured the deep meaning of his chapter B25 (in which the eco-cognitive and "paleo"-logical aspects of the ancient widespread concept of ἀπαγωγή was clearly addressed).

In the present case of enthymemes, still seeing at the possible consequences of the confinement of abduction, we might add that the epistemic relevance of *selective abduction*, even if clearly stated in chapter B27, is still in some sense killed or weakened, because strongly received by the commentators as belonging to the area of rhetoric and of the tools for persuasion, efficacious even when related to plausible/uncertain syllogisms, but substantially thought outside the perimeter of the established dominant ideas about the status of rational ways of correct reasoning endowed with a higher epistemic status.

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Chapter 6
Maximizing Cognition in Science: Affirming Truths Implies Negating Truths

Irrelevance and Implausibility Exculpated

When dealing with the so-called "inferential problem", which affects current research in logic and epistemology, I will opt for the more general concepts of input and output instead of those of premisses and conclusions. From this perspective abductive inferences can be first of all seen as related to logical processes in which input and output fail to hold each other in an expected relation, with the solution involving the modification of inputs, not that of outputs. The chance of finding an abductive solution still appears to depend on the Aristotelian concept of "leading away" (an expression which translastes what Aristotle calls ἀπαγωγή, that is "abduction"), that is, on the starting of the application of a supplementary logic implementing an appropriate formal inference engine. In this perspective—and given the fact science produces and "maximizes" cognition through a process in which affirming truths implies negating truths—the most important consequence for epistemology I can clearly illustrate is that irrelevance and implausibility are not always offensive to reason. For example, we cannot be sure, more broadly, that our guessed hypotheses are plausible (even if we know that looking—in advance—for plausibility is a human good and wise heuristic), indeed an implausible hypothesis can later on result plausible.

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6.1 Reprise: Ignorance-Preserving, Immunization, Validity, Ἀπαγωγή Now

6.1.1 Ignorance-Preserving and Knowledge Enhancing Abduction

In the previous chapter I have illustrated that abduction (ἀπαγωγή, in ancient Greek, often translated as "leading away" or "reduction") is a procedure in which something that lacks classical explanatory epistemic virtue can be accepted because it has virtue of another kind: (Gabbay and Woods 2005) contend (GW-Schema, cf. chapter one, Sect. 1.1 and the previous chapter, this book) that abduction presents an *ignorance-preserving* or (ignorance-mitigating) character. From this perspective abductive reasoning is a *response* to an ignorance-problem; through abduction the basic ignorance—that does not have to be considered a total "ignorance"—is neither solved nor left intact. Abductive reasoning is an ignorance-preserving accommodation of the problem at hand.

An important question arose: is abduction really ignorance-preserving? To better answer this question I have introduced (and took advantage of) an *eco-cognitive model* (EC-Model) of abduction. I have illustrated that through abduction, knowledge can be enhanced, even when abduction is not considered an inference to the best explanation in the classical sense of the expression, that is an inference necessarily characterized by an empirical evaluation phase, or an inductive phase, as Peirce called it. To further deepen the eco-cognitive character of abduction I have also provided a simple genealogy of logic: Aristotle clearly states that in syllogistic theory local/environmental cognitive factors—external to that peculiar inferential process, for example regarding users/reasoners, are given up.

6.1.2 Eco-Cognitive Immunization: De-Moralizing Truth

Indeed, to define syllogism Aristotle first of all insists that all syllogisms are valid[1] and contends that the *necessity* of this kind of reasoning is related to the circumstance that "no further term from outside (ἔξωθεν) is needed", in sum syllogism is the fruit of a kind of eco-cognitive *immunization*:

[1] Aristotle insists that all syllogisms are valid (by definition) (Woods 2014, p. 150), there is no such thing as an invalid syllogism. We know the syllogistic tradition began to relax this requirement quite early on. In the following sections, I will use the term syllogism in this modern not strictly Aristotelian sense. Furthermore, no argument that is not a syllogism is in canonical notation, and is beyond the reach of Aristotle's decision procedure for validity. This is not to deny that some non-syllogisms are recognizably invalid. It only shows that it cannot be made so by Aristotle's decision procedure. If we liken that procedure as a function, we could say that the function is undefined for invalid inputs.

> A deduction (συλλογισμὸς) is a discourse (λόγος) in which, certain things having been supposed, something different from the things supposed results of necessity because these things are so. By "because these things are so", I mean "resulting through them," and by "resulting through them" I mean "needing no further term from outside (ἔξωθεν) in order for the necessity to come about" (Aristotle 1989, A1 24, 20–25, p. 2).

Woods clearly notes that an important Aristotelian step regards the premiss-admissibility measures on arguments expressible in the usual canonical/categorical notation. These are the ones noted in the definition of syllogism I have just quoted, concerning the absence of terms that come from "outside". Close on their heel come two further reducibility claims. One, about which Aristotle is somewhat equivocal, is that all deductively correct reasoning is syllogistically expressible or is—as I have already anticipated above—otherwise transparently valid as it stands (e. g. conversion). The other is the perfectibility thesis: an imperfect syllogism is an argument whose premisses necessitate the conclusions in a way that does not make it evident that they do. Indeed, Aristotle thinks that any argument crafted as a syllogism is "perfect" if and only if it makes its validity unmistakably evident as it stands to any neurotypical individual who understands the language of the argument. The perfectibility thesis asserts that the validity of an imperfect syllogism can be made unmistakably evident by unmistakably valid proof rules which "reduce" it to a perfect one (Woods 2014, p. 24 and Chap. 8).

Through this immunization Aristotle luckily distills and idealizes a practice already devoted to seeking truth, but instead pregnant from the eco-cognitive point of view: Plato's dialectical conduct aiming at truth, contrasted with the argumentative practices of sophists and rhetors. The following are some of the aspects of Plato's virtuous cognitive conduct, which are transformed and reverberated in syllogism: hearing both sides of the story (in the case of syllogism this is reflected by the importance of explicitly stating and respecting the two true syllogistic premisses); open-mindedness, tolerance, impartiality, carefulness and sensitiveness to details, respect for the evidence (avoiding to change at will the starting data and the involved rules), being willing to question assumptions, giving and asking for reasons (applying reliable rules and checking their appropriateness), being curious, being intellectually courageous—that is, not simply believing what it is convenient to believe (that is being involved in efficiently practicing syllogistic arguments, even when difficult), etc. These behavioral traits are also called "epistemic virtues".[2] Being involved in the syllogistic practices, so to speak, compels you to be virtuous in one fell swoop, thanks to the acquaintance with the externalized logical—soon not anymore perceived as "moral"—rules. In this perspective the eco-cognitive immunization due to the birth of Aristotle's syllogism constitutes at the same time a *de-moralization of truth*: to reach truth it is sufficient to follow logical rules and requirements, which result abstract and neutral and promote new "regimes" of truth related to the inessentiality for the cognitive agents of their presence in a rich eco-cognitive setting, so pursuing the orchestration of its collapse: of course we know this is still a moral

[2]For further details cf. Cozzo (2012).

option, but hidden and disguised, too epistemic to appear "moral", a "moral epistemology" we can say.[3]

In sum, Aristotle, by inventing the syllogistic system, takes pains to strip away all strict dialectical considerations; further, to give rise to the distillation and idealization I have just illustrated, with respect to a practice already devoted to seeking truth but extremely eco-cognitively rich, the problem of *recognizing validity* is favored and resolved, as I will explain in the following subsection.

6.1.3 "Recognizing" Validity

In the previous chapter I have also repeatedly insisted on the special Aristotelian way of interpreting validity, which we can now see intertwined with what I have just classified as a "de-moralization of truth". I contended that the current notion of deduction or deductive validity is not what Aristotle meant by συλλογισμὸς and I followed Woods in contending that Aristotle considers validity a necessary condition of *syllogismos* and enlists it for that purpose as an undefined primitive of his logic. In the previous chapter I pointed out that Aristotle himself draws a distinction between a simple valid argument as an *anagkion*, and a *syllogismos* as a special case of it and that we find in this distinction two notions of following from, "straight necessitation" and "syllogistic necessitation". Corresponding is the distinction between straight consequence and syllogistic consequence. (Woods 2013, p. 257) contends that in Aristotle's earlier logic, straight consequence is a theoretical primitive". Also, still following Woods, Aristotle seems to draw (or at least implicitly honors) a distinction, between concretely dynamic arguments, which are social events subject to situatedness and all the rest, and arguments in the abstract and static sense, in which agents, agendas, and context, have no appearance whatever. These latter are syllogisms. Woods concludes that syllogisity, therefore, is a proper subproperty of validity (Woods 2014, p. 13). We now know that validity does not suffice for premiss-conclusion argumental goodness, although it does suffice for truth-preservation. It is well-known that logicians like their arguments to be sound—valid with only true premisses, but soundness assures truth preservation, not truth. That is, sound: valid when premisses are assumed to be true. Other logicians ask that premisses be at least well-backed. Soundness is also asked for or at least well-based premisses.

After all, to preserve an already reached truth and to derive from it other truths—by that "necessity" of reasoning which syllogisity requires—we certainly need the reliable true knowledge contents themselves, already available, as the starting point, but also the indication of some *explicit* and *stable* expressions (finite sequences of linguistic objects which Aristotle calls categorical propositions) and inferential rules and procedures. In turn, to have available these last "tools" Aristotle was compelled

[3] I have quickly illustrated the concept of "moral epistemology" in the footnote 32 of Chap. 1 of this book.

to reform natural language: he devoted considerable attention to the linguistic phenomenon of meaning change and ambiguity and to the inferential corruptions, to favor the aim of putting Greek into a canonical, economical, and essential notation: "Aristotle writes his logic for the Greek language and formal logicians write their logics for artificial formal languages", Woods clearly remarks (Woods, 2014, p. 66).

In summary, the de-moralization of truth I have described in the previous subsection is directly linked to the fact, still stressed by Woods (2014, pp. 178, 203–208), that Aristotle wants validity to be a property that is either practically "recognizable" or made to be by an infallible and at least quasi-mechanical decision procedure that is briefly executable by persons of normal mental abilities. Indeed, as I have observed in details in the previous chapter when dealing with what I have called *arche-validity* (see Sect. 5.1),[4] validity is required for the success of various kinds of premiss-conclusion reasoning and argument, notably scientific demonstration. Sometimes an argument is obviously and unquestionably valid, but it is notoriously otherwise in lots of other cases. While some of the monographs of the *Organon* devote themselves to various other matters—refutation in *On Sophistical Refutations* and scientific demonstration in *Prior Analytics*—the recognizability project dominates over them all.

6.1.4 Ἀπαγωγή *Now*

I have finally described that at the same time Aristotle presents a seminal perspective on abduction: the second part of the previous chapter considers the famous passage in the chapter B25 of *Prior Analytics* concerning ἀπαγωγή ("leading away"), also studied by Peirce. I contended that some of the current well-known distinctive characters of abductive cognition are already expressed, which are in tune with my EC-Model. By providing an illustration of the role of the method of analysis and of the middle terms in Plato's dialectic argumentation, considered as related to the diorismic/poristic process in ancient geometry—also, later on, emphasized by Proclus—I contended that it is just this intellectual heritage which informs Aristotle' chapter B25 on ἀπαγωγή. Even if, in general, Aristotle seems to sterilize, thanks to the invention of syllogistic theory, every "dialectic" background of reasoning, nevertheless in chapter B25 he is still pointing to the fundamental inferential role in reasoning of those externalities that substantiate the process of "leading away" (ἀπαγωγή). Hence, we can gain a new positive perspective about the "constitutive" eco-cognitive character of abduction, just thanks to Aristotle himself. Finally, the previous chapter presented an excursus on Aristotle's enthymemes from signs, disregarded by Peirce, but extremely important to stress the Aristotelian treatment of what I have called *selective abduction*.

[4] On this issue cf. also the Sect. 5.4, "Dialectics, rule of interrogations, syllogisms: dialectical logic versus syllogistic logic?", previous chapter of this book.

In this chapter I will further deepen the EC-Model of abduction stressing stricter logical aspects: the first result will be that, contrarily to the classical logical view, relevance and plausibility in abductive reasoning have to be relativized and so the epistemologically embarrassing concepts of irrelevance and implausibility exculpated, they are not always offensive to reason. I will also illustrate the ways for overcoming that eco-cognitive immunization established by Aristotle I have reminded above: let me repeat that Aristotle seems to sterilize, thanks to the invention of syllogistic theory, every "dialectic" background of reasoning, and nevertheless in chapter B25 he is still pointing to the fundamental inferential role in reasoning of those externalities that realize the process of "leading away" (ἀπαγωγή). I will further substantiate the eco-cognitive role in abductive inferences of these externalities, which refer to a remarkable amount of "historical", "contextual", "dialectical", and "heuristic" memories and constraints.

6.2 EC-Model of Abduction and Logic: Relevance and Plausibility Relativized

6.2.1 Inferential Problems: Input and Output Versus Premisses and Conclusions

From the perspective of the EC-Model the available logical views concerning abduction have to be reconsidered. By now this fact is acknowledged by some logicians. Estrada-González (2013, p. 182), for example, by referring to the properties called *consistency*, *minimality*, etc. stated in the AKM-schema[5] usefully notes:

> We think that overemphasizing the characteristics of abduction as it occurs in scientific practices and daily life scenarios has led to overlook some features that abduction in those circumstances shares with other phenomena in which some given outputs fail to stand in a certain relation with some given inputs and thus a modification on those inputs is in order.

Indeed, abduction in an eco-cognitive perspective is not circumscribed by indicating particular requirements of each particular field of application, such as scientific discovery, diagnosis, machine discovery in artificial intelligence (AI), and computational creativity. The available logical models of abduction (orchestrated around the properties of classical deduction), the so-called nonmonotonic, adaptive, etc. logics, which restrict their structure to some of the above requirements, are extremely important and provide images of abduction that, even if logically powerful, are partial, limited, and not appropriate to represent general perspectives. We still expect a more comprehensive image from a new and more *naturalized* logic of abduction.[6] Let us try to furnish some new insights.

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[5] Cf. Sect. 1.1, Chap. 1 and the previous chapter on the EC-Model of abduction, this book.

[6] A general introduction to the issue of naturalization of logic is given in the recent Magnani (2015). See also below, chapter seven, sect. 7.1.3, this book.

Obviously, in the case of abduction the relation involved between data and hypotheses is not a consequence relation in classical sense, and we need provide an appropriate logical meaning to it, to vindicate the positive cognitive value of this kind of fallacy: indeed we perfectly know abductive cognition coincides—in the light of classical logic—with the fallacy of the affirming the consequent. We can reach this result thanks to that process of *naturalization of logic*, just quoted few lines above, recently proposed and emphasized by John Woods (Woods 2013). Abduction is a case of "consequence-drawing",[7] and not of a merely classical "consequence-having", as I have described in (Magnani 2015) and in Sect. 5.1, previous chapter of this book.

Indeed, a complete revision of mainstream logic is an urgent task to be achieved. This revision will be able to bring logic into a creative rapprochement with cognitive science. This can be achieved by trying to do for logic what over forty years ago Quine and others attempted for epistemology. It is necessary to propose a "naturalization" of the logic of human inference. Woods holds a naturalized logic to an adequacy condition of "empirical sensitivity". This is achieved in three ways. One requires that the logicians familiarize themselves with the data that cognitive science seeks to account for: "At a minimum, the decision to naturalize the logic of reasoning is a decision to take into account well established lawlike results of the cognitive sciences" (Woods, 2013, p. 62). A second requires an informed acquaintance with the findings of the best-confirmed of those theories. The third requires logic's empirical disconformities with the data and findings of the partner sciences be accounted for, under pain of having to give them up.[8] In this perspective we should conclude that "It is not in the general case preferable—indeed it is not smart and not even possible—to upgrade our cognitive targets in ways that favor truth-preservation or experimental/statistical confirmation as general cognitive strategies" (Woods, 2013, p. 198).

Of course we acknowledge that the rich research on abduction already available in the fields of logic, cognitive science, philosophy, and artificial intelligence (AI), has already rehabilitated the "cognitive" importance of the fallacy "affirming the consequent" (abductive reasoning corresponds to this fallacy in the light of classical logic), traditionally taken as the mistake of having a conditional and its consequent, and from this deriving the antecedent. When reframed in the spirit of the naturalization of logic this fallacy becomes a form of abduction endowed with a positive cognitive value, in most of the real-life reasoning contexts in which it occurs, included diagnosis and creative processes. It can exhibit what some writers have called "material validity",[9] in this case to refer to the fact that an invalid

[7] In the field of philosophy of logic Prawitz's studies are in my opinion intertwined with the need of a naturalization of logic and with the importance of consequence-drawing. For example Prawitz richly reworks the concept of valid inference, beyond traditional model and proof theories, taking into account the role of context in terms of the so-called "grounds" (Prawitz 2012).

[8] Indeed the author maintains it is necessary to construct an "empirically sensitive logic": a logic considered as an "empirically sensitive and epistemologically responsive account of the reasoning practices of beings like us" (Woods 2013, p. 386).

[9] Cf. the previous chapter, footnote 1.

form provides a cognitive good semantic outcome. We need a new logical framework for abduction appropriate to the naturalization project I have just illustrated: an important step of the naturalization of this fallacy is certainly the already widespread acknowledgment of the *agent-based nature* of abduction but also—as I will stress below, taking advantage of my EC-Model—of its *eco-cognitive situatedness*.

The already available taxonomy of the various kinds of abduction, which myself and many authors have proposed and analyzed, is extremely useful because it shows that we are dealing with cognitive activities extremely variegated but also tremendously fruitful, resorting to the common aim of guessing hypotheses which can provide various kinds of reliable knowledge, common, scientific, moral, aesthetical, etc. These abductively established kinds of cognition do not necessarily aim at providing truths in the sense of the word established by the tradition of the epistemology of natural sciences: for example, abduction certainly works when performed to establish a new "truth" in physics, but also when exploited to make a "good" hypothesis (for example about a person) in gossip.[10] In this last case the reaching of a truth based on evidence, that is a truth that would be such because in tune with the spirit of scientific rationality—is usually a secondary concern. For example, in the case of cognitive moral interplays of gossip it is the produced hypothesis (about a person or an event) that establishes—constitutes, we could say—a special kind of "truth" by itself, that truth that is such because locally/situationally accepted and efficiently adopted by the involved human group: this is just what it takes, to promote the narratives or the actions—sometimes violent—which the relationships between the individuals of the group aim at performing.[11]

First of all, we have to say that an abductive inference is not different from other inferences: it presents outputs derived from inputs: the AKM and GW schemas[12] treat abduction in this way. A special perspective can be assumed, which shapes the inferential status of abduction in a smart way. I can anticipate that, in this perspective, abduction appears orthogonal to deduction, but not incompatible with it, such as it is occurring when abduction is seen as a fallacy, in the light of the classical Peircean syllogistic framework: the important difference is indeed that in the perspective I will soon illustrate no direct reference to the fallacious character of abduction is postulated. Hence, to the aim of "naturalizing" abduction in logic,[13] and to follow the main tenets of my EC-Model, it is provisionally appropriate to adopt a broad logical view of the so-called *inferential problems*, in which the semantic problem of the *fallacious* character of abduction and the problem of its *presumptive* character (stressed by the GW schema) are not primarily taken into account.[14]

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[10] On gossip and its role in sociable interaction, cf. chapter one, Sect. 1.8, this book.

[11] More details about hypothetical cognition in gossip are illustrated in Magnani (2011) and Bertolotti and Magnani (2014).

[12] Cf. Sect. 1.1, chapter one and the previous chapter on the EC-Model of abduction, this book.

[13] Again, a general introduction to the issue of naturalization of logic is given in the recent Magnani (2015). See also below, chapter seven, Sect. 7.1.3, this book.

[14] Anyway, we have to remember that the presumptive character of abduction manifestly stresses that necessity—taken in the received Aristotelian sense—is just only one criterion which can char-

Let us adopt, following Estrada-González (2013) the more general concepts of input and output instead of premisses and conclusions: this view consists in seeing inference not only in terms of the reaching of an output or the modification of it, like in the standard view of deductive proofs, but also as the *process of modifying part of the inputs, or both inputs and outputs*, in order to obtain a desired relation between inputs and outputs.[15] In this framework abductive cognition is easily depicted in terms of the situation in which some given output fail to stand in a certain relation with some given inputs and thus a modification on those inputs is needed. It is a received and common way of modeling abduction in logic (cf. for example Aliseda (2006)).

Still following Estrada-González, let us consider a simple example such as the consequence relation of a logic L, $\Vdash_L$, and let α, β be formulas of the language of L, © is a certain binary connective. An abductive problem can be illustrated by the following incomplete argument, in the sense that the conclusion does not L-follow from the premisses

$$\alpha \copyright \beta \nVdash_L \beta \qquad (1)$$

The making of an abduction I have just described represents the logical counterpart of the cognitive (and epistemological) *fill-up problem* (see Sect. 1.2 of Chap. 1), that is the finding of a suitable improvement of the context (the premisses), here the variable ?, such that from the original context and its enrichment the conclusion L-follows

$$\alpha \copyright \beta, ? \Vdash_L \beta \qquad (2)$$

Obviously, there are many ways to complete the argument above. A list of various presumptive very elementary solutions can be easily provided (for example α, or β), showing that to the aim of choosing among them we need some preferential measure: this resorts to the *cutdown* problem (see Chap. 1, Sect. 1.2, this book).

It is clear that in principle there might be infinitely many ways to complete the above argument. Estrada-González (2013, p. 183) notes that abduction "[...] is usually thought as the construction of a (scientific) hypothesis for adding it to a theory

acterize the solution of an inferential problem, if we consider it from a wide point of view. Also plausibility, probability, possibility, sufficiency, defeasibility are completely legitimate (Woods 2013 Chap. 8). A general inferential problem is not inevitably characterized by "necessity" of classical deduction, in Aristotelian sense, other aspects have to be taken into account and considered legitimate.

[15]From this point of view, deductive and inductive inferences are situated at the same level, because they concern the finding of suitable modifications in the outputs (Estrada-González 2013, pp. 189–191).

and other previous knowledge (the premises) in order to explain a problematic phenomenon (the conclusion)". If we adopt this received schema of abduction in our simple example various solution should be discarded because they are not good options: for example, according to some chosen criteria, we can say that solutions do not have to be trivial, redundant: for example, if one has a connective K such that β is L-implied by both $(\alpha \copyright \beta)K\beta$ and $\alpha \copyright \beta$, the solution can obviously be to add the formula $(\alpha \copyright \beta)K\beta$. Also, they do not have to lack explanatory power (such as for example the solution β). Furthermore, a solution that is not simple, and so excessively explanatory, certainly less simple than another available, has to be discarded, such as in the following cases, in which complicated solutions are added: $\alpha \copyright \beta, \vartheta, \beta, \alpha, (\alpha \copyright \beta)K\beta \Vdash_L \beta$ or $\alpha \copyright \beta, (\alpha \copyright \beta)K\beta, \Vdash_L \beta$. Indeed, there is another solution available that is the preferred one—the solution α.

In sum, by adopting the received logical view of abduction (AKM-schema), we restrict our general idea of abduction being conditioned by special cases (such as the dominant ones of medical diagnosis): unfortunately, by restricting our perspective in this way, some good solutions that would be remarkable and productive in other cases (for example different with respect to scientific discovery and medical diagnosis) can be ruled out. To avoid this result the GW-schema and the EC-Model of abduction (cf. chapter one, this book) can be of some help. The GW-schema does not refer to consistency and minimality as necessary requirements. Hence, AKM 4 and AKM 5 are not necessary: in the first case we have to remember that knowledge bases not only are incomplete but often incorporate inconsistencies; in the second one there is not compelling need to consider that a solution for an abductive problem should be one with an assigned length.

However, it has to be said that many standard perspectives on abduction still demand two properties, which are presented as possessed by "every" kind of solution for an abductive problem:

1. *Relevance*: the solution, the guessed hypothesis H, should be relevant to the problem: for example, if an agent's knowledge does not suffice to know why the bartender in Kuala Lumpur has been killed, releasing the true Newtonian hypothesis that the planets move according to the law of gravitation has nothing to do with the given problem: it is not relevant.
2. *Plausibility*: The abduced hypothesis H should be characterized by some designated degree of plausibility. If an agent's knowledge does not suffice to know who killed the bartender in Kuala Lumpur, releasing the hypothesis that the killer is the President of United States has to do with the problem (because, after all, the President is a human being and we know human beings are potential killers) but is sufficiently implausible as to count as a solution.

6.2.2 *Irrelevance and Implausibility Exculpated*

To further deepen the cognitive character of these two properties, the EC-Model is of great help. In Sect. 1.2 of Chap. 1 I have said that in a wide eco-cognitive perspective the cutdown and fill-up problems in abductive cognition appear to be spectacularly *contextual*.[16]

Indeed in the eco-cognitive perspective the relevance of a guessed hypothesis would seem a trivial requirement, because it is "hard to see how it might fail to be relevant", as Estrada-González says (2013, p. 185). He further adds: "Someone might press the point that what is required is the relevance not of solutions, but of candidates to be solutions. However, I think it might go against all those pleas connecting abduction with creativity, hypothesis generation, guessing, etc." I basically agree with him. This is exactly the point to be stressed and further explained. First of all we have to note that relevance is *context-* and *time-dependent*. When Feyerabend (1975) emphasizes the role of what he calls "counterinduction", he is just presenting to us the complete unreasonable and unwarranted character of scientific discovery: the guessed hypothesis could be devoid of relevance to the problem in the framework of the upholders of the rival theory but also, even if not necessarily, in the perspective of the agent herself that—paradoxically—guessed the new "strange" hypothesis. Of course the relevance requirement is related to the current state of knowledge of both agonists. However, the new hypothesis can result "relevant" later on, for example when recognized as a genuine new discovery. To summarize, candidates to be solutions which seem weird—irrelevant—soon can become relevant if they are recognized as solutions.

Something similar can be said in the case of *plausibility*. First of all, in general we cannot be sure that our guessed hypotheses are plausible (even if we know that looking for plausibility is a human good and wise heuristic), indeed an implausible hypothesis can later on result plausible. Moreover, when a hypothesis solves the problem at hand, this is enough as to count as solution of the abductive problem (even if, not necessarily a *good* solution or the *best* solution). If we want to preserve the property of plausibility, at most we can say that in some cases it is just *potential*, given the time-dependency I have illustrated.

[16]Expressly dealing with a formalization of abductive reasoning (Piazza and Pulcini 2015) aim at reconciling classical logic and abductive reasoning by means of what they call *context-sensitiveness* (Piazza and Pulcini 2017). In particular, they aim at producing fragments of classical logic in which instances of abductive or backwards reasoning are allowed. It is also interesting to note that recent studies, even if not directly related to the naturalization of the logic of abduction, are strongly concerned with the role of context in reasoning: Zardini emphasizes, in a recent rich formal treatment, the role of simple temporal "intercontextual" logics, which aim at adequately modeling the validity of certain arguments in which the context changes (Zardini 2014). In the footnote 7 above I have also quoted Prawitz's emphasis on the role of context in redefining validity. Also Callaway (2014, p. 277) stresses that the logic of abduction has to be bound to a particular context, and dependent on the specifics of content.

To make an example, the strange Cartesian hypothesis of a plenum vortices made of particles, destroyed by the Newtonian concept of action at distance, later on appeared more rational and fully compatible with the Einsteinian framework:

> Thus Descartes was not so far from the truth when he believed he must exclude the existence of an empty space. The notion indeed appears absurd, as long as physical reality is seen exclusively in ponderable bodies. It requires the idea of the field as the representative of reality, in combination with the general principle of relativity, to show the true kernel of Descartes' idea; there exists no space "empty of field" (Einstein 2014, pp. 375–376).

In sum, irrelevance and implausibility not always are offensive to reason:[17] to delineate the fill-up problem neither relevance not plausibility are necessary, they are just two "typical" smart and fruitful principles human beings subjectively adopt to look for hypotheses. Unfortunately, they are no longer "typical", for example, in the case of high-level kinds of cognitive creativity. Also the GW-schema acknowledges the fact that relevance or plausibility cannot be taken to be general conditions on hypothesis-selection.

6.2.3 Becoming Relevant, Becoming Plausible: The Role of Ignorance and of Creative Agency

First of all we can say that plausibility and relevance are not initial properties of those creative propositions that for example scientists guess, although they can be good properties of propositions that evolve from those guesses. It appears clear that relevance and plausibility may be assigned to guessed hypotheses at some later stage, as the inquiry proceeds and new evidence is acquired. In that respects relevance/plausibility are not that different from explanations, though they can be much weaker requirements. The really interesting question to be further analyzed seems to be how and when a hypothesis acquires relevance/plausibility, for it should do that to some degree in order for example to be submitted to test. Even if there are various linguistic, logical, and cognitive accounts of relevance and plausibility, all more or less referring to the context-change potential of assertions, I will limit my analysis to the role of both plausibility and relevance in the light of a new concept of ignorance and to the role of relevance in the dynamic character of abductive reasoning as an agentive cognitive process. First-person (subjective) and third-person (objective) perspectives on plausibility and relevance can be advanced and analyzed.

[17] Scientists would agree that the really surprising and fruitful thought arising from abduction has to challenge prevailing conceptions by suggesting ideas that are *prima facie* neither relevant nor plausible, or that even appear to contradict pre-established notions (see e.g. the book by Livio 2013).

6.2.3.1 The Role of Ignorance

First of all we can say that plausibility and relevance are context- and time-dependent relatively to the agent's *degree of contextual ignorance*, seen in a third-person perspective. By this expression, I mean the lack of knowledge or expertise displayed by the agent regarding the available data in her cognitive environment. In (Magnani et al. 2016; Bertolotti et al. 2016) Magnani, Arfini and Bertolotti define two degrees of contextual ignorance, which determine the type of abductive reasoning that could be constructively enacted by the agent in order to find a cognitive chance (an event with a significant impact on various kinds of further cognitive performances and of decision-making). The analysis started by considering the complex of data the agent possesses and manages, together with those that are within reach in her cognitive environment, as an agent-centered system. Her topics of expertise, the knowledge she usually employs, correspond to the *central information*.

Conversely, the information that is still within the agent's cognitive system but not in her dominion of expertise, corresponds to the *peripheral information*. Abductive inferences are performed upon and within these two parts of her system, albeit in two very different manners and making use of two very different degrees of ignorance.

The first degree of ignorance is set in the agent's central information; it involves a part of delusion about the actual knowledge the agent has on her field of expertise. Here, the agent enacts a selective abductive inference—for example in diagnostic reasoning, where abduction is merely seen as an activity of "selecting" from an encyclopedia of pre-stored hypotheses[18]—which gives her the possibility to find the best explanation, selecting it from a discrete number of choices. In this context, as Estrada-González stresses (Estrada-González 2013, see above), all the hypothetical candidates, to be considered as potential solutions, must be believed as relevant and plausible. Unfortunately, believing that candidate hypotheses are relevant and plausible does not make them so. Indeed, the degree of contextual ignorance on the hypothetical set of possible solutions could involve their relevance and plausibility; a plausible solution could later on seem implausible to the agent, as she acquires new data in her central information. In this context, even if the agent considers plausibility and relevance quite strict demands for the candidate hypotheses, they are just—objectively—context-and time-dependent requirements, relative to her degree of contextual ignorance.

Conversely the second, deeper, degree of ignorance is set in the peripheral information of the agent and it is even harder to manage than the first. The agent knows little about the set of data she wants to investigate and the possibility that she could find an implausible or irrelevant hypothesis in this context is quite high. At the same time, she is also aware of this possibility, and so she knows she cannot perform

[18]I have proposed the dichotomic distinction between selective and creative abduction in (Magnani 2001). A recent and clear analysis of this dichotomy and of other classifications emphasizing different aspects of abduction is given in (Park 2015).

a selective abduction to direct her inquiry. The method she can usefully employ now is a creative abduction (abduction that generates new hypotheses—cf. my book of 2001 (Magnani 2001)), which could lead her to find an unexpected solution in the uninvestigated field. Here, the hypothesis found does not strictly require plausibility and relevance as qualities in order to be considered, because the agent has too little information to believe in the relevance and plausibility of the hypothesis. At the same time, she is also aware that she is mostly ignorant about the data she is investigating: she can, instead, consider it a *potentially* good (thus relevant and plausible) guess, worth of being pursued, cognitively enriched and linked to other new pieces of knowledge and, possibly, at the end, to be tested. Doing so, she performs a creative abduction, activating the hypothesis and "essaying" its plausibility and relevance. These qualities only become *actual* once the abduction is definitely performed and accepted.

As we can see, the relevance and plausibility requirements, are very context-and-time-dependent not just relatively to the knowledge of the agent, but also with respect to her degree of contextual ignorance and her awareness about it. Not only, especially considering the process of a creative abduction, relevance and plausibility cannot be considered as strong qualities, or as the ones the agent is sure about in the first place. Albeit they are good requirements for a rational inquiry, they are hardly ever the initial ones the agent is looking for, or those that effectively trigger the abductive process.

6.2.3.2 Agenda and Relevance

It is certainly an important fact about abduction that successfully abduced hypotheses can be highly implausible and remain such in spite of the abduction's success. But relevance could be a different matter. When construed probabilistically or in Anderson & Belnap's (Anderson and Belnap 1975; Anderson et al. 1992) full-use sense, relevance is nothing close to a condition on abductive success.

But if construed in the manner of Gabbay and Woods's first-person perspective of *Agenda Relevance* (Gabbay and Woods 2003, p. 182), abduction goes hand in hand with relevance:

- Information I is relevant for agent X with respect to his agenda A if and only if in processing I, X is affected in ways that advance or close A.[19]

[19] "Relevance is defined as a four-place relation on the set $< X, I, B, A >$, where X is an individual cognitive agent, I is information, B is his background information, and A his cognitive agenda. Then I is relevant for an X with background information B if and only if in processing I, X is put in a state of mind which advances or closes his agenda. When this happens, the state of mind in which X's processing of I has put him either produces a saturated b-state with respect to A or a b-state to the effect that A, while still open, holds promise of closure, or, finally, in a state which, whether or not he experiences it as so, improves his prospect of attaining closure. Since the human individual is an efficient evader of irrelevant information, it stands to reason that the causal processes that advance the mind in the direction of agenda-closure won't fire if his processing

To the extent that my eco-cognitive approach preserves a Peircean flavor, an abducer's agenda *A* is to find a hypothesis which, if true, would make the triggering event or phenomenon "a matter of course". Let *H* be the hypothesis that has been successfully abduced. It could not have been unless the abducer believed that were it true then, when added to what is already known, the triggering event would be a matter of course. Thus the abducer has processed *H* in ways that have closed or at least considerably advanced his agenda *A*, sufficiently so as to warrant the provisional adoption of *H*. Whereupon we have it that *H* is agenda-relevant for the abducer.[20]

6.2.4 Abduction and the Production of a Deduction

In subsection 6.2.1 above we have remembered that the making of an abduction represents the logical counterpart of the cognitive (and epistemological) *fill-up problem* described in Sect. 1.2, chapter one of this book, that is the problem of finding a suitable improvement of the context (the premisses), for example the variable ? below, such that from the original context and its enrichment the conclusion *L*-follows

$$\alpha \copyright \beta, ? \Vdash_L \beta \qquad (2)$$

This abductive need of improving the context (the premisses) echoes what is described in the chapters A27-A30 of the first book of *Prior Analytics*,[21] that is the group of procedures—we could now call heuristic–for finding premises to decently solve certain problems, Aristotle says "τὸ ποιεῖν συλλογισμὸν" (Aristotle 1989, A28, 43a, 19–24, p. 42), that is to the aim of *producing* a syllogism in a satisfactory way. Indeed, at the beginning of Chapter A27 Aristotle contends that "Now it is time to explain how we may ourselves always be supplied with deductions about what is set up, and the route by which we may obtain the principles concerning any particular subject. For surely one ought not only study the origin (γένεσιν) of deductions, but also have the power to produce (ποιεῖν) them" (Aristotle 1989, A28, 44b, 26, p. 46). In this perspective syllogisms are concerned with problems,

(Footnote 19 continued)
devices fail to screen out irrelevant inputs. So effective irrelevance protection is a natural inhibitor of information processing" (Woods 2013, pp. 282–283).

[20]The GW-schema for abductive inference (cf. Sect. 1.1, Chap. 1 this book) satisfies (trivially) the Anderson & Belnap term-sharing notion of relevance. *H* occurs in the conclusion and also in preceding lines, so it is *A* & *B* relevant in this sense. Still, saying so is a bit of a stretch. *A* & *B*'s relevance was defined for propositional deductive logics and functions there as a constraint on its entailment relation. Since entailment plays no load-bearing underlying role in abductive inference, it is doubtful that *A* & *B* relevance has a load-bearing relevance for abduction.

[21]It has to be noted that this abductive need of improving the context seems to reverberate, from an epistemological perspective and perhaps as its main component, the scientist's search for new sources of information (in this respect cf. also Hintikka's interrogative model (Hintikka 2007) and below Sect. 7.2.3.1, Chap. 7, this book).

when seen as regarding situations in which the conclusion is already given, and the problem is how to find/discover premisses in order to set up a syllogism.[22]

The procedure above, in particular, reduces to a procedure for finding the middle term: during the Middle Age it was called *inventio medii*, that is discovery of the middle term, because it is essentially a procedure for finding the middle term of a syllogism, given the conclusion. The *Pons Asinorum*, or "bridge of asses", is a diagram embodying Aristotle's *rules of argument-finding* of the *Prior Analytics* chapters I have just quoted. Hamblin (1976, p. 131) contends that "these rules were elaborated by Alexander of Aphrodisias, who speaks of a 'diagram' and may reasonably be credited with having invented it".

' seems given by John Philoponus, it is discussed by Averroes, Albert the Great, by the major logicians in the thirteenth and fourteenth centuries, and Bochenski finds it in Thomas Bricot's commentary on the work of George of Brussels. In the fifteenth century it appears in John Dorp's commentary on Buridan, and in Peter Tartaret, who is the first to use the name *pons asinorum* and gives an elaborately drawn diagram with an allegory about an ass (which may be indicates a logical beginner) crossing one of a number of bridges between a major and a minor term. Because of Rabelais the name has become proverbial and it has to be said that it is also sometimes applied to the fifth proposition of the first book of Euclid, concerning the equality of the angles at the base of an isosceles triangle, which is the first difficult theorem in that work and has a figure slightly reminiscent of the logical diagram. Bayle speculates that the name *pons asinorum*, French *pont aux ânes*, arises from a pun between *âne* and *an*, "whether", and refers to the choice between alternative middle terms; he also proposes a link with the fable of Buridan's ass, which could not choose between equally distant heaps of hay. Other authors have connected the doctrine of the pons with Buridan, because of the section *De arte inveniendi medium* of his *Compendium* (Hamblin 1976, pp. 131–132).

In the previous chapter I have described this same procedure for finding the middle term in the light of the cognitive (and epistemological) *fill-up problem* of abduction, I have introduced in Sect. 1.2 of chapter one. It is worth to be noted that in dealing with this problem I have stressed the special role played by model-based procedures (especially diagrammatic). Indeed, I have first of all emphasized the role of the method of analysis and of the introduction of new/additional middle terms in Plato's dialectic argumentation,[23] in their relationships with Aristotle's concept of ἀπαγωγή. In the case of the *Meno* dialogue Plato needs determine whether a certain rectilinear figure could be constructed along the diameter of a circle; to this aim Socrates establishes a new diagrammatic hypothesis, that incarnates the "leading away" (ἀπαγωγή), which, following Aristotle, opens up the reasoning to an eco-

[22] A detailed description of this part of Aristotelian logic is given in cf. (Cellucci 2013, Chap. 7).

[23] An interesting recent revival of these dialectical roots of abduction is represented by the formal treatment and justification of abduction as IBE (inference to the best explanation) in terms of meta-arguments, called by Betz *practical meta-syllogisms* (Betz 2013). The so-called "dialectical structures" are introduced, which involve the maximization of robustness of one's point of view in an interplay of negotiations. This new logical framework delineates a further step in the direction of that naturalization of the logic of abduction I have described above in Sect. 6.2.

cognitive dimension, which in our case corresponds to an abduction, endowed with its degrees of uncertainty. In the previous chapter (Sect. 5.3.1) I also suggested that the function played by diagrams in reasoning was also typical of diorismic/porismic processes and of their creative counterparts, eventually endowed with an objection-refuting role. Levy eloquently says that in Peirce's theorematic reasoning, typical of productive geometrical diagrammatic constructions, "a foreign idea" is introduced, that leads away from previous definitions or known results suggesting new cognitive chances(Levy 1997, p. 97).[24]

An echo of this reference to the importance of diagrams in analyzing abductive reasoning is indeed still vivid in Peirce, also thanks to the emphasis on the role of icons: "I said, Abduction, or the suggestion of an explanatory theory, is inference through an Icon" (Peirce 1997, p. 276). It is well known that, for Peirce, signs are icons, indexes, and depending on the nature of the relationship of them to the objects signified. An icon[25] is the middle term of abduction (Trajkovski 2017), because Peirce aims at stressing the role of *resemblance*, such as in the following case, a syllogism of the second figure [As I have already illustrated above—footnote at p. 114—Aristotle insists that all syllogisms are valid (by definition) (Woods 2014, p. 150), there is no such thing as an invalid syllogism. We know the syllogistic tradition began to relax this requirement quite early on. I am using the term syllogism in this extended sense]:

> This woman is pale,
> Being with child is accompanied with paleness; therefore
> This woman is with child.

where "to be pale" represents the middle term.[26] It *functions* as an icon: a pale women resembles a woman who gave birth, she has some features in common with her, and she looks like her. In general, abduction and icon share the common feature of *creativity*, in so far as an icon can present—through resemblance—*unexpected outcomes*.

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[24] See also (Campos 2010, p. 131) and (Marietti 2010, pp. 153–154). On theorematic and corollarial reasoning in mathematics and on "geometrical constructions interpreted as manipulative abductions" cf. (Magnani 2009, Chap. 3, Sect. 3.6.3). It is here very interesting to note that the fifth proposition of the first book of Euclid's *Elements* —I have quoted above when dealing with the procedures for finding the middle term and the *Pons Asinorum*—is also one of Peirce's favorite examples in order to illustrate theorematic diagrammatic reasoning in geometry (Campos 2010, p. 132).

[25] An index instead refers to deduction and a symbol refers to induction, see below.

[26] This and the following examples—reworked in a Peircean perspective—are directly derived from the part of *Prior Analytics* Aristotle devoted to the enthymemes as syllogisms "from likelihoods or signs" (Aristotle 1989, B29, 70a, 10, p. 136). As I have illustrated in the previous chapter of this book, Sect. 5.5, this part represents a kind of "proto-semiotic" treatment of various aspects of reasoning.

On the contrary index is related to deduction, such as in the case of the middle term "to have milk" , which is *taken* as an index, a natural sign of giving birth to a child, see the following related syllogism of the first figure:

This woman has milk,
Having milk means to be with child; therefore
This woman is with child.

In the following example (syllogism of the third figure):

Pittacus is wise,
Pittacus is good; therefore
Wise men are good

"to be Pittacus" is the middle term. Pittacus is, so to speak, a paradigmatic case of wise men, taken by convention, and so represents the foundation for a generalization, not an index, not an icon, but precisely *taken* as a symbol.

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Chapter 7
Science Maximizes Abducibility

The Optimization of Eco-Cognitive Situatedness in Ampliative Inferences

The analysis of abductive processes illustrated in the previous chapters, in terms of the effort to naturalize the logic of its special consequence relation, leads us to the emphasis on the importance of the following main aspects: "optimization of eco-cognitive situatedness", "maximization of changeability" of both input and output of the general form of an inferential abductive problem, and high "information-sensitiveness". Furthermore, a naturalized logic of abduction must acknowledge the importance of keeping record of the "past life" of abductive inferential praxes, contrarily to the fact that traditional demonstrative ideal systems are prototypically characterized by what I call "maximization of memorylessness". In this perspective I will provide an analysis of the importance of the *maximization of abducibility*, which is typical of science, together with a discussion of the relevance of the various aspects above for a new eco-cognitive epistemology.

7.1 Abductive Cognition and the Optimization of the Eco-Cognitive Situatedness

7.1.1 A Logic of Abduction Is Eco-Cognitively Disciplined

A good "mimetic"[1] abductive logical system is classically characterized by the following general distinct levels, which resort to the fill-up and cutdown aspects:

- a *base logic* L_1 with proof procedures Π;

[1] Cf. Sect. 3.3, Chap. 3, this book.

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- an *abductive algorithm* which deploys Π to look for missing premisses and other formulas to be abduced;
- a *logic* L_2 for deciding which abduced formulas to choose, which criteria of selection apply, etc. This logic is related to the specification of suitable constraints regarding plausibility, relevance (topical, full-use, irredundancy-oriented, probabilistic), etc., and economy, making the ideal agent able to discount and select information which does not resolve the task at hand (Gabbay and Woods 2005).

We already know (cf. Chap. 1, this book) that it is thanks to the GW-schema that Gabbay and Woods criticize the so called AKM-schema of abduction. A primary gift provided by the GW-schema was the opening of the discussion about *ignorance preservation* but also about *non-explanatory* and *instrumental* abduction, considered as not intrinsically consequentialist.[2]

I the previous section I have maintained that relevance and plausibility are *context-* and *time-dependent*, and so not necessary aspects of all potential successful abductions: this means that eco-cognitive environmental situatedness of abductive cognition matters more than expected. From the perspective of logic the first consequence is that the fill-up problem should consist in a logic *eco-cognitively disciplined* and *multimodally* built. In Chap. 5 of this book I have indicated—also taking advantage of the analysis of the Aristotelian concept of "leading away" ἀπαγωγή—that looking for a naturalization of the logic of abduction, it is fruitful to follow the main tenets of my EC-Model. Consequently it is appropriate to adopt, when dealing with the the so-called "inferential problem", the more general concepts of input and output instead of those of premisses and conclusions. In such a way there is one more advantage: it is more natural to accept the *multimodal* character of the inferences involved. In this perspective we expect to have a logic in which the artificial language presents an *extendable* expressive capacity and that can also be itself composed by icons and not only by symbols, like for example it is occurring in the case of heterogeneous logics. Some logicians seem to acknowledge this need when dealing with a broad view of the inference problems: "An inference can be seen as an argument completion process, where premises are reduced either to a single formula or to multiple formulas, depending on whether single—or multiple—conclusion logics are used. But although the conclusion might consist of a single formula, we might need to add rules, theories, etc. in order to complete an argument, and not just adding formulas in the context. Nonetheless, the conclusions could be also rules (if for example, in a logic we want a rule to be a derived one, we may need to make some inputs to the original logic), theories, valid arguments, diagrams, etc." [...] (Estrada-González 2013, p. 186).

Let $\Theta = \{\Gamma_1, ..., \Gamma_m\}$ be a theory, $P = \{\Delta_1, ..., \Delta_n\}$ a set of true sentences corresponding – for example— to phenomena to be explained and $\Vdash$ a consequence relation, usually—but not necessarily—the classical one. According to the AKM schema (cf. Chap. 1), abduction refers to the inference of P from Θ and

[2]I have illustrated non-explanatory and instrumental abduction in (Magnani 2009, Chap. 2), also providing some case studies.

$H = \{A_1, ..., A_k\}$, a collection of hypotheses, given some further constraints, which can basically relate to consistency, minimality, and preference, as we have repeatedly stated. In this perspective an abductive problem concerns the finding of a suitable improvement of $A_1, ..., A_k$ such that $\Gamma_1, ...\Gamma_m, A_1, ..., A_k \Vdash_L \Delta_1, ..., \Delta_n$ is *L-valid*. It is obvious that an improvement of the inputs can be reached both by additions of new inputs but also by the modification of inputs already available in the given inferential problem.

In the perspective above in terms of inferential problems an inference is not only seen in terms of the process that leads to the generation of an output or to the proof of it, like in the traditional and standard view of deductive proofs, when we have to obtain the output from the input. In this broader logical view an inferential problem is also the process of *increasing* or *modifying* part of the inputs, or both *inputs and outputs*, in order to obtain a desired relation between inputs and outputs. Of course, the reached extension or modification is the solution of the inferential problem. It is clear that in the case of abductive cognition input and output fail to stand each other in an expected relation and the solution requires the modification of inputs, not of outputs: these modifications represent the solutions of the abductive problem.

I have already said that this process of modification of inputs is basically multimodal and various context-depending conditions have to be fulfilled in order to reach the (best) solution. From this perspective the general form of an inferential abductive problem can be symbolically rendered as follows (Estrada-González 2013, p. 189):

- $A_1, ..., A_i, ?_I \Vdash_L^X \Upsilon_1, ..., .\Upsilon_j$ (3)

in which $\Vdash_L^X$ indicates that inputs an outputs do not stand each other in an expected relation and that the modification of the inputs $?_I$ can provide the solution.

In general, in this characterization the direction is not from evidence/premisses to abductive result but the forward fashion is adopted, where the inferential parameter $\Vdash$ sets some appropriate logical relationship between an input which consists in both the abductive guess to be found and a background theory (or just some premisses), and an output—for example an evidence, a novel phenomenon to be abductively "explained" through facts, rules, or even new theories. The inferential parameter does not have to be considered neither the semantic entailment above nor the classical derivability. Aliseda observes that it ranges—at least in the case of the main received non-standard logical accounts—over diverse values such as for example probable inference, logic programming or dynamic inference: "abduction is not one specific non-standard logical inference mechanism, but rather a way of using any one of these" (Aliseda 2006, p. 47); also, she stresses that it is logically useful to depict "explanatory" consistent abduction by extracting those sets of "top-down" (van Benthem 2007, p. 272) basic properties that are called *structural rules* of inference, such as conditional reflexivity, simultaneous cut, conclusion consistency, modified monotonicity, modified cut, rejection of permutation in dynamic inference, etc., which "fit a logical format" (Aliseda 2006, p. 150).

The structural rules reverberate—Aliseda (cit., p. 95) says they "state how abductive explanatory logic behaves"—the fact that abduction can be expressed by deviant (but still logical) systems, endowed with extra-systematic specific notions of validity, even if, unfortunately, they do not provide methods for *generating* abductive explanations, such as it is occurring computing abduction thanks to logic programming and semantic tableaux.

Finally, it has to be remembered that, if we consider the modification of the inputs $?_I$ that provides the solution as *subjunctively* attained, such as in the case of the ignorance-preserving abductions illustrated by the GW-schema, then these computing devices do not appear to be "genuine" abductions. In this perspective Woods observes that in the case of semantic tableaux abduction resembles enthymeme resolution and so does not reflect its presumptive character: the task resorts to the rehabilitation of an ailing deduction. In semantic tableaux abduction, "the task is to find a ϕ that closes a $model$-connection between a theory and some (usually) empirical data, which also is the repair of a decrepit deduction" (Woods 2007, p. 310). In the light of the *presumptive* character of the GW schema, and only in this light, there is nothing that is abductive about such closures. Indeed $\models$-closures are possible without there being any ignorance-problem to which the closure is a response.

7.1.2 Anthropomorphizing the Logic of Abduction

We see immediately that the chance of finding an abductive solution still appears to depend on that Aristotelian "leading away" (), that is on the starting of the application of a *supplementary logic* implementing an appropriate formal inference engine which can provide a solution. This supplementary logic implements a new inference engine from the output of the formula (3)—cf. above, the previous subsection, this chapter—(which belongs to the *other logico-cognitive process* that originated the abductive problem above) and its remaining available inputs. If we want to naturalize the logic of the abductive processes and its special *consequence relation*, which has to be strongly "eco-cognitive-sensitive", $\Vdash_{EC}$, we must note that a naturalized abductive logic would have to refer to the following main aspects:

1. *optimization of situatedness*. Situatedness is related to eco-cognitive aspects: to favor the solution of the abductive problem input and output of the formula above have to be thought as *optimally positioned*;
2. this optimality is made possible by a *maximization of changeability* of both input and output. Not only inputs have to be enriched with the possible solution but, to do that, other inputs have usually to be changed and/or modified;
3. consequently, abductive inferential processes are highly *information-sensitive*, that is the flux of information which interferes with them is continuous and systematically human(or machine)-promoted and enhanced when needed. This is not true of traditional inferential settings, for example proofs in classical logic, in which the modifications of the inputs are *minimized*, proofs are usually taken

with "given" inputs, and the burden of proofs is dominant and charged on rules of inferences, and on the smart choice of them together with the choice of their appropriate sequentiality (see below Sect. 7.2);

4. indeed, in our eco-cognitive perspective, an "inferential problem" can be enriched by the appearance of new outputs to be accounted for and the inferential process has to restart. This is exactly the case of abduction and the cycle of reasoning reflects the well-known nonmonotonic character of abductive reasoning. Abductive consequence is ruptured by new and newly disclosed information, and so defeasible. In this perspective abductive inference is *not only* the result of the modification of the inputs, but, in general, actually involves the intertwined modification of both input and outputs.

In sum, considering an abductive "inferential problem" as symbolized in (3) (cf. above, the previous subsection, this chapter), a suitably anthropomorphized logic of abduction has to take into account a continuous flux of information from the eco-cognitive environment and so the constant modification of both inputs and outputs on the basis of both

1. the *new information available*,
2. the *new information inferentially generated*, for example new inferentially generated inputs aiming at solving the inferential problem.

Finally, let us remember, as already stressed, the importance of

- *multimodality*. The logical inferential process of modification of inputs has to be strongly intended as *multimodal* not only from the point of view of the *cognitive devices* "represented" (not merely propositions, but also diagrams, for example) but also from the point of view of the *applied rules*: model-based, but also computational aspects, have to be taken into account.

To conclude, optimization of situatedness is the main general property of logical abductive inference, which—from a general perspective—defeats the other properties such as minimality, consistency, relevance, plausibility, etc. I have described above. These are special subcases of optimization, which characterize the kind of situatedness required, at least at the level of the appropriate inference able to generate the new inputs of an abductive "inferential problem" as symbolized in formula (3) (cf. above, Sect. 7.1.1, this chapter). In this book I am especially dealing with the important case of science, in which the optimization of eco-cognitive situatedness has to respect various constraints that basically resort to the relevance of those epistemic virtues I have illustrate in Sect. 6.1.2 of the previous chapter and other methodological aspects I have described in the remaining chapters. In the last chapter of this book I will stress that constraints, methods, cognitive virtues, etc. which characterize scientific cognition certainly substantiate limitations of the cognitive behaviors but at the same time they are clearly finalized to the maintenance of the optimization of eco-cognitive openness, that solely can grant the flourishing of abductive scientific creativity.

7.1.3 A Logic of Abduction Is Naturalized

In *Truth in Fiction: Rethinking Its Logic* John Woods (Woods 2017) illustrates those canonical ten Commandments of a naturalized logic *NL* I am reporting below, appropriately culled from various sites of the book. I am adding their specification in the case of the naturalized logic of abduction I have detailed above in Sect. 7.1.2. Furthermore, in Sect. 7.2.2 I will also add other relevant considerations including the fact that, contrarily to the case of classical demonstrative systems, which are characterized by what I call a *maximization of memorylessness*, naturalizing a logic of abduction is related to the need of keeping record of the past life of abductive inferential praxes.

1. Naturalized logic *NL* is an enquiry into the processes of human reasoning, chiefly premiss-conclusions reasoning (or information input-output cognitive processing, cf. above Sect. 7.1.1), together with a specification of conditions under which reasoning is well or badly done, and an examination of the relation between premises (inputs) and conclusions (outputs) in virtue of which this is so.
   I will contend that in the case of abduction a reasoning will be well-done when an optimization of situatedness is displayed: to favor the solution of the abductive problem the relationship between input and output of the formula above have to be thought as *optimally positioned*.
2. *NL* is an agent-centered, goal-directed, dynamic and interactive account of intelligent information-processing.
3. *NL* is relationally pluralistic, recognizing different good-making ties between the premisses and conclusions of a human individual's reasoning, and can be suitably aggregated and adjusted for collective reasoning. Standards of rightness vary accordingly, and are subject to circumstantial considerations. They include the logician's usual standards of deductive validity and inductive (statistico-experimental) strength, as well as the relations underlying hypothetical, abductive, explanative, defeasible and nonmonotonic reasoning.
   The eco-cognitive model of abduction illustrated in this chapter, the previous one, and in Chap. 1 is perfectly in tune with the agentive aspect stressed in the previous two items.
4. *NL* is empirically sensitive, and subject to the influence of well-confirmed law-like regularities in the best of our sciences of cognition. In particular, NL openly promotes a restoration to logic of relevant disclosures from psychology. Thus logic naturalized is logic psychologized. It is therefore an inherently cross-disciplinary mode of enquiry.
5. *NL* accordingly is a data-rich logic, reserving its theoretical speculations until the requirements of data collection and data analysis have been met. Data-bending is eschewed.
   The case of the naturalized logic of abduction instantiates these two items by referring to the fact that the optimality I quoted few lines above is made possible by a *maximization of changeability* of both input and output, a changeability

which first of all refers to a wide psychological/epistemological openness. Not only inputs have to be enriched with the possible solution but, to do that, other inputs have usually to be changed and/or modified.

6. In keeping with its naturalistic character *NL* carries a positive but defeasible bias towards naturalistic accounts of normativity. Especially in the case of premiss-conclusion reasoning, the bias favors the idea that an agent in given circumstances is reasoning competently to the extent that people in general normally reason that way in such circumstances.
7. Any investigative device implicated in the success of disciplinary partner is eligible for consideration of *NL*'s appropriation. Idealizations and abstractions in the manner of their use in model-based science are appropriate for *NL* use provided the artificialities of borrowed models are properly compensated for, either by doing well at the empirical checkout counter or by successful negotiation of the logic's normative expectations. This is particularly important for stipulations of ideal rationality.
8. *NL*'s medium of exchange is the natural language in which its target agents give their reasoning linguistic expression. Properties and provisions of theories framed for formalized or artificial languages are subject to appropriation subject to the proviso imposed by (7).

   In the case of abduction the previous three items are specified saying that if traditional logical systems are *abstract* in the sense that they are based on a *maximal independence* regarding sensory modality, and so they strongly stabilize experience and common categorization, on the contrary this requirement is no longer crucial, but "abstractness" is circumstance-based and so eco-cognitively conditioned. Moreover, multimodality of formalization is really important: a naturalized logic of abduction is open to a modification of both language and rules (see Sect. 7.2.2).
9. The causal influences on good reasoning should be respected. For example, *NL* should be open to characterizations such as the following: "A human individual *X* knows that *P* on information *I* when *P* is true, *X* believes *P*, *I* causally induces *X*'s belief-forming devices to produce the belief that *P*, *X*'s cognitive devices are in good working order and operating here as they should, *I* is good information and there is no interference caused by negative externalities".
10. This last condition is, in importance, the first. Abandon all pretense that deductive validity is the gold standard for premiss-conclusion reasoning. It is the gold standard for truth-preserving reasoning. But to make truth-preservation a desideratum for human reasoning in general dooms almost all it and science too—to an unearned subparness.

    The whole research about abduction and its virtues illustrates the truth of this last item: first, the fact that abduction is "akin to the truth" (see below Peirce's quotation at p. 155, Sect. 7.2.3); second, research on abduction in the last decades certainly has described it as an exceptional example of a significant and fruitful truth-generating non-deductive reasoning. I will come back to the issue in the following Sect. 7.1.4, still dealing with the puzzling relationship between naturalization of logic and deductive validity.

7.1.4 A Logic of Abduction Is Distributed: Benacerraf's Dilemma Revisited

One could say that the naturalization of logic is the right track, but that excessive naturalization makes questions for the validity of reasoning (deductive, abductive, inductive) matter of empirical concern. For example, she could ask: could an empirical observation prove reasoning wrong? In this case we clearly see that our interlocutor suspects that relations of premiss-conclusion adequacy (or information input-output cognitive processing) can be subject to naturalistic constraints, when the relation of deductive validity is clearly free of similar constraints. I think this is a typical worry that easily comes out in the perspective of a "logico-centered" approach to reasoning—often latently active even in the presence of very "liberal" logical views.

To answer the question we can resort to some argumentations given by Woods in the recent book *Errors of Reasoning. Naturalizing the Logic of Inference* (Woods 2013, pp. 42 and 305). Woods says, and I agree with him, that deductive validity is instantiated in "logical space", whereas all the non-deductive relations of premiss-conclusion adequacy are instantiated in epistemic (hence psychological, and eco-cognitive, I would add) space: "Proposition 1.8b: Having and Drawing:*Consequence-having occurs in logical space. Consequence-drawing occurs in a reasoner's mind*" (p. 42). There is, of course, a standing problem about this, certainly related to the so-called Benacerraf's dilemma (Benacerraf 2014), still emphasized by Woods (2013, pp. 315–316): how can psychological beings like us make cognitive contact with the facts that obtain in logical (and mathematical) space, free of agency and context? One possible answer is that, simply, it seems that we do make contact, securely and reliably. In the perspective of the naturalization of logic, however that feat is brought off, because the other relations are inspectable in psychological space. Accordingly, non-deductive consequence relations, such as abduction, will not be well understood as logical space's poor cousins. Moreover, a conviction often related to the "logico-centered" approach quoted above—sometimes implicit—is that deductive validity is mathematically definable, whereas many of the non-deductive counterparts are not: the simple but patent counter-objection is that most of good premiss-reasoning in science, law and life on the ground owes its goodness to considerations beyond the feeble reach of deductive necessitation.

A further consideration that can provide an answer to the Benacerraf's dilemma resorts to some considerations that take advantage of the theory of distributed cognition. As I have already said in Chap. 3, the so-called "disembodiment of the mind" is extremely interesting, in the case of semiotic cognitive processes occurring in general in science. I have illustrated that the disembodiment of the mind refers to the fact the mind "disembodies" itself by projecting representations on the external environment, that is it refers to the cognitive interplay between internal and external representations, *mimetic* and, possibly, *creative* (in this last case they are not necessarily mimetic), where the continuous interaction between on-line and off-line intelligence can properly be addressed. I consider this interplay crucial in explaining

the relation between meaningful semiotic internal resources and devices and their dynamical interactions with the externalized semiotic materiality stored in the environment (for example artifactual models, but also theories of natural science and, of course, also the logical and mathematical ones, such as in our case, related here to the Benacerraf's dilemma).[3] In Chap. 3, I concluded that minds are "extended" and artificial in themselves. In this perspective logical and mathematical systems are the creative fruit of the interplay between internal and external representations and, once available, they represent an external materiality that plays a specific role in the interplay due to the fact that it (external materiality) exhibits (and operates through) its own cognitive constraints. It is at the level of that continuous interaction between on-line and off-line intelligence that I underlined the importance of what I called *manipulative abduction*.[4]

How can psychological beings like us make cognitive contact with the facts that obtain in logical (and mathematical) space, free of agency and context? In the light of the above considerations first of all external representations (for example logical notations and deductive proofs), if not too complex, can be transformed in internal representations by memorization. But this is not always necessary if the external representations are easily available. Internal representations can be in turn transformed in external representations by externalization, that can be productive—and in this *interplay* new concepts[5] can arise. Hence, contrarily to the old view in cognitive science, not all cognitive processes happen in an internal model of the external environment. The information present in the external world can even be "directly" picked out without the mediation of memory, deliberation, etc. Moreover, various different external devices (for example the logical ones) can determine different internal ways of reasoning and cognitively solve the problems, as is well-known.

I argue that ideal logical agents have to be seen as "demonstrative environments". They are the fruit of cognitive externalizations in objective logical systems, endowed with symbolic, abstract and rigorous cognitive features, which are made maximally stable and often "institutional" (in Gabbay and Woods sense (Gabbay and Woods 2005)). The contact between psychological beings like us and the facts that are obtained in logical (and mathematical) space, free of agency and context, is granted by the interplay between internal and external representations illustrated above.

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[3] On the fact that considering logical reasoning a discursive process is an "optical illusion" cf. Sect. 7.2.3.1: for example Hintikka maintains that deduction is a form of "experimental model construction".

[4] Cf. Sect. 1.3, Chap. 1, this book.

[5] An evolved mind is unlikely to have a natural home for complicated concepts like the ones logic introduced, as such concepts do not exist in a definite way in the natural (not artificially manipulated) world: so whereas evolved minds could construct reasoning frameworks and perform some simple reasoning inferences in a more or less tacit way by exploiting modules shaped by natural selection, how could one think exploiting explicit complicated logical concepts without having picked them up outside, after having produced them?

7.1.5 *Deductive Consequence Repels Information, Logic Programs Are Information-Sensitive*

It is in the area of distributed cognition studied by cognitive science that the importance of the interplay between internal and external representations and information has recently acquired importance (cf. for example Clark (2003) and Hutchins (1995)). This perspective is particularly coherent with the agent-based framework I have indicated above as appropriate to abduction, as we will see. It is interesting to note that a clear attention to the agent-based nature of cognition and to its interplay between internal and external aspects can also be found in the field of logic programming, which Aliseda (Aliseda 2006) describes as one of the two main ways—we already said that the other is the semantic tableaux method—of logically and computationally dealing with abduction.[6] I think in logic programming a new idea of logic—contrasted with the classical one – arises, which certainly opens to abduction that door able to grant access to a new "logical" treatment. Indeed, logic programs can be seen in an agent-centered, computationally-oriented and purely syntactic perspective.

It is interesting to stress some aspects of this tradition because the appearance of logic programs during the second half of the last century created a first interest about the need for logic to take into account situations in which a huge quantity of information outside of a logical system arrives to the system itself: it is exactly the counterpart of my emphasis in the previous section on the constant flux of information which characterizes a naturalized logic of abduction. Deductive consequence repels information, logic programs instead are information-sensitive. Logic programs already embryonically stress the importance for inferential problems of what I have called in the previous section eco-cognitive environment and so the constant modification of both inputs and outputs on the basis of both

1. the *new information available*,
2. the *new information inferentially generated*, for example the new inferentially generated inputs aiming at solving the inferential problems (cf. formula (3)—cf. Sect. 7.1.1, this chapter).

Let us say some words about the approach in terms of logic programs. Already in 1994 Kowalski (1994) in "Logic without model theory" introduced a knowledge assimilation framework for rational abductive agents, to deal with incomplete information and limited computational capacity.

"Knowledge assimilation" is the assimilation of new information into a knowledge base, "[. . .] as an alternative understanding of the way in which a knowledge base formulated in logic relates to externally generated input sentences that describe experience" (Kowalski 1994, p. 35). The new pragmatic approach is based on a

[6]We have to remember that one limitation of ALP (Abductive Logic Programming) is that it requires a set of "abducibles" in advance, and these are limited to facts (literals). From this perspective, this framework is not better than any other inferential-based one.

proof-theoretic assimilation of observational sentences into a knowledge base of sentences formulated in a language such as CL.[7] Kowalski proposes a pragmatic alternative view that contrasts with the model-theoretic approach to logic. In model theory notions such as *interpretation* and *semantic structures* dominate and are informed by the philosophical assumption that experience is caused by an independent existing "reality composed of individuals, functions and relations, separate from the syntax of language" (Kowalski 1994, p. 38).

On the contrary logic programs can be seen as agents endowed with deductive databases considered as *theory presentations* from which logical consequences are derived, both in order to *internally* solve problems with the help of *theoretical sentences* and in order to assimilate new information from the *external* world of observations (*observational sentences*). The part of the knowledge base, which includes observational sentences and the theoretical sentences that are used to derive conclusions that can be compared with observations sentences, is called *world model*, considered a completely syntactic concept: "World models are tested by comparing the conclusions that can be derived from them with other sentences that record inputs, which are observational sentences extracted—*assimilated*—from experience" (Kowalski 1994, p. 40). The agent might generate outputs—that are generated by some plan formation process in the context of the agents's "resident goals" – which affect its environment and which of course can affect its own and other agents' future inputs. Kowalski concludes "The agent will record the output, predict its expected effect on the environment using the 'world model' and compare its expectations against its later observations" (Kowalski 1994, p. 67).

The epistemological consequence of this approach is fundamental: in model theory truth is a static correspondence between sentences and a given state of the world. In Kowalski's computational and "pragmatic" theory, the important is not the correspondence between language and experience, but the

> [. . .] appropriate *assimilation* of an inescapable, constantly flowing input stream of observational sentences into an ever changing knowledge base. Correspondence between an input sentence and a sentence that can be derived from the knowledge base is only a limiting case. In other cases some weaker form of coherence may be all that can be obtained. In the most extreme form of incoherence, which arises in the case of inconsistency, assimilation of an input might require a non-deterministic revision of the knowledge base (Kowalski 1994, p. 45)

Hence, we face with the appropriate assimilation of an inevitable and continuous flowing input stream of "external" observational sentences into an ever changing "internal" knowledge base. Of course the fact that the computational resources available are bounded usually suggests to the agent to make the best use of them, for instance—as we have already described—avoiding redundant and irrelevant derivation of consequences. The correspondence (we can say the "mirroring") between

[7] CL, computational logic, refers to the computational approach to logic that has proved to be fruitful for creating non-trivial applications in computing, artificial intelligence (AI), and law.

an input sentence and a sentence that can be derived from the knowledge base is considered by Kowalski only a limiting case. Of course the agent might also generate its own hypothetical inputs, as in the case of abduction, induction, and theory formation.

Aliseda seems to acknowledge this fact and further improves this perspective. The task is accomplished with the help of the semantic tableaux framework which can control in several ways various and meaningful logical and computational abductive strategies, some of them reflecting types of abducing already present in "actual" human performances: "That is, we must provide the automatic procedures to operate a logic, its control strategy, and its procedures to acquire new information without disturbing its coherence and hopefully achieve some learning in the end" (Aliseda 2006, p. 23). It is important to stress that thanks to this perspective in the logic of abduction the sensitivity to the growth of information [and the suitable extension of logical language] is definitely considered fundamental for the whole logic itself. Her analogy with the non-Euclidean revolution is striking and conclusive: "Whether non classical modes of reasoning are really logical is like asking if non-Euclidean geometries are really geometries" (Aliseda 2006, p. 92).

The conceptual framework above, that is derived from a computationally-oriented logic approach that strongly contrasts with the traditional one in terms of model theory, is extremely interesting. It stresses the attention on the flowing interplay between internal and external representations/statements, so *epistemologically* establishing the importance of the agent-based character of cognition.

We have to stress that also Belief Revision (BR) is one of the other main frameworks over which abduction as a process of epistemic change has been developed. Some of the formal models of abductive reasoning, for instance (Boutilier and Becher 1995), are based on the theory of the epistemic state of an agent (Alchourrón et al. 1985; Gärdenfors 1988, 1992), 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*).

Let us resume the kinds of change considered in the original belief revision framework. The *expansion* of a set of beliefs K taken from some underlying language (considered to be the closure of some finite set of premise *KB*, or *knowledge base*, so $K = Cn(KB)$) by a piece of new information A is the belief set $K + A = Cn(K \cup A)$. The addition happens "regardless" of whether the larger set is *consistent*. The case of *revision* happens when $K \models \neg A$, that is when the new A is *inconsistent* with K and we want to maintain consistency: some beliefs in K must be withdrawn before A can be accommodated: $K \dot{-} A$. The problem is that it is difficult to detect which part of K has to be withdrawn. The least "entrenched" beliefs in K should be withdrawn and A added to the "contracted" set of beliefs. The loss of information has to be as small as possible so that "no belief is given up unnecessarily" (Gärdenfors 1988). Hence, *inconsistency resolution* in belief revision framework is captured by the concept of revision. Another way of belief change is the

process of *contraction*. When a belief set K is contracted by A, the resulting belief set $K + A$ is such that A is no longer held, without adding any new fact.[8]

We have to remember that this kind of logical frameworks exclusively deals with selective abduction (for example: diagnostic reasoning)[9] and relates to the idea of preserving *consistency*. Exclusively considering this view of abduction does not enable us to say much about creative processes (for example in science) and, therefore, about the nomological and most interesting creative aspects of abduction. It mainly refers to the *selective* (diagnostic) aspects of reasoning and to the idea that abduction is mainly an inference *to the best explanation*: when used to express the creative events it is either empty or it replicates the well-known *Gestalt* model of radical innovation. It is empty because this view stops any attempt to analyze the creative processes: the event of creating something new is considered so radical and instantaneous that its irrationality is immediately called out.

Already in the initial Peircean logico-syllogistic conception, we immediately see that abduction (intended as the fallacy of affirming the consequent) is perfectly compatible with the *Gestalt* model of discovery. In the syllogistic model the event of creating something new (for example a new concept) is considered external to the logical process, so radical and instantaneous that its irrationality is immediately involved: "the abductive suggestion comes to us like a flash. It is an act of insight, although of extremely fallible insight" (Peirce 1931–1958, 5.181). It is exactly in this logico-propositional perspective that also Peirce considers abduction as "a capacity of guessing right", and a "mysterious guessing power" common to all scientific research (Peirce 1931–1958, 6.530).

Notwithstanding the supposed mysterious character of abduction advocated by Peirce it is well known that for him abduction is soon depicted as an *inferential process*: 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,[10] where the word sign includes "feeling, image, conception, and other representation" (Peirce 1931–1958, 5.283), and, in Kantian words, all synthetic forms of cognition. In this perspective, a considerable part of the thinking activity is "model-based" and not only sentential/propositional. 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 also think in terms of model-based abduction (and not in terms of sentential abduction) to explain complex creative processes.

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[8] In (Magnani 2009, Chap. 1, Sect. 4) I have provided an illustration of the tradition of logic programming related to the exploitation of the belief revision framework: I described the application to selective abduction also in the field of artificial intelligence (AI) and the role of coherence and foundations approach, reason and truth maintenance systems, model-based diagnosis, etc. Abductive belief revision in science is illustrated in the recent (Schurz 2011).

[9] 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).

[10] Cf. also (Fischer 2001).

To further favor a potential progress toward a naturalization of the logic of abduction, which nicely vindicates the positive cognitive value of the old concept of "fallacy of affirming the consequent", in the following section I will illustrate the main differences we expect to find when comparing the logic of abduction—and the naturalization of it—with some basic aspects of the traditional demonstrative inferences in deductive reasoning.

7.2 Comparing Traditional Demonstrative Inferences and Abductive Inferences

7.2.1 Some Basic Cognitive Features of Traditional Demonstrative Inferences

Let us start from a description of some discriminating cognitive features which are at the basis of the inferential skills that human beings have *externalized* and *idealized* in traditional demonstrative systems (cf. also Longo 2005), features that I believe deserve to be further analyzed and which can further fuel new intellectual chances for a naturalization of logic. *Traditional* logical systems are, when seen in a general cognitive naturalistic perspective:

1. *symbolic*: they activate and "anchor" meanings in material communicative and intersubjective *mediators* in the framework of the phylogenetic, ontogenetic, and cultural reality of the human being and its language. From a cognitive—naturalistic—point of view, it seems these *ideal* logical agents originated in embodied cognition, gestures, and manipulations of the environment we share with some mammals but also non-mammal animals (cf. the case of monkeys' knots and pigeons' categorization, in (Lestel and Herzfeld 2005; Aust et al. 2005))[11];
2. *abstract*: they are based on a *maximal independence* regarding sensory modality; they strongly stabilize experience and common categorization. This maximality is especially important: it refers to their practical and historical invariance and stability;
3. *rigorous*: the rigor of proof is reached through a difficult practical experience. For instance, already in the case of mathematics—and, later on, in the so-called mathematical logic—proofs are presented as the maximal place for convincing and sharable reasoning. Rigor lies in the stability of proofs and in the fact they can be iterated. Following this perspective mathematics is the best example of maximal stability and conceptual invariance. Logic is in turn a set of proof invariants, a set of structures that are preserved from one proof to another or which

[11]Cf. also the cognitive analysis of the origin of the mathematical continuous line as a preconceptual invariant of three cognitive practices (Theissier 2005), and of the numeric line (Châtelet 1993; Dehaene 1997; Butterworth 1999).

are preserved by proof transformations. As the externalization and result of a distilled praxis, the praxis of proof, it is made of maximally stable regularities;

4. I also say that a *maximization of memorylessness* "variably" characterizes traditional demonstrative reasoning. This is particularly tangible in the case of the vast idealization of classical logic and related approaches. I derive this expression from Leyton (1999; 2001), who introduces this concept in a very interesting new geometry where forms are no longer memoryless as in classical approaches such as the Euclidean and the Kleinian one, in terms of groups of transformations.[12] The inferences described by classical logic do not yield sensitive information—so to say—about their real past life in human agents' use, contrarily to the "conceptual"—narrative—descriptions of human concrete reasoning processes, which variously involve a remarkable amount of "historical", "contextual", "dialectical", and "heuristic" memories and constraints. Indeed, externalized written proofs in traditional logic usually do not track explicit record of previous cases, both about their real past life as previous similar logical proofs and in human agents' use. This does not mean that memories are not important, but we have to note that they are exclusively delegated to—and eventually stored in—the mental internal representations of the proofs performers, that is in the dark and partially obscure practical dimension which arises in the interplay between humans and external cognitive tools and devices (written proofs, sketches, diagrams, artifacts, etc.).

7.2.2 Abductive Inferences

What about abduction with respect to the aspects I have just illustrated? Certainly also abductive inferences have to be expressed by a logic that is characterized by *symbols* (item 1 above), but, as already said, *multimodality* appears to be important.[13] The case of the heterogeneous logical systems already shows the opportunity of involving model-based aspects in logic: they produce representations in a demonstrative framework which originate from a number of different representation systems, sentential, but also model-based, diagrammatic, traditionally considered non-demonstrative. The advantage is that they allow a reasoner to bridge the gaps among various formalisms and to construct threads of proof which cross the boundaries of the systems of representations (Swoboda and Allwein 2002). In doing this, heterogeneous systems allow the reasoner to take advantage of each component system's ability to express information in that component's area of expertise. For example "recast" rules are clearly elicited as rules of inference that allow the exchange of information between the various representations. We have two ways to use them: one for the extraction of information from a diagram to be expressed in a senten-

[12] From this mathematical perspective artifacts, in so far as they are expressed through icons, visual and other non-linguistic configurations, are "memory stores" in themselves (Leyton 2006).

[13] A recent survey about the importance of models in abductive cognition is illustrated in (Figueroa 2012).

tial form and another that allows the extraction of information from a formula to be incorporated into a diagram (Swoboda and Allwein 2002).[14]

Moreover, the symbolic level cannot disregard the reference to the *manipulative* aspects of abductive reasoning. Inputs and outputs frequently derive from the command "manipulate", which is referred to external cognitive devices and aspects that in turn can be usefully represented both from the static and dynamic perspectives, by providing a wide range of possible logical procedures. This aspect is perfectly in tune with that "leading away" (ἀπαγωγή, that is "abduction"), which for Aristotle characterizes this kind of reasoning (cf. Chap. 1, Sects. 1.2 and 1.3, this book).

It is also interesting to note that Bruza et al. (2006) insist that it would be misguided to adopt a simple traditional, symbolic perspective of an abductive logical system by assuming a propositional knowledge representation and proof-theoretic approaches for driving it, a perspective that seems conceptually incomplete because it ignores what is going "down below" (Gärdenfors 2000), which can be interpreted as the conceptual and subconceptual levels of cognition. They propose semantic spaces as a computational approximation of Gärdenfors' conceptual space. Abductive hypotheses generated from semantic spaces do not have a proof-theoretic basis, but rather they are computations of associations by various means within the space: the passage from the sub-conceptual to the conceptual level usually involves a reduction of the number of dimensions that are represented. Not only, from a cognitive perspective it seems that interesting hypotheses and dimensional reduction are inextricably related as information passes from the subconceptual to conceptual level.

More recently Bruza et al. (Bruza et al. 2012) have interestingly analyzed concept combinations in human cognition by showing emergent associations still as the result of abductive reasoning within conceptual space, below the symbolic level of cognition, but in terms of a tensor based approach which conceptualizes combinations as interacting quantum systems. They show how some concept combinations may behave like quantum-entangled (non-separable) particles. I think this approach stresses two important aspects of abductive cognition: 1) the emergent character of hypothesis generation especially in the case of creative abduction (i.e. concept combination cannot be fully understood in terms of the constituent words of the combination) and 2) pre- or sub-conceptual aspects play a role that goes beyond the merely symbolic level: only within the uppermost level information is represented symbolically. At the intermediate level properties and concepts have an eco-cognitive modal representation (geometrical) in a dimensional space, in which abducing concepts derives from combinations that are non-separable in a way similar to quantum entangled particles.

A logic of abductive inference is still *abstract* (item 2) but the *maximal independence* regarding sensory modality is not longer crucial because, if experience and common categorization are certainly stabilized, they are at the same time subjected to changes depending on the continuous multimodal flow of new information. Invariance and stability are considerably practically and temporally constrained.

[14]Clarifications of exact processes and semantic requirements of manipulative inferences and distributed cognition are given in (Shimojima 2002).

The *rigor* of proof (item 3) is still important because canonical ways of abductively inferring have to be established and provisionally fixed, to distill abductive praxes in form of multimodal language and rules, but they are multiple and canonical and not mutually exclusive, even if general. A naturalized logic of abduction is not only open to a continuous modification of input and output as symbolized in formula (3) (cf. Sect. 7.1.1, this chapter), but also to a modification of both language and rules.

Memorylessness (item 4) is not at all maximized: naturalizing a logic of abduction is related to the need of keeping record of the past life of abductive inferential praxes. Proofs would have to be enriched by labels that refer to previous logical cases and demonstrative or algorithmic habits. This should be done because, if the inferences described by traditional logic do not yield much sensitive information—so to say—about the real past life of previous logical proofs and algorithmic processes in human agents' use, on the contrary the "conceptual"—narrative—descriptions of actual human inferences not described by classical logical processes variously involve a remarkable amount of "historical", "contextual", "dialectical", and "heuristic" memories and constraints, which have to be "mimed".

Indeed many thinking behaviors in human agents—not only abductive inferences, especially in their generative part—are strongly context-dependent and eco-cognitively constrained. As already noted their *stories* vary with the multiple propositional relations the human agent finds in her environment and which she is able to take into account, and with various cognitive reasons (for example resulting from manipulations of external phenomena, experiments, or artifacts) to change her mind or to think in a different way, and with multiple motivations to deploy various tactics of argument. Abductive praxes evolve and present new creative unforeseen cases constructed on previous inferential habits, and so a naturalized logic of them has to be capable of *evolving*, not only because of its constant openness to new multiple external information, but also on the basis of its previous demonstrative histories: to conclude, memorylessness has to be *minimized*. In this regard Gabbay and Woods appropriately criticize the lack of locality of classical validity and inductive strength, which leads to a lack of cognitive goodness of inferences:

> Good reasoning is always good in relation to a goal or an agenda which may be tacit. [...] Reasoning validly is never *itself* a goal of good reasoning; otherwise one could always achieve it simply by repeating a premiss as conclusion, or by entering a new premiss that contradicts one already present. [...] It is that the reasoning actually performed by individual agents is sufficiently reliable not to kill them. It is reasoning that precludes neither security not prosperity. This is a fact of fundamental importance. It helps establish the fallibilist position that it is not unreasonable to pursue modes of reasoning that are known to be imperfect "Given the cognitive goals typically set by practical agents, validity and inductive strength are typically not appropriate (or possible) standards for their attainment" (Gabbay and Woods 2005, pp. 19-20, 25).

Indeed, human agents, as practical agents, are for example hasty inducers and bad predictors, unlike ideal (logical and computational) traditional agents. In conclusion, we can say abductive inferences in human agents have a memory, a story:

consequently, an abductive ideal logical agent has to variably modify many of the aspects of traditional logic and to overcome the relative demonstrative limitations.

Let us now give the following explanation of the cognitive interplay between ideal—classical—logical systems and actual human cognitive reasoners taking advantage of the sophisticated Peircean philosophical lexicon. In the Peircean philosophical (and "semiotic") perspective, where the so-called "logical interpretants" can lead to relatively stable cognitive or intellectual "habits" and "belief" changes,[15] the externalizations of the inferential skills typical of traditional classical logic—that is their invention and the fact that they are made available to be adopted and picked up as tools for reasoning—can be seen as resulting from the formation of a kind of ultimate "meaning", still in Peircean terms.

As objectified in—symbolic, abstract, rigorous, memoryless—cognitive logical tools, available and crystallized over there, in the environment, these inferential skills can be picked up to generate habit-changes in individuals' rational attitudes and actions "[...] the ultimate logical interpretant of the concept [...] that is not a sign but is of a general application is a *habit-change*; meaning by a habit-change a modification of a person's tendencies toward action" (Peirce 1931–1958, 5.476). Of course, even if classical ideal logical systems as logical interpretants in Peircean sense provide the widest scope or "general meaning" of a class of signs, so justifying their cognitive stability and—so to say—universality, they are never final, because they are always in relation to other logical interpretants, to which they are in turn related or under which they are subsumed, in a situation of infinite progression, that in fact impedes their ever actually having an ultimate "meaning". Hence, even in the case of logical systems, which certainly are strongly made stable and "institutional" (in Gabbay and Woods' sense) thanks to their artificial and abstract languages.[16]

To render a new naturalized logic of abduction more eco-cognitive oriented I think that an interesting contribution was given by Gabbay who created the *labelled deductive systems* (and their application to the logic of abduction), where data is structured and labelled and different insertion policies can be formulated (Gabbay 2002; Gabbay and Woods 2006). The labelled deductive systems fulfill the request of weakening the rigidity of classical logic but also of many non-standard logics strictly related to it, opening a new era in logic: the attention to the role of *meta-levels*—for instance in the logic of abduction—can formalize the flexibility and "historicity" of many kinds of human thinking which are meaningful in certain application areas they address. Intuitively, labels might easily express the eco-cognitive aspects of the environment endorsed by the EC-Model, for example: "The power of our labelling mechanism can be easily illustrated by a more refined use of the labels. If atoms are labelled, for example, by cost (laundry example) the abduction principle can aim for minimal cost. One can also 'cost' the computation itself and

[15] Often made possible thanks to conceptual creative abductions.

[16] Woods provides other examples of institutional agents, such as Nato, M15 or an university. In this perspective individual organic agents possess "fewer" cognitive assets than institutional agents (Woods 2013, Chap. 8).

aim to abduce on formulas giving maximal provability with a least number of modus ponens instances" (Gabbay and Woods 2005, p. 405).

Gabbay and Woods' conclusion about psychologism is clear and leads to a new conception of logic "If [...] it is legitimate to regard logic as furnishing formal models of certain aspects of the cognitive behavior of logical agents, then not only do psychological considerations have a defensible place, they cannot (Gabbay 2002; Gabbay and Woods 2006) reasonably be excluded" (Gabbay and Woods 2005, p. 2).

An analogous example of the new modeling flexibility of recent logic is represented by the work in the dynamic logics of reasoning of van Benthem (1996). This logic offers a distinction between inferences that are dependent on short term representations and those that depend on long-term memory, which involve the processing of representations of greater abstraction. In this way it is possible to formally and flexibly reproduce the interplay that occurs in human agents' thinking both at the level of short-term memory—more inclined to be damaged by inconsistencies—and at the level of the long-term memory, where inconsistencies can be inert.

We can conclude by also stressing the fact that "human, all too human" inferential processes such as abduction (which were called non-demonstrative and fallacious when contrasted to the ideality of classical logic) are more and more externalized and objectified at least in three ways:

1. through Turing's Universal Practical Computing Machines we can have running programs that are able to mimic "the actions of a human computer very closely"—in Turing's classical sense (Turing 1950)—but also to amazingly mimic those human agents' "actions" that correspond to complicated abductive inferential performances (cf. the whole area of artificial intelligence (AI), machine learning, computational discovery, medical diagnosis, etc.);
2. they are more and more externalized and made available in a multiplicity of explicit narratives and learnable informal and formal templates of cognitive behavior. For example, the "informal" study of fallacies as important tools of the human "kit" that provides evolutionary advantages is a very interesting case: in this perspective the fallacy of the affirming the consequent—which, as we have repeatedly said in the previous sections, depicts abduction in classical logic—can be easily seen not only and simply "better than nothing" but also a positive cognitive carrier of good reasoning—(Woods 2004)[17];
3. new *naturalized* demonstrative systems—logical agents—are created able to model in a deductive way many traditionally ungenerously called "non-demonstrative" thinking processes, like abduction, analogy, creativity, spatial and visual reasoning, etc.

Finally, after having described some differences between traditional demonstrative inferences and abductive inferences, we have to show some basic similarities. Looking at the question of the presence or absence of the fill-up and cutdown problems, of the heuristic and strategic rules, and of the ampliative character of abduc-

[17] Cf. also (Gabbay and Woods 2005, pp. 33–36) and the whole treatment concerning the so-called "errors of reasoning" contained in (Woods 2013).

tion, their differences are more fuzzy than expected: the differences can be tracked more at the level of details than at the level of the fundamental reciprocal fundamental tenets. I will treat this significant issue in the following final subsection.

7.2.3 *Multimodal Abduction Is Present in Traditional Deductive Proofs: The Role of Definitory and Strategic Rules*

In this subsection I would like to illustrate two central issues, regarding the similarity between traditional and abductive demonstrative systems, in the perspective of the eco-cognitive model of abductive cognition I have described in the previous chapters: (1) abduction is present in traditional deductive proofs, (2) iconicity hybridates logicality so that the sentential aspects of symbolic disciplines like logic coexist with model-based (iconic) features.[18]

Hintikka has repeatedly stressed that a kind of "in-formal" (that is human-based and human-directed) model-based abduction also operates in traditional deductive reasoning *when performed by humans* who are building proofs in logical systems. Hintikka's approach is both game-theoretic and erotetic. Following Hintikka and Remes's analysis (Hintikka and Remes 1974), proofs of general implication in first order logic need the use of instantiation rules by which "new" individuals are introduced, so they are "ampliative" (ampliative exactly as we usually qualify abductive reasoning). This situation was already present in the less formal ordinary geometrical proofs in which auxiliary constructions are introduced in term of "conveniently chosen" figures and diagrams. In Beth's method of *semantic tableaux* the "strategic ability" performed by humans to construct impossible configurations is striking (Hintikka 1998; Niiniluoto 1999). I have already illustrated that Aliseda's approach provides interesting uses of the semantic tableaux as constructive representations of theories, where for example, abductive expansions and revisions, derived from the belief revision framework, operate over them. In the case of tableaux, their symbolic character is certainly fundamental, but it is also particularly clear they also are configurations—model-based—of proofs externalized through suitable notations.[19] It is well-known that the formulation and the proving of theorems in an established mathematical theory, of the kind that creativity theorists typically consider, takes place by means of well established rules which are the same for all theorems (Hin-

[18] A recent book by Caterina and Gangle (2016), addresses the problems involved in formalizing abductive cognition by implementing the concept and method of iconicity, modeling this theoretical framework mathematically through category theory and topoi. Peirce's concept of iconic signs is treated in depth, and it is shown how Peirce's diagrammatic logical notation of existential graphs makes use of iconicity and how important features of this iconicity are representable within category theory.

[19] It is worth to be noted that semantic tableaux method provides further insight on the problem of theory evaluation, intrinsic in abductive reasoning. Semantic tableaux can deal with "causal" aspects of abductive reasoning that cannot easily be considered with the only help of the logic programming tradition—cf. Aliseda (2006, Chaps. 6 and 7).

tikka 1997a). There is no distinction between the rules that permit the derivation of "merely novel" theorems or "genuinely original" ones from the axioms.

Hintikka clearly finds the above perspective misleading and proposes a distinction between *definitory* and *strategic* rules. This distinction cuts across the deduction-induction-abduction trichotomy (Gabbay and Woods 2005, p. 139). The first ones are merely permissive and do not say anything as to what the player should do or about which moves are good or bad or better than others. In the case of chess, if "you only know the definitory moves" (Hintikka 1997a, p. 68), you cannot say that you know how to play chess. You need some appropriate knowledge of what counts as a good or bad move. These are called strategic rules: "Strategies in this game-theoretical sense are rules that specify what a given player should do in every possible situation that can arise in the course of a play of the game", and, Hintikka concludes "Creativity is a matter of strategic rules" (*ibid.*) that of course involve long sequences of strategic moves. I precisely referred to this kind of rules when in my research I always emphasized the importance in abduction of the so-called "heuristic strategies". Strategic rules are smart rules, even if they fail in individual cases, and show a propensity for cognitive success, a propensity which echoes what Peirce said about abduction considering it "akin to the truth": "It is a primary *hypothesis* underlying all abduction that the human mind is akin to the truth in the sense that in a finite number of guesses it will light upon the correct hypothesis" (Peirce 1931–1958, 7.220). Moreover, definitory rules are recursive but in several important cases strategic rules are not: therefore, playing a game strategically requires some kind of creativity. An initial consequence would be that the rules of inference of deductive logic are merely definitory rules, they define the rules of the game—and certainly cannot be considered rules that reflect the way people actually reason or how they should reason. At this point an important problem concerns the clarification of the role of creativity in deductive reasoning: in the following paragraphs I will try to solve this conundrum.

Following Hintikka, we can say that the "ground floor" of deductive reasoning, the first-order logic, is nothing but operating with certain models or approximations of models, as is just simply demonstrated by some fundamental techniques such as Beth's semantic tableaux. It is important to note that Hintikka is perfectly aware of the double character of these "models", *internal* and/or *external*, and of the hybrid cognitive activity they substantiate when intertwined with the symbolic aspects:

> These models can be thought of as being mental, or they can be taken to consist of sets of formulas on paper—or in this day and age perhaps rather on the screen and in the memory of a computer. In fact, in this perspective all rules of "logical inference" obviously involve "mental models". Johnson-Laird's discovery hence does not ultimately pertain to the psychology of logic. It pertains, however confusedly, to the nature of logic itself. *The most basic deductive logic is nothing but experimental model construction* (Hintikka 1997a, pp. 69–70).[20]

[20]In this perspective, the employment of logical rules in deduction calls for a strategic reasoning: this kind of reasoning is not co-extensive with heuristic reasoning in general, which seems more psychological, but this fact does not attenuate the "logical" nature of these strategies in deductive proofs. Moreover, even if heuristic reasoning seems, at a first sight, more psychological than

In this way Hintikka implicitly rejoins the distributed cognition approach to logic I have stressed in my research and in this—and in the previous chapter, where the interplay between internal and external—as kinds of "semiotic anchors", *symbolic/iconic*, in this case—aspects of logical reasoning are illustrated. For example the role in logical deduction of the strategies of "experimental" (counter) model-construction is stressed, but also the importance of the introduction of the right new individuals by means of existential instantiation to be introduced in the model.[21] The most important "strategic" question—in deductive reasoning – is to determine in *what order* the instantiations are to be treated. In elementary geometrical reasoning the role of existential instantiation is obvious and occurs through the iconic so-called "auxiliary constructions"—the diagrams—where conceptually manipulating a configuration of geometrical objects and extending it by introducing new individuals is at stake. The possible creative character is for example reflected in the fact that there is not always a mechanical (recursive) method for modeling these human deductive performances: in this case the role of what I have called"manipulative abduction"[22] is implicitly at play. Of course, as Aliseda (2006) shows in Chap. 4 "Abduction as computation" of her book on abduction, an appropriate computational counterpart inside the logical system can take advantage of algorithms which render mechanical the suitably chosen reasoning processes, and so suitable to be implemented in a computational program, but this does not cancel the strategic character of the human-based inferential choices.

7.2.3.1 Logical Reasoning as a Discursive Process: An Optical Illusion

The logical tradition of Frege and Russell rejected all reasoning that had been made in terms of geometrical icons as being responsible for introducing an appeal to intuition. On the contrary, I am very inclined to agree with Hintikka, who maintains that the traditional idea of logical reasoning as a discursive process is wrong, it is an "optical illusion", because all deduction is a form of "experimental model construction" which follows that interplay between internal and external representations I have indicated in the previous subsection[23] by quoting the distributed cognition

(Footnote 20 continued)
logical, we do not have to forget that heuristic templates of reasoning can be rendered explicit and objectified in a kind of classificatory system (see for example the well-known works by Gigerenzer and his colleagues (Gigerenzer and Selten 2002; Gigerenzer and Brighton 2009; Gigerenzer et al. 2016)).

[21] A rich analysis of the role of *individual diagrams* in deduction and in problem solving processes (that is in abductive cognition) is given by Shin (2012). The interesting interplay between *contentual axiomatics* (dealing with the locality of diagrams) and *formal axiomatics* in Hilbert's research is deeply analyzed by Smadya (2012). Indeed, Hilbert held that diagrams are to be thought of as "drawn formulas", and formulas as "written diagrams", suggesting that the former encapsulate propositional information which can be extracted and translated into formulas.

[22] Cf. above, Chap.1, Sect. 1.3, this book.

[23] Cf. also Sect. 7.1.4.

approach in cognitive science. It is important instead to note, following Hintikka, that for instance already at the level of elementary geometry:

> [...] geometrical figures are best thought of as a fragmentary notation for geometrical proofs alternative to, but not necessarily intrinsically inferior to, the "purely logical" notation of formalized first order logic. [...] They are intrinsic features of certain deductive methods. They are part of the semantics of logical reasoning, not only of its psychology or its heuristics. If it is suggested that heuristic ways of thinking are needed to make mathematical reasoning intuitive, I will borrow a line from Wittgenstein's *Tractatus* 6.233 and say that in this case the language (notation) itself provides the intuitions (Hintikka 1997a, p. 73).

Moreover, in the case of human performances, and also in many forms of deductive proofs, there are not trivial and mechanical methods of making inferences but we have to use "models" and "heuristic procedures" that refer to a whole set of strategic abductive principles. (Grialou and Okada 2005), quoting Hilbert of the late 1910s and the 1920s, who goes beyond a nominalistic/formalist view of logic in terms of rule-based syntax, also emphasize the importance of studying logical and mathematical proof not only at the level of models or mathematical object domains but focusing on the properties of formal proof "figures", considering them as concrete objects whose structure is determined by a set of formal inferences rules. From this perspective Grialou and Okada speak of a Hilbertian "finitist evidence theory", in which human perceptual/sensitive-based finitist "intuitions" of proof play a fundamental role related to model-based spatial/figural cognitive processes.[24]

The presence of strategic aspects clearly means that when we have found a proof we have applied various criteria both for finding it and—in case we have found many proofs—for selecting the best one. We prefer proofs which are minimal, elegant, proceeding by direct means, interesting, new, etc. Does not this mean that also at the level of standard proofs in deductive inference we already face with both the fill-up and the cutdown problems—exactly like in the case of abductive inferences? In sum, Hintikka is convinced that in interrogative moves, we need also choose which one of the already reached truths are suitable presupposition of a question: "[...] thus there are strategic choices about deduction quite as much as there are strategic choices about questioning" (Hintikka 1997b, p. 246). Hence, definitory rules do not exhaust the characterization of what we now call deductive reasoning.

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[24] Also the notion "of proof-nets" (a geometry of proofs), such as graphical representations of proof in Girard's linear logic (Girard 1987) can be related to this perspective resorting both to Hilbert and Gentzen.(Grialou and Okada 2005) also provide neurological evidence of the involvement of both language and visual/diagrammatic processing systems in logical reasoning. On the role of errors, due to the context, in spontaneously performed logical reasoning in humans and on their rudimentary deductive competence see the classical (Evans 2002).

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Chapter 8
Human Creative Abduction Assaulted

Impoverishing Epistemological Niches

In this chapter I will analyze some important aspects of the organization of Research and Development (R&D) in the case of biopharmaceutical companies, which represent a prototypical situation of what I call impoverished epistemological niches. At least in this case we clearly see a challenge to the epistemic integrity of modern science. Taking advantage of the logical and cognitive studies illustrated in the previous chapters, which emphasize the crucial role played in abductive cognition by the so-called "optimization of eco-cognitive openness and situadedness", this chapter first of all aims at illustrating the importance of *knowledge in motion*—in multidisciplinary, interdisciplinary, and transdisciplinary scientific research. Various subsections also introduce the hot problem of the current emergence of various kinds of "*epistemic irresponsibility*".[1] Various cases related to the commodification and commercialization of science, marketing of technoscientific products, impoverishment of the so-called epistemological niches are illustrated, which show that human fruitful abductive cognition is increasingly assaulted and jeopardized, and at the same time human creativity seriously endangered. The challenges against human abduction and epistemic rigor on the part of what I call computational invasive "subcultures" and unwelcome effects of selective ignorance are finally illustrated.

[1] In this chapter I prefer to adopt the expression epistemic irresponsibility (instead of epistemological irresponsibility), because I attribute to the adjective epistemic a restricted meaning. "Epistemic" pertains to scientific knowledge or the conditions for acquiring it, which involve eco-cognitive situations in which not only scientists but also other economical, political, and institutional agents directly or indirectly intertwined with scientific research are involved. Instead "epistemological" also expressly refers to the philosophical community of epistemologists, who in general are not affected by epistemic irresponsibility, but by other problems such as, for example, philosophical irrelevance or scholasticism.

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8.1 "Knowledge in Motion" Defended: Favoring Scientific Abduction through the Eco-Cognitive Openness

In Sect. 7.1 of the previous chapter I have illustrated the role in abductive cognition of what I have called the *optimization of situatedness*. Of course situatedness is related to eco-cognitive aspects: to favor the solution of the abductive problem input and output of the formula (3) given at p. 137 have to be thought as *optimally positioned*. Not only, this optimality is made possible by a *maximization of changeability* of both input and output; again, not only inputs have to be enriched with the possible solution but, to do that, other inputs have usually to be changed and/or modified. This changeability first of all refers to a wide psychological/epistemological openness. Is the current situation of scientific research facing with problems that jeopardize the optimization of situatedness needed by good abductive cognition? I plan to illustrate in the following sections some negative aspects that have to be stressed when dealing with the current challenges to the creative productiveness of abductive cognition in science.

It is in this perspective that we will clearly see that in many fields of current scientific and technological research we are not simply dealing with ethical problems, such as for example it is the case of research on information technology, engineering, biomedical sciences, etc., but also with "epistemological" problems. Some processes related to what I call "epistemic irresponsibility" are currently active: this fact presents a new task for philosophy of science, now more directly social relevant with respect to the whole community of citizens. Philosophy of science, traditionally related to the analysis of scientific knowledge, methods and cognitive procedures, now can also address the problem of trust in the relations between science and society (Whyte and Crease 2010) and at the same time the crucial obligation of detecting the situations in which epistemic rigor is jeopardized in a way that renders scientific rationality annihilated or at best—so to speak—"faked".

In what I have called epistemological niches,[2] that is cognitive niches which are expressly built to host and favor scientific rationality and scientific reasoning, mindful dissent is free and promoted, but also respected and taken into account, secrecy abolished, exchange of ideas encouraged and always active, reliable evidence respected, publicly recognized standards for the evaluation of research established, etc. It is in this perspective that we can clearly see science as a valued-laden enterprise, a perspective in which there is not a strict distinction between the moral and the epistemic: practicing science requires a moral commitment to follow certain adopted methods, rules, cognitive behaviors. In the absence of these aspects an epistemological niche is simply no more epistemological, that is devoted to the progress of science.

Longino contends that to make possible scientific research we need an appropriate social dimension, that is communities that approximate an ideal free communication of ideas, such as that the one illustrated by John Stuart Mill. Biddle makes a clear criticism to this perspective (Biddle 2009): Longino presupposes a conception of the

[2] See above Chaps. 3 and 4, this book.

individual that undermines her own claim that scientific knowledge is necessarily social. She would think that certain social arrangements are just helpful ways of producing scientific knowledge, but not necessary. I simply think wide individual freedom from any kind of constraint, which is granted in certain communities (for example in the epistemological niches) is extremely important. Of course this character of the community needs a special care to be maintained and preserved: for example in the case of scientific creative abduction, in which that situation of eco-cognitive openness (related to the need of optimization of eco-cognitive situatedness) I described in the previous chapters of this book is crucial. Given the fact in creative abduction irrelevance and implausibility have to be exculpated (see above Chap. 6), free production and communication of ideas, without barriers, remains fundamental to foster innovation.

This does not mean that other—contextual—values play no role in science: Popper emphasized that metaphysical or theological beliefs orient the kinds of theoretical frameworks available to scientists, and moral, economical, and political values orient the choice of one theoretical framework over another. The essential point, however, is that given that contextual values do play an inevitable role in scientific reasoning, the ideal of value neutrality should be rejected. Actually we can say that certainly science is oriented by values but these values do not contaminate its epistemic purity and its *neutrality*: just to make an example, we have a lot of scientific research about biological cell and less research about animal cognition, and this is definitely due to some external constraints that oriented research in a certain direction, but in both cases epistemic purity is intact. Researchers in both fields need an optimization of eco-cognitive openness, which can be reached thanks to both the individual attitude and the social conditions of maximal elimination of obstacles to free communication of ideas and criticism.[3]

Biddle continues his critique to Longino saying that the emphasis on what he calls the "unencumbered selves" produces a false idea of individuals who have complete freedom to choose their own aims, values, and conceptions, and this would not reflect the attitude of real scientists (Biddle 2009). I think that he is wrong, at least in the perspective of the creative aspects of science. Creative abductive scientists are individuals who have to actually be open to everything and who live in a situation of "openness to all perspectives: no claim or belief can be held immune to criticism" (Longino 2002, p. 159). This does not mean they are not socially located and that this freedom has to be seen active in other aspects of scientific research, unrelated to creative abduction: in these last cases individuals need not be—so to speak—completely open-minded, because they belong to precise epistemological niches which provide established rules and heuristics, and also methodologies and evaluative criteria, making them capable of questioning and evaluating certain beliefs (and not all of their beliefs).

In sum, eco-cognitive openness regards the creative aspects of scientific enterprise. In this perspective we do not have to see any tension between Longino's employment of Mills political philosophy and her account of the social character of scientific

[3]Cf. also below Sect. 8.2.1.

enterprise. Individual scientists can be considered open to everything at the cognitive level of abductive creativity, but at the same time they live in social epistemological niches characterized by established paradigms, research programs, exemplars, etc., which provide firm rules and criteria of various kinds able to govern a great part of scientific cognitive processes, as already richly illustrated, during the postpositivistic renaissance of philosophy of science, by Kuhn, Lakatos, Feyerabend (Kuhn 1962; Lakatos 1970; Feyerabend 1975) and by their many followers. In conclusion, individual scientists are certainly to be considered as "advocates for particular approaches, paradigms, or research programs" as Biddle says (Biddle 2009, p. 622)—Lakatos famously wrote of "the rationality of a certain amount of dogmatism" (Lakatos 1970, p. 175)—but *also* individuals who are open to everything when they face with the problem of abducing new ideas.

Hence, sustaining a situation of optimization of eco-cognitive openness is not only related to the individual attitude of the good "creative" scientist but also to the specific character of the social, political, and economical environment in which a certain scientific research is embedded, that must constitute a good background, appropriate to the end.[4]

Hence, let us come back to the problem of the suitable conditions of eco-cognitive openness necessary to creative adduction. Even if many contemporary scientific research problems transcend disciplinary boundaries imposed by institutions of higher education, narrow-minded specialization certainly represents a limitation to the flourishing of abductive cognition: this aspect represents a first challenge to the exercise of a good abductive cognition. A contrary example if furnished by recent HIV/AIDS studies, I will illustrate below. This contemporary prosper creative scientific research has been strongly characterized by cross-fertilization of ideas in a kind of situation of "knowledge in motion".

Let us take a look of some recent aspects of scientific research related to health problems, which demonstrate the importance for abduction of the optimization of eco-cognitive openness. Recent studies in HIV/AIDS do not completely fit into the research fields typically found in the excess of blind disciplinarity. Researchers and funding agencies have instead devoted increasing attention to projects that span multiple disciplines. Taking advantage of scientometric computational techniques (the so-called "topic models" of over 9000 abstracts from two prominent journals on HIV/AIDS, from their inception through the end of 2010) Light and Adams, in an article eloquently entitled "Knowledge in motion: the evolution of HIV/AIDS research" (Adams and Light 2014; Light and Adams 2016), describe how research programs in this area moved through various states of integration including disciplinarity, multidisciplinarity, interdisciplinarity and transdisciplinarity. In my perspec-

[4]Social epistemologists always emphasized the role in scientific rationality and objectivity of the institutions and processes of knowledge acquisition and production (Longino 1990; Kitcher 1993). Recently Reiss—manly referring to biomedical research—noted the importance of not restricting normative judgments about how to organize research to ethical aspects alone (for example discriminating against diseases of ethnic minorities and the poor in the Western world, or the diseases of the global poor) but also to the epistemic components of research when for example epistemic decency is disrespected (Reiss 2010).

tive these aspects are all related to the actual promotion of an optimization of that eco-cognitive openness which characterizes creative abductions in science.

Multidisciplinary research engages any single research area from the vantage point of multiple disciplines, this approach poses little challenge to the specialization which characterizes the more disciplinary-based approaches. Light and Adams (2016, pp. 1229–1230) report that, following the suggestions given by the U.S. National Academy of Sciences "[…] interdisciplinary research is a more integrative form: interdisciplinary research consists of research conducted by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice". Finally, "transdisciplinarity is characterized by relatively complete elimination of the salience of disciplinary boundaries in the scientific enterprise. Within the literature conceptually clarifying the typology of many-disciplined science, transdisciplinarity's boundaryless science arises via two quite different processes. The first form comes from a reorganization of scientific efforts—starting with the identification of questions, and extending straight through the strategies employed in answering them—around problem-based areas. That is, research is no longer bound up within disciplinary confines".

Fortunately research on HIV/AIDS of the last decades has been characterized by a balance between specialization and cross-pollination of ideas. The integration across disciplinary boundaries is fundamentally dynamic:

> HIV/AIDS research appears to have grown more multidisciplinary also consistent with increased specialization, after an initial period of more interdisciplinary integration. In other words, after an initial period of high cross-fertilization and joint problem-solving, the researchers returned to their silos working on overlapping topics in a more disciplinary fashion. As evidenced by the case of HIV/AIDS research, integrated programs are dynamic and situate themselves into different states of organization (Light and Adams 2016, p. 1245).

8.1.1 Marketing Technoscientific Results

The example of HIV/AIDS studies I have just illustrated exemplifies a case of what we can call *epistemic responsibility*: scientists and the various agents involved in decision making concerning their eco-cognitive environments all concur in building policies, attitudes, intellectual habits, social and economical institutions, appropriate artifacts, able to promote responsible epistemic actions: what happens when "knowledge in motion" is not favored? To have an idea of the current situation of the whole scientific research in U.S. it is sufficient to quote the following passage:

> We are currently witnessing profound changes in the way in which scientific research in the United States is organized. In 1964, 30.8% of U.S. R&D was funded by industry, while 66.8% was funded by the federal government. The years between 1964 and the present have witnessed an almost exact reversal; in 2004, 63.8% of national R&D was funded by industry, while only 29.9% was funded by the federal government. […] Growing numbers of

> both university and government scientists are developing financial relationships with private corporations, and many university scientists are starting their own companies, simultaneously playing the roles of academic researcher and entrepreneur. The result of these changes is that commercial considerations are exerting increasing influence within the practice of science, in both universities and governmental laboratories (Biddle 2011, pp. 245–246).

(Lazonick 2007, p. 11) draws a similar picture but looking at the data about internal R&D (i.e. R&D made in house by pharma companies). He makes the example of Pfizer reporting that

> In response to complaints that U.S. drug prices are at least twice those in any other country, Pfizer and other U.S. pharmaceutical companies have argued that the profits from these high prices—enabled by a generous intellectual- property regime and lax price regulation—permit more R&D to be done in the United States than elsewhere. Yet from 2003 through 2012, Pfizer funneled an amount equal to 71% of its profits into buybacks, and an amount equal to 75% of its profits into dividends. In other words, it spent more on buybacks and dividends than it earned and tapped its capital reserves to help fund them. The reality is, Americans pay high drug prices so that major pharmaceutical companies can boost their stock prices and pad executive pay.

In few words, scientists are now forced into areas that have the potential to be profitable, first of all they are much less free than in the past to decide for themselves which questions to study. The introduction of market values—particularly encouraged by the neoliberal politics—for example into the U.S. practice of science aims at resulting in continued scientific progress (and so discovery) but also in a huge economic and social growth. It is well-known that this policy also favors deregulation, by removing the government-imposed barriers, the flow of information between private and public sectors, the sharing of expertise and the transfer of scientific research into marketable products.

Unfortunately, allowing market forces to guide some fundamental areas of research, such as the biopharmaceutical one, has generated a degradation of the epistemic quality: "a sacrifice of epistemic standards at the altar of profit" (Biddle 2011, pp. 246). Knowledge is no more "in motion". The U.S. Congressional Patent and Trademark Amendments Act of 1980—known as the Bayh-Dole Act—allowed universities and private corporations to patent the results of publicly-funded research, while the Stevenson-Wydler Technology Innovation Act of 1980 (later on revised in 1986) allowed for the patenting of results obtained in government laboratories (Biddle 2011). Prior to these acts, results deriving from privately-funded research could be privately appropriated, whereas inventions resulting from publicly-funded research obviously remained in the public domain. We are facing with a clear "[…] proprietary treatment of research results, with the commercial interest in secrecy overriding the public's interest in free, shared knowledge" (Brown 2000, p. 1701). In sum, the new "obsession" regarding commercialization generally, and patenting in particular, has obviously been generated not by the scientific community, but rather by political and economic decisions (Biddle 2012).[5]

[5] I think that things are even worse as the neoliberals nowadays push (public) universities to actively pursue the so-called "technology transfer"—which means that universities need produce knowledge

This change has profoundly affected the eco-cognitive environment of important parts of science: in the following sections I will illustrate many aspects of the current eco-cognitive situations which put in danger the productivity of scientific discovery and consequently jeopardized and are jeopardizing the richness of human abductive cognition in science. I will take advantage of the prototypical case of biomedical and pharmaceutical research, in which the dangers of an objective situation of epistemic irresponsibility are already more than remarkable. I consider this example prototypical because it represents a clear kind of epistemic irresponsibility, which might very likely spread all over many other areas of science and of technological research and which surely is already seriously threatening the survival of areas not directly marketable, such as ample parts of humanities, mathematics, and science, instead fundamental to preserve and "feed" western civilization.

A first example regards the role of positive and negative freedom of research in our era. Knowledge in motion, which is necessary to promote that "optimization of eco-cognitive situatedness" needed by fostering good human abductive creative reasoning, is only promoted by the existence of the so-called positive freedom, as freedom to act in particular ways or to achieve particular results. Unfortunately, neoliberals sustain a short-sighted view of the nature of freedom, as freedom from external obstacles, which is not sufficient to guarantee substantial freedom in scientific research. Commercialized scientists have less obstacles—neoliberals weakened the state institutions which now no longer can satisfactorily rule behaviors and circumstantiate distinctions between public and private interests—but are oppressed by pre-established agendas. Not only, paradoxically, and contrarily to all expectations—a new big obstacle appeared: once "commercialized" and dependent upon the private sectors, the scientists are no more free to communicate research results freely, so that negative freedom, otherwise defended, is instead violated. For example, this outcome affects both sponsored biopharmaceutical industry and agricultural biotechnology, where for-profit corporations have a tendency to only consider research that is beneficial to them financially and to avoid research that is not (Elliott 2012).[6] A second example relates to the fact that "for-profit corporations have a history of biasing studies to increase the likelihood of obtaining desired results" (Biddle 2014, p. 17). Big pharma tend to withheld information that might call the safety or efficacy of their drugs into question.

The industry influence over scientific research is also related to the problem of inductive risk I have illustrated above (cf. Sect. 1.5, Chap. 1 of this book). Financial considerations directly influence the choice of research problems, the choice of methods, and the interpretation of data, and the ways in which research is disseminated

(Footnote 5 continued)
which is quickly transferable to firms so that they can exploit it commercially. So researchers are also affected by the fact they are also constantly put at pressure by this "technology transfer" obsession—which often sounds absurd in those countries which invest ridiculous amounts of money in research.

[6]This author also illustrates, on the contrary, how strategies of information dissemination are often implemented for example just to dissipate public suspicions (for example in the case of the genetic modification (GM) of crops.)

and rendered public, and indirectly influence research by generating an atmosphere in which researchers fear to study particular topics. The overall effect resorts to a kind of inhibition of various kinds of research and at the same time of its potential creativity). (Biddle and Leuschner 2015, p. 274) observe: "A recent study (Shulman 1999) found that more than one-third of recently published articles produced by University of Massachusetts scientists had one or more authors who stood to make money from the results they were reporting. That is, they were patent holders, or had some relationship, for example, as board members, to a company that would exploit the results. The financial interests of these authors were not mentioned in the publications (Brown 2000, p. 1701). It is also interesting to quote the so-called "publication bias", due to the fact that some research results are not published, usually the scientific publications which indicate "problems" with respect to some important patented—or to be patented—products.[7]

To the eyes of a researcher in logic, epistemology, and cognitive science like me it seems perverse to see realized the commercialization of many scientific processes and results, for example the fact that few owners can control the "product" of a scientific discovery/invention. Its seems perverse because we all know that science is a communal enterprise, which grew generation after generation so that all the new results are in themselves also indebted to the past achievements. Some new technologies would have been impossible without previous so-called "theoretical" discoveries—which of course it was impossible to market—that now seem to mean nothing in the perspective of the current commercialization process. Geniuses and personalities are obviously important but their contribution has always been strongly tied to the human social settings in which they worked and to the rich cultural heritage arrived from the past, that is to something related to the cultural "commons". In this perspective, just to make a simple example, how to justify exclusive property rights, when not a painting or a romance but a GMO is at stake, appears to be extremely problematic.

8.2 Jeopardizing Human Abduction through Impoverished Epistemological Niches

8.2.1 Epistemic Irresponsibility I: Expensive Drugs Now and the Undisciplined Commodification of Abduction in Science

The problem I will address in this section concerns other threats to the flourishing of human creative abductive processes when performed in high technological

[7] We have to say that it is not unusual that in economics and management studies, research papers that find non statistically significant relationships between variables (i.e. they find neither positive nor negative statistical relationships) are not even published in journals. This is amazing because studies that found non-statistically significant results actually could potentially be highly interesting, especially for the fact that they might reverse assumptions (van Hilten 2015).

business-oriented environments, in which what has been called a "commercialization of science" (Brown 2000; Biddle 2007) is active, consequent to an increasing dependence of universities on industry and philanthropy. It is not only important the simple social and political fact that in the background there are forces that are transforming the universities into servants of industry, rather we also need address the "epistemological" consequences of this processes on creativity and its survival in scientific practice.

In general the effects of private sectors in orienting scientific (and not scientific)[8] research are very well-known. When orienting values are "private" or "philanthropic" values, less neutral that the public ones, the situation is clear. Brown illustrates this aspect, not related to our problem of the threat to human abductive reasoning, but worthy to be reported, taking advantage of an amazing consideration, which also indicates that promoting a certain kind of knowledge is at the same time an act of "selecting ignorance" (Tuana 2006; Proctor and Schiebinger 2008; Elliott 2012)[9]:

> […] financial institutions donated a very large sum to a Canadian university economics department to study "the effects of high taxation on productivity". The results may influence government policy. In such cases, the public and its political decision-makers get information only of a certain kind, because there is no private, well-funded foundation called The Consortium of Single Mothers on Welfare that bestows similar massive funding to discover the effects of poverty on the development of children. Public policy decisions should be based on a variety of sources of information, but the privatization of research means that one point of view—guess who's?—will tend to prevail. Publicly funded science, though far from perfectly serving all interests, has at least a chance of serving more (Brown 2000, p. 1701).[10]

Further, Brown nicely describes the bad effects of a philanthropic group which, for example, provides funds to a university for studying science and religion, inclining the research to show that science and religion are in perfect harmony (and giving

[8] In this case one of the more patent effect has been the decimation of humanities, because neoliberals continue to ignore that the utility of a liberal arts education resorts to the development of general analytic and writing abilities which are fundamental in industry, government, and administration. It has to be said that also various "scientific" departments, not inclined to do patentable and marketable work, disappeared.

[9] I have already introduced the notion of selective ignorance in Chap. 2 of this book, Sect. 2.5

[10] An extreme paradoxical case of selective ignorance case is illustrated by (Elliott 2012, p. 335): "Another crucial way in which the choice of questions can contribute to selective ignorance is by steering society's responses to a problem toward scientific or technical fixes rather than social or political solutions. Thus, before scientists even begin to formulate their own specific questions about a research topic, a significant and value-laden decision may already have been made tacitly by citizens or policy makers—namely, the decision to treat the problem primarily as a set of questions for scientists and engineers to address. For example, the IAASTD [International Assessment of Agricultural Knowledge, Science and Technology for Development] emphasizes that there are a number of non-technical solutions to agricultural problems: increasing poor farmers' security of access to land, promoting more transparent and high functioning markets, and providing better social safety nets." On the problem of ignorance with respect to the women's health movement and feminists' commitment to uncovering the ways women's bodies have been ignored, also by science, such as for example in the case of drug companies that decided research in the area of hormonal contraception for men would not be profitable, cf. (Tuana 2006).

the students this impression), also creating the premises for a potential slippery slop "If religious foundations can fund science and religion courses, then why can racist foundations not fund race and IQ courses?" (Brown 2000, p. 1701). Another example regards biopharmaceutical research: in approaching a health problem the way that leads to market a new drug will be favored, another, for example involving diet, exercise, or environmental control disregarded. Vaccine research itself has declined also because these drugs are not profitable as the ones for clear chronic conditions. The cognitive atmosphere that in these cases is created is very epistemologically poor: the paucity of rival theories and approaches always deprives science of the fundamental aspect of comparative evaluation, so strongly emphasized by Popper and Lakatos.

It seems that in various areas of research the integrity of scientific knowledge is challenged by heavily funded interest groups who aim at influencing research to serve their needs: "These influences can take a wide variety of forms: funding specific areas of research, designing studies so as to obtain particular results, suppressing undesirable findings and harassing scientists that disseminate them, paying scientists to produce opinionated letters or commentaries or review essays, and developing strategic public-relations campaigns via the mass media. […]. These interest-group strategies can affect scientific language as well as other areas of science" (Elliott 2010, p. 16).

However, we have to illustrate a more focused concern: I contend that the commercialization of science is detrimental to both scientific—especially with respect to the *creative* parts of scientific cognition—and social progress. For example the situation created in the case of biomedical research by the so-called "Tragedy of Anticommons" is strikingly anti-innovative. Biddle contends it is particularly interesting this tragedy, proposed by (Heller and Eisenberg 1998), for biomedical research: "According to this thesis, the proliferation of intellectual property rights upstream (i.e., over the results of basic research included engineered living organisms that are not 'natural', so to speak) creates a series of obstacles to downstream (i.e., applied) research and product development; the result is that upstream patenting not only fails to incentivize the development of innovative products, it also discourages it" (Biddle 2012, p. 821). For example, patents in areas such as DNA diagnostics seem to jeopardize the development of certain kinds of knowledge and certain technological capabilities that have the potential to save lives. It is possible that, for many scientists—even unconsciously—projects that have little commercial potential or little prospect of obtaining a patent are never seriously considered. Empirical studies are reported that confirm the anticommons thesis, which I think represents a further humiliation of that need of also respecting the "irrelevance" and the "implausibility" of guessed scientific hypotheses,[11] which is only occurring thanks to a minimization of cognitive restrictions or obstructions.

A typical case of science privatized and commercialized is obviously represented by pharmaceutical industries. There is a widespread agreement among researchers

[11] I have illustrated above in Chap. 6 of this book the role of irrelevance and implausibility as crucial to productive abductive discovery.

that it is plausible to predict a further progressive decline of the pharmaceutical industries commitment to invest in Research and Development (R&D): new discoveries—and so new creative abductions—will dramatically decrease and, consequently, we will have less new drugs than expected. Currently, novel pharmaceutical discovery and development is already a very expensive, difficult, and inefficient process, especially due to the lack of models that accurately present the appropriate condition or that reflect the appropriate response. This means that ascertaining potential efficacy and off-target toxicity of drugs is a large part of the development process, often accomplished through the use of nonhuman animal models (Anson et al. 2009).

Fewer targets and more whole-animal experimentation were replaced during the 1990s by more targets and in vitro screens. However, one key component of animal model-based reasoning is the admission that we do not know a lot of what we should know (or think we know): currently, several animal disease models are not predictive of clinical outcome (oncology, immunology, central nervous system (CNS) and other neurological and psychiatric conditions or pain—which are especially in need of new medications), whereas other models tend to be more reliable. We have to remember that protest against animal experimentation has had a heavy effect upon the pharmaceutical industry: unfortunately, the availability of well-characterized, reproducible and moderate throughput animal models still furnishes a great reward during drug invention. The societal and regulatory consequences on animal experimentation have resulted in relocation to other countries, often involving obvious ethical outcomes. However, it is worth quoting the following interesting considerations provided by Bennani, concerning animal models predictivity: "Pharmaceutical research aimed at cancer treatment, neurological or psychiatric diseases, in particular, are areas in utmost need of new therapeutics, yet the most underserved from the discovery-to-clinical-success standpoint. As mentioned above, animal models in these disease areas are not predictive, yet regulatory agencies require preclinical investigational new drug (IND) packages to contain in vivo animal efficacy and data based on non-predictive or nonrelevant disease models. It is sad to see that many companies are giving up on these diseases rather than tackling the fundamental biological, pharmacological and developmental causes of the failures. Perhaps the industry needs to tackle this very problem to demonstrably affect change in the success rate of oncolytics, neurological agents or neuroleptics, to name but a few" (Bennani 2011, p. 784).[12]

The recent phenomenon of expensive drugs is already a clear consequence of the fact that pharmaceutical discovery and development is highly commercialized and at the same time a very expensive, difficult, and inefficient process. Indeed very expensive and very effective hepatitis C and cancer medications recently appeared in the market: private health insurers in U.S. and EU and welfare assistance in some EU countries limited prescriptions to few considered very sickest people. It seems we are facing with a kind of financial hazard—a kind of unintended, potential economic harm or paradoxical damage of therapy—which is consequently a critical issue that

[12]On some epistemological problems related to the role of animal models in bio-pharmaceutical research cf. for example (Shelley 2006)

has to be seriously considered as some new treatments disregard the aspect of affordability to patients and their health systems.[13] Of course it can be said that insurers, by paying for the drug now, they can avoid later on paying for costly complications, for example liver transplants in the case of hepatitis C, also freeing up liver transplants for other people who need them. Is this true? Some economical modeling seems to confirm this prediction, but U.S. private insurance companies are skeptical in taking this long view, which involves a huge amount of short-term costs. Indeed they say that people regularly switch health plans, so insurers might not reap the long-term economic benefits of covering their members' hepatitis C treatments. Of course this fact discourages insurance companies from investing in hepatitis C treatments for more of their members: "The misalignment between short-term treatment costs and long-term benefits that private payers face, however, may not promote socially optimal treatment strategies" (Moreno et al. 2016, SP242).[14]

The rising costs of some drugs contract household budgets as well as federal and state budgets, Medicare, Medicaid and other EU public health care programs that use taxpayer money to pay for drugs. The debate ranges from a discussion on how these expensive drugs affect the economy overall, for example by reducing the number of expensive hospital visits and allowing more people to get back to work faster. Anyway, in so far as we will not be able to solve the problem of actually having the people properly medicated using those expensive drugs, it will be difficult they will become cheaper. Not only, with aging population, the health care costs and demands on price-control of medicines are expected to increase. We can also clearly note that the pharmaceutical industry's profitability and growth prospects are under pressure as health care budgets become increasingly strained because of the worldwide neoliberal policies which devastated the financial equilibria of modern western states.

The situation I have just described carries a clear consequence, which is exquisitely epistemological: we have to figure out how to address these problems, or run the risk that pharmaceutical companies will stop investing in the research and development of cures. Recently, in 2015, two researchers in the area of pharma consulting clearly addressed this aspect:

> […] that cancer drug prices have been rising at rates well above the rate of inflation. This is of concern to all the major stakeholders because it could impact the quality of cancer care and bring undue financial hardship to the patient. In addition, it may compromise innovation and new drug discovery because it could force governments to implement arbitrary price controls. Government-mandated price drops have already occurred in some European countries. In addition, developing countries could also issue a compulsory licence, which would enable local production of the patented drug. This is possible under the "Trade Related Intellectual Property Rights" agreement of the World Trade Organization and has already occurred with

[13]The recent western financial crisis has increased the exposure of patients and health systems to the financial hazard, because of cuts in health budgets along with soaring unemployment and underemployment (Carrera and Olver 2015).

[14]The case of expensive new drugs recently convinced few U.S. Politicians to hold some investigations into pharmaceutical companies such as Turing, whose former CEO Martin Shkreli said he would have raised the price of an anti-malarian drug by 5,000%. Shkreli resigned after he was charged with securities fraud. Democrats have invited as a witness Valeant Pharmaceuticals executive Michael Pearson, formerly criticized for having increased the prices of two heart medications.

> some HIV drugs. The Indian government did this for imatinib (Gleevec®), and it was recently upheld by the Indian Supreme Comt. Such events do not support innovation and the discovery of new drugs to fight cancer (Dranitsaris and Papadopoulos 2015, p. 299).

In summary, it is patent that both cognitive and technological creative processes in biopharmaceutical science,[15] which in the case of pharmaceutical companies are highly commodified, are (and will further be) seriously compromised. In these cases the commodification of science resorts to a form of objective "epistemic irresponsibility", which of course also has a quick practical outcome: the worsening of the general conditions of public health.

8.2.2 *Epistemic Irresponsibility II: How to Avoid the Eco-Cognitive Shutdown of Creative Abduction*

The reader would have noticed that the expression *epistemic irresponsibility* carries a moral halo which seems unexpected when associated to the word epistemology: let us further explain in detail my perspective on the interplay between epistemology and ethics and its relationship with my eco-cognitive approach. Stating that epistemology[16] and ethics are *entangled* does not only mean that reasoning and morality can be studied together, but rather that *it benefits* to study them together. The word *entanglement* is clearly borrowed from the language of quantum physics: even if the two philosophical disciplines have each their own theoretical dignity, many of the objects they deal with are just deeply entangled, so that ignoring one aspect or the other may cause a philosophical misperception of the matter at stake. For instance, by failing to appreciate the inferential dimension in a moral judgement and its enactment, or conversely, how moral priorities strongly inform and override our best hypothetical reasonings.[17]

The entanglement of epistemology and ethics has also tacitly emerged over the past recent years, transcending the philosophical impasses of the *is/ought* debate. Such appreciation seems to be more strongly nested in applied epistemology: Coady explicitly connects the origins of applied epistemology to the tradition of applied

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[15] Already in 2010 (Paul et al. 2010) said "A key aspect of this problem is the decreasing number of truly innovative new medicines approved by the U.S. Food and Drug Administration (FDA) and other major regulatory bodies around the world over the past 5 years (in which 50% fewer new molecular entities (NMEs) were approved compared with the previous 5 years)".

[16] In this paragraph I exceptionally refer the word epistemology to the whole area of cognitive reasoned activities, such as it happens in a considerable part of current academic literature. Anyway, the reader would have realized—I also made a remark in the preface—that in the present book I adopted its classical intended meaning, which is only referred to scientific cognition.

[17] Some topics that powerfully display such entanglement are gossip studies (Bertolotti and Magnani 2014), but also any epistemological approach on religion that cannot overlook how the violence entailed by religious cognition is rooted both in the moral assumptions and in the inferential regime that are typical of religion (Bertolotti 2015), and overall the philosophical approach to the relationships between morality and violence (Magnani 2011).

ethics (Coady 2012, p. 1 and ff.), highlighting a theoretical practice of mutual borrowing that has characterized the different branches of philosophy since the very beginning. Clearing up the relationship, and the entanglement, between epistemology and ethics will help to shed light on another entangled relationship, that is the one between morality and violence. Indeed, the understanding of each theoretical entanglement (epistemology-ethics, morality-violence) rests on the understanding of the other, as the four poles are connected in a double dyadic system that I also explored in previous works (Magnani 2011, 2015).

In this section I will deal with a second kind of epistemic irresponsibility that I think could be avoided taking advantage of some eco-cognitive suggestions that patently incorporate both methodological recommendations and also the commitment to a certain kind of what I call "moral epistemology",[18] such as in the case of the so-called "Innovation ASAP", I will soon illustrate.

The crisis of pharmaceutical research in big pharma,[19] I have described in the previous section—had been caused by reduced output of new medicines from research laboratories, drug pricing pressures, stricter regulatory environments and the current economic downturn—together with the recent job losses and a considerable decrease of investments in Research and Development (R&D). This situation surely depicts the final result of previous eco-cognitive actions we see as informed by a remarkable epistemic irresponsibility, which surely harmed the productive performance of human abductive cognition in these areas of science and technology. Impoverished epistemological niches generated the reduction of scientific products and the breakdown of conceptual innovation.

Bennani (2011) first of all observes that previous investments in high throughput screening (HTS), combinatorial chemistry, genomics and proteomics over the past two decades (the very technologies that were supposed to keep the industry from the abyss) have yielded a low return on investment, and consequently he suggests a complementary perspective on the corporate culture aspect of innovation. The epistemological aspects that are proposed are interesting and certainly highlight updated eco-cognitive good features needed to foster good creative abductions in science. The concept of "innovation ASAP" is introduced (an acronym for asking powerful questions, seeking the outliers, accepting defeat and populating astutely). In the background there is more than a suspect that the recent so-called (mega) blockbuster business model has had a profound effect on the pharmaceutical industry, positive in terms of earnings but negative in terms of "epistemology":

> Nobody could argue, in this capitalistic world, against marketing a drug to achieve great revenues. Revenue enables further investment, with the goal of repeating an even greater achievement. Most major pharmaceutical companies have adopted this paradigm and invested heavily in R&D over the past two decades, more so than any other industry as a percentage of sales. This approach has forced R&D-intensive companies to focus mainly on opportunities with $> U.S.\$ 1$ billion annual market potential, which, in return, has created

[18] I have quickly illustrated the concept of "moral epistemology" in the footnote 32 of Chap. 1 of this book.

[19] A nice complementary summary of opportunities and pitfalls for big pharma Research and Development (R&D) is given in Table 8.1

Table 8.1 Opportunities and pitfalls for big pharma R&D (Lundberg and Reilly 2009, p. 441). ©2009 Elsevier, reprinted by permission

Big Pharma R&D

Opportunities	Pitfalls
Strong drug-hunting expertise. Accessing best scientists internally and externally	Bureaucracy; process oriented static culture; poor corporate reputation
Genuine willingness to consult and learn from collective memory	
Broad technology platforms	Lack of focus with frequent strategic shifts
Value chain integration (Discovery, Development, Production, Market)	Unwillingness to change; 'silo mentality'
Global asset and knowledge exploitation, learning from failures	'Not-invented-here' syndrome
Small unit feel (empowerment) within large global organization (power)	R&D funding mainly late stage and short term
External transparent mindset	
Intelligent risk taking, broad portfolio	'Me too' approach
Long-term innovation with constant improvements. Clear, sustained goals	Constant reorganizations and mergers-demotivation

> blind spots toward many diseases and perceived medical needs that did not meet these return levels. In addition, it tended to attract several players into similar markets, which led to many years of heavy investments to demonstrate clinical non-inferiority or marginal superiority to gain Food and Drug Administration (FDA) approval. The current trend to catch the current biologics or bio-similar(s) wave, could well backfire in a similar way to small-molecule follow-on approaches, over the next few decades. Furthermore, commercial functions have been in the driver's seat in clinical trial design, which has led to a business- rather than science-led clinical trial approach, often leading to failure. Although large revenues were sometimes achieved through this model, it seems to have led the industry to the edge of a cliff, given how difficult it has been to reproduce it routinely (Bennani 2011, p. 780).

It is in this perspective of capitalistic competition, compelled to the innovation in drug discovery, that also a big pharma (Vertex) researcher and manager like Youssef L. Bennani has to recur to a program that is basically "epistemological", rather than *directly* "ethical", even seen as a "survival necessity": "innovation ASAP" (see above the various items that compose the acronym) is the motto, and the program seems to delineate a possible new fruitful policy able to foster creativity and technological innovation. Indeed the whole idea of a culture of innovation in the drug discovery settings remains unclear, given the multitude of pressure points: investment, competition, science knowledge, time, management, the diversity of sources of innovation and the still-unpredictable nature of medicinal chemistry, drug discovery and clinical outcomes: an approach which exemplifies some of the eco-cognitive features characterizing good creative abductions seems appropriate to solve the problem. Here the main aspects of the program that, as I observed above, incorporate at the same time both methodological recommendations and the commitment to a certain kind of "moral epistemology":

1. *asking powerful questions*. It echoes the specific character of creative abduction, which has to be performed in a knowledge-rich epistemological niche. The corporate epistemological environments have to avoid to be dominated by a culture of copycats, in which all work on the same targets, all do combinatorial chemistry, all use outsourcing and the same consulting firms. All these negative aspects depict a strong limitation to that eco-cognitive openness that characterizes creative abduction in science;
2. *seeking the outliers*. "Outliers, as defined here, are a composite of key individuals, teams, observations, research approaches, work environment, corporate tolerance for, and reinforcement of, different perspectives, adequate reward systems and the ability to seize those 'aha' moments: innovation is all about culture. Outliers are not necessarily individual contributors; they are observations, unique data relationships that do not fit the hypothesis or dogma, or that cause a rethink of assumptions" (Bennani 2011, p. 785).[20] Rules- or guidelines-based drug discovery is widespread in the pharmaceutical industries and represents a manager's dream: unfortunately the establishment of too many rules, both epistemological and pragmatic, constitutes barriers to innovation and to the finding of new answers. In Chap. 6 we have seen that creative abductions are looking for guessed hypotheses where implausibility and irrelevance do not have to be discriminated: having rules at all levels of a human enterprise of science (cognitive activities included) is important and wise, but blindly following rules can also lead to "blindness" and to repress creativity and exceptional innovations;
3. *accepting defeat*. Looking for falsification is part and parcel of an epistemologically good scientific behavior. In the process of abductively guessing a new idea, one will need to accept failure. We know that in every process of abductive innovation the ability to deal with failure and to pass to new hypotheses is fundamental. The perseverance in the face of negative research outcome is extremely negative but often affects R&D in pharmaceutical firms;
4. *populating astutely*. It suggests that, Bennani says, on the human resources side, a fundamental component of employing or forming a new team is related to a reasonable balance between people who disagree with the current standard of knowledge and those that execute orders. Organizations should promote people and teams able to enrich the various innovation incubators with complementary cognitive attitudes to foster creativity, rather than rewarding "me-too"[21] or "fast-follower" products.[22] Benchmarking itself can be creativity-threatening because it tends to only favor incrementally inventive products.

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[20] Jaakko Hintikka would have called these outliers "oracles", fundamental to perform good abductions (cf. Sect. 1.3 of Chap. 1, this book).

[21] Copies of existing drugs, not exact copies because they need to be slightly different to be patentable.

[22] Brown reports the following amazing case related to the pathetic—and totally business oriented—strategy of "inventing of a new disease": the drug maker Eli Lilly promoted a new medical disease concept, "premenstrual dysphoric disorder" (PMDD), allegedly in order to create new markets and patent protection for its drug Prozac (Brown 2008, pp. 201–203).

8.2.3 *Epistemic Irresponsibility III: Neoliberalism Assaults to Epistemic Integrity of Biopharmaceutical Research*

Interesting theoretical "philosophical" and sophisticated discussions about the ethics of pharmaceutical pricing could be further speculated, for example taking advantage of a Rawlsian view of distributive justice (Rawls 1971; Spinello 1992), contending that necessary drugs should be priced so that ability and willingness to pay will be within the reach of everyone, and a plenty of other argumentations could be advanced and further refined. The price of the AZT therapy puts it beyond the reach of a lot of people suffering from AIDS. Communicable diseases such as HIV/AIDS, malaria and tuberculosis affect people that live mostly in third-world countries, receive only a small part of the investment per share in the global disease burden as compared to first-world diseases such as cardiovascular disease and diabetes. (Gewertz and Amado 2004) obviously contend (and admonish) that "While the moral significance Rawls places on the basic liberty of life and the right to health is appealing and consistent with natural humanitarian concerns, the practical limitations associated with implementing these ideals are overwhelming. Ignoring economic factors and incentives in favor of providing treatment to every individual in need of medication, as Rawls's theory dictates, may undermine the ability of a company to function as a viable business" (Gewertz and Amado 2004, p. 305). I think ethical lucubrations of this type, typical of the tradition of moral philosophy—even if very honorable—mean almost nothing in our neoliberal era, so I will immediately save my time and the time of the reader by renouncing to further propose these kinds of edifying but unfruitful—because a decent and appropriate context in which they could be listened to is lacking—intellectual exercises.

What is really the worst is that not only we are facing with huge general ethical problems, but also to challenges to the epistemic integrity of modern science. Typical of scientific research in our era is the presence of strong relationships between university and government researchers, on the one hand, and for-profit entities, on the other, which involve the funding of research projects by for-profit entities, consultancy arrangements, gifts, stock ownership, and management of start-up companies. In this context *epistemic integrity* of research is jeopardized, because scientists are biased toward the companies with whom they have relationships: conflicts of interest proliferate. The epistemologist James Robert Brown I have already quoted warns us about some epistemological perversions: "The editors [of the *New England Journal of Medicine* already in 2002] also claim in their editorial—and this is shocking—that it is increasingly difficult to find people to do reviews who do not have economic ties to the corporate world. If they left out such reviews, they claim, they would nothing at all on new products, leaving readers with no means of evaluation except that provided by the manufacturers themselves" (Brown 2008, p. 194). Furthermore, by illustrating the famous Calabrese case (Shrader-Frechette 2010) a list of four main ethical problems which afflict various fields of scientific research is provided (1) having financial conflicts–of-interest (extensive industry funding); (2) failing to follow guidelines for disclosing financial conflicts-of-interest; (3) failing to disclose

coauthors' correct affiliations and conflicts-of-interest; and (4) censoring whistle-blowers who reveal questionable behaviors. It is more than obvious that these four ethical problems can easily be responsible of damages to various levels of epistemic integrity.

Indeed, as I have already remarked in the previous subsection, the problem is that not only we are assisting to the birth of hyperexpensive drugs (for example the recent cases of Hepatitis C and some cancer treatments) but the current economical system challenges the chances of making new discoveries themselves, and so the possibility of freely exercising human creativity and capacity to discover and innovate. It can be clearly said that economic medicalization of research "[…] is a process where the traditional values associated with the scientific method are replaced by research ethics that reflect the values of the market place" (Poitras and Meredith 2009, p. 318).

(Reiss 2010, pp. 435–436) usefully remembers to us that care legislation in the United States since 1980 has been extremely "business friendly", not always acting with the patient's welfare in mind and "doing violence to the production of scientific knowledge". Inadequate regulation ("both the failure to regulate certain practises as well as the introduction of new regulations with adverse effects") has created a completely business oriented system where everyone can make profits: "companies and their stock holders by high sales and profit margins; doctors, by gifts and financial contributions from the industry; academic researchers, by the possibility to patent the fruits of their research; politicians, by board memberships in the industry and campaign donations; regulators, by so-called 'user-fees', paid for by the industry; and 'apparently' patients, by an allegedly highly innovative industry that is spending billions to find new treatments for their health problems".

In our era the practice of neoliberal economics is strongly associated with a "one dimensional" ethics that privileges market valuation principles over all others, and, regrettably, the epistemological ones included. How can the prevalence of the idea of "economic liberty", when privileged over all others, in the context of a deteriorated democratic processes, jeopardize, and damage or pervert received epistemic values? In the previous subsections I have described some of the so-called "impoverished epistemological niches", which represent an attack to the flourishing development of human creative abduction: it is obvious that at the basis of such a challenge we can see a system that putting profits over people will likely lead to a shortage of essential drugs and instead to an increment of irrational, unessential, disused and insecure drugs, with thousands of brand names, promotional vacuities, etc. After all big pharmaceutical corporations pursue strategies consistent with shareholder wealth maximization (SWM).

Neoliberalism plus globalization also lead to more experimentation of new drugs to third world countries and often the subjects of these trials are not be clearly given the information about risks[23]: the main strategic decision variables at stake are pricing, quantity to be produced, advertising and publicity, product—often superficial—reshaping and development, and investment as strategic decision variables. Pricing

[23] In the western world doctors are sometimes hugely paid to favor these experiments so opening the door to possible abuses (Brown 2008, p. 195).

may be largely determined by marketing considerations, of course related to compensate costs by suitable margin, which would be decided by contribution to fixed costs and the profit rate and profitability commanded by the capital markets (D'Mello 2002, p. 180). In sum, being a product and process innovations are part of a competitive strategy and have to be coherent with advertising and promotion: "This may entail deliberate product proliferation, product differentiation, including irrational combinations, the manipulation of patents and the codes and standards set voluntarily by an industry".

Moreover, medicalization is a social process where the medical profession involves not only doctors and associations of doctors, but also the pharmaceutical industry providing the drugs, the academic institutions and journals involved in forming doctors and promoting fundamental research activities, the government granting agencies and other sponsors, etc. As for now, given the fact that the source of capital for the pharmaceutical industry is the global financial markets, the primary ethical motivations of big pharma profoundly differ from those of the other actors.[24] A dilemma for government regulators arises: how to balance public health needs "with the need to restrict the economic footprint of the regulatory framework on an industry that produces and distributes some of the most important products of modern science?" (Poitras and Meredith 2009, p. 313). After all since the famous public policy disaster generated by thalidomide in the 1960s, it has been acknowledged that in medical research and development (R&D) the conflict of interests between profit maximizing of private sphere firms and those of governments would need a severe regulatory supervision.

Another aspect of current business oriented medicalization is related to the fact that it is becoming a process where more and more aspects of everyday life come under medical dominion, influence and supervision. (Poitras and Meredith 2009, p. 315) also stress the excesses of the so-called "marketing of disease" and illustrate a "list of categories consistent with economic medicalization, including: senior male disorders, such as andropause, baldness and erectile dysfunction; behavioral disorders, such as hyperactivity in children and adult ADHD; and, biomedical enhancements, such as human growth hormone and steroids".

Finally, here a list of some derived forms of commercialization or commodification of aspects of the biomedical research (also other aspects are included), which the neoliberal era has transformed in real challenges to epistemic integrity, which the philosopher of science has the duty to highlight:

1. instead of trying to reduce the possibility of bias in the interpretation of the observed data, the "moral codes" of the marketplace "require firms to be basically concerned with abnormal gains (losses) associated with 'positive' (negative) research results": in few words economic medicalization "occurs because there

[24]The epistemologist Brown presents a very negative description of big pharma: "The swaggering entrepreneurs of the pharmaceutical industry boast that they are doing risky, innovative research. This is pure nonsense. […] Big pharma consists of business people exploiting the intellectual work of others. Frankly, who needs these parasites? Their only contribution to medicine has been marketing […] (Brown 2008, p. 205).

is a decided bias towards unjust acceptance and against unjust rejection" (Poitras and Meredith 2009, p. 318). The tendency is to publish only favorable clinical trial results regarding an experimental drug and suppress discordant evidence, avoiding any kind of adversarial system (Biddle 2013). It is obvious that it is not rewarding, so to say, to present negative information concerning products, which already costed millions of dollars of investments[25];

2. the so-called "muzzle clauses" in the contracts—which can involve lawsuits etc.—intend to prevent researchers from releasing any information about the clinical trial without the sponsor's permission: when negative data are found they tend to remain secret, even when could predict dangers to the public health. The knowledge in motion which I have described as necessary in Sect. 8.1 above is stopped: scientific information cannot appropriately circulate. But also terrible pragmatic and not only epistemic costs and consequences can derive. The tragic consequences of OcyContin, Neurontin, Paxil, Accutane, Baycol (Caplovitz 2006), Aprotinin and Vioxx (Avorn 2006)[26] testify more or less terrible dangers and speak clearly regarding long-term effects emerged only after long periods of time already in the market place, due to a lack of preventive trials before marketing;
3. opinion leaders (also academics) and companies are too often complicit: for example they are financed for lectures at conferences or act as paid consultants to some corporations so showing low degrees of independence. Some drug companies adopt the so-called "ghost-writing" when they send the results (only the positive ones) of their research to an author trying to secure her endorsement to favor acceptance of their new drugs in the marketplace. Academics are often seduced by the chance offered of publishing in prestigious journals appropriate to favor career progress. Symmetrically, it is unlikely that unsuccessful clinical trials will be published and physicians are in general exposed to articles that support certain drugs or devices;
4. commercialization can affect even doctors' diagnostic inferences (selective abductions, as we know). The reliance of drug detailing and sampling on pure marketing tactics raises suspicion of unethical economic medicalization. Drug and medical devices are offered and sales representatives bring research literature and clinical trial results to the doctors in efforts to influence their prescription pattern

[25] Elliott links this behavior to the concept of the so-called *selective* ignorance: "[…] the category of selective ignorance can sometimes merge with the category of ignorance as a strategic ploy or active construct. For example, industry groups may purposely study the beneficial or neutral effects of their products while avoiding research that might yield negative information" (Elliott 2012, p. 332).

[26] Justin Biddle reports findings to the effect that Merck, the producer of Vioxx, mischaracterized the state of knowledge regarding its possible cardiovascular side effects between 2000 and 2004 and accounted for data on the drug deficiently (Biddle 2007). 17 members (against the remaining 15) of the FDA advisory committee in February 2005 decided to put Vioxx back on the market, after Merck had removed it, and 10 of those 17 had financial conflicts of interest with at least one of the pharmaceutical companies that had drugs under examination, such as Merck, Pfizer, and Novartis (Biddle 2013). It is more than obvious that regulatory agencies have a very small influence on private companies, given the fact such agencies are subjected to corporate funding and to committee members who are scientists that are related to those companies.

choice (Turner et al. 2008). Representatives make donations of free samples to hospital and doctors tending to insidiously influence general medical staff, avoiding to firstly contact pharmacologists, who are more expert and so more able to criticizing and evaluate drugs;

5. clinical trials themselves[27] are more oriented by marketing than by deep R&D motivations: the physicians can licitly receive fees for the recruitment and tracking of subjects admitted into the clinical trials. Two particularly famous cases are 1) Bayer admitting to a "mistake" in suppressing a study that showed dangerous side-effects related to the drug Baycol, and 2) the already cited Merck's suppression of research that showed Vioxx doubled the risk of myocardial infarction and stroke (Avorn 2006). Only the fact these drugs presented adverse outcomes in a large quantity of treated people made possible the discovery of these misconducts, which are horrible certainly from the ethical point of view but in our perspective, especially from the epistemological point of view.

In sum, epistemic decency and integrity are constantly in danger or at risk thanks to the neoliberal attack—through excessive, almost anarchistic, commercialization—to academy and public research, but we have to say that also other more practical aspects were not favored by the neoliberal turn, such as for example the ones described by Brown in 2008 in a famous article published in *Science*:

> The United States is unique among industrialized countries in not having a national health system. Health care is overwhelmingly private and largely in the hands of insurance companies. The cost is approaching 15% of the U.S. gross domestic product, and more than one-quarter of the population is not covered. By contrast, Canada (like most other industrialized countries) has universal coverage at a cost of under 9% of gross domestic product. Aside from the cost, it is hard to compare the relative quality of the health-care systems, but one statistic is revealing: Cancer patients in Canada live an average of 14 months longer from the time of detection than those in the United States (Brown 2000, p. 1702).[28]

We academics all know that philosophers of science are not involved—neither directly nor indirectly—in decisions regarding public policy: it seems that policy decisions must be based on social goals and other factors that have nothing to do with epistemology. At this point it is clear that various aspects of current decision making in commercialized research are jeopardizing scientific creativity and human creative abduction in general. As an epistemologist I am just indicating the problem: too many aspects of the socio-economical organization of science—increasingly business oriented—put in danger the genuine tradition of objective science and some of the best aspects of the human abductive scientific cognition.[29] I do not have

[27] The outsourcing of medical research has become a strong imperative in the global pharmaceutical industry. Pressed by competition, the importance of speed in drug development, and higher domestic costs, pharmaceutical companies have to outsource critical contract, clinical research, and drug testing, in general into emerging markets.

[28] See also the Wikipedia entry: Comparison of the healthcare systems in Canada and the United States.

[29] Indeed it seems that other political, economical, and social processes are jeopardizing the good performance of various human expert cognitive skills, not only creativity. On social networks as ignorance-makers cf. (Arfini et al. 2017).

practical suggestions solutions, but surely the smart people who are involved in economical and political decisions and at the same time are interested in favoring the further growth of science in the western world, will find ones.

8.3 Optimizing the Eco-Cognitive Situatedness: Human Creative Abduction Between Academia and Corporations

To further analyze the role of the optimization of eco-cognitive situatedness in its relationship with creative abduction in science it is important to deal with some interesting aspects of the current interplay between academia and corporations. The case of biopharmaceutical research is still exemplar. Still now, in an era of powerful attack to higher education (Giroux 2014), innovation and creativity are generally fostered in academia, but pharmaceutical firms tend to redefine the word "new" as a trivial "me-too" or "me-better" (just modifications of existing substances), as I have illustrated in the Sect. 8.2.2 above. Indeed biomedical research basically produce drugs which are not at all innovative—but often very expensive—with uncertain medical value and often not clearly checked from the point of view of safety and effectiveness.

These scarce innovative fruits also derived from a change of the nature of academia received from the past. For example, in the case of biopharmaceutical research, profit-oriented companies have substituted academic and other non-profit institutions in performing various medical research such as for example clinical trials. Reiss observes that 71% of industry-sponsored clinical trials were outsourced to academic medical centers in 1991 but, by 2001 this percentage had dropped to 36%; moreover, we have already said that industry-sponsored research tends to present results that are favorable for the tested drug. The commercialization of research has also attenuated the standards and drugs are sometimes tested on patients who are younger and more healthy than the general target population. Finally a considerable number of clinical trials is never published or described in a way which makes possible positive judgments about the validity of the reported results (Reiss 2010, p. 431–432). Indeed, some of the countries targets of medical trials outsourcing have been seen as serving of "guinea pigs" to the world (D'Mello 2002; Shah 1993), and also clearly testify the shift of clinical research and drug development from academy to commercial contract research organizations. Multinational companies like Pfizer, Eli Lilly, GlaxoSmithKline, Sanofi Aventis and Roche have ousourced clinical studies abroad, especially in India.[30]

Academic research remains relevant in commercially unattractive therapeutic areas, such as rare disorders and parasitic diseases, and in research into natural prod-

[30] Various cases of clinical trial misconduct are described in (Adobor 2012).

ucts, which are robustly disregarded by the big pharma.[31] Unfortunately, after the 1990s, the golden era of big pharma, the productivity is now very low and the R&D costs are rising, and dissipation of proprietary products and "dwindling pipelines" are still active (Khanna 2012).[32] In the case of biomedical research we are currently in front of a kind of unsurprising paradox: in academy great biomedical science is frequently done, but without immediate applicability to human pathologies, instead pharmaceutical firms are engaged in a kind of "drug hunting" often far from being highly innovative but simply resorting to an activity of making medicines that just work in human beings. It is well-known that genomic sequencing will not deliver large numbers of new, valid targets: the anti-infective, antiviral and antiparasitic areas have had the complete genomic sequence of their target organisms available for many years. Similarly, understanding the etiology of a disease is not necessary positively linked to finding treatments: cystic fibrosis is well studied and understood, but is still poorly treated.

Bennani eloquently observes that the different organizational structure of industry of research might be responsible of the failures and of the low level of innovative results:

> […] higher education systems are organized around scientific disciplines and departments, whereas researchers naturally tend to congregate around similar models in the industrial setting. Alternatively, the industry tends to be organized around diseases or therapeutic areas, with emphasis on centers of excellence. There are few organizational models based around "drug discovery excellence" or "integrated disease discovery and development centers" or, better still, "chemical biology-pharmacology", "pharmaceutics development", and so on. The point here is that much innovation, speed, productivity are probably lost through lack of better integrative organizational, cultural and scientific communication models. Innovative organizational and management models, along the entire spectrum of R&D, will be key in helping address current shortcomings (Bennani 2011, pp. 784–785).

The contraction in research within pharma is surely due to the lack of that eco-cognitive activity in which an environment characterized by that "knowledge in motion" I have described above in Sect. 8.1 is active. This decline seems to be accompanied by a renaissance of research within the academic setting: often, groups grow organically from academic research laboratories, exploiting a particular area of novel biology or new technology, and we are facing with an increment of drug discovery activities in the academic, charitable, and non-forprofit sectors. This is the case of the Cancer Research UK (CR-UK) where the drug discovery team at the Manchester

[31] Big pharma are generalists and orphan drug development represents a small proportion of their product portfolio (Bruyaka et al. 2013). I have already said in Sect. 8.2.1 that the excess of patenting tends to discourage the creation of new drugs, and especially for the third and developing world. In these worlds medicines cannot be easily found: a commodified scientific research privileges the medicines that already exist and, moreover, the program of developing new drugs to treat diseases that afflict primarily or exclusively the developing world is fundamentally disregarded.

[32] In between 2008 and 2012, the top ten pharma companies have lost more than 200,000 jobs. A decline not stopped even considering the exploitation of both China and India, which are offering less expensive preclinical and clinical services (at savings of 30-80%), in a situation in which informed consent and patient safeguard are often—de facto—lacking (Lee Chang 2017).

Institute has been established to translate novel research from the Manchester cancer research community into drug discovery programmes (Jordan et al. 2015).

Anyway, also other general comments concerning the future of drug discovery are rather pessimistic, as eloquently illustrated by the following passage, published in the relatively recent and rich collective book *Drug Discovery and Development*:

> However, there is cause for concern. Declining government funding and reformed educational policies in the western world are likely to have serious implications for drug discovery educators and practitioners, which could widen the already significant gap between research scientists at the highest level and the education of students at undergraduate and postgraduate level. There is a real concern that the scientists of tomorrow will not possess the right tools in the toolkit to be able to effectively interrogate and address the questions being asked by research scientists in academia and industry today. The challenges can only be met if the government agencies worldwide are willing to invest in the education of academics and students alike (Pors 2011, p. 91).

8.3.1 "The Symbiotic Model of Innovation" and the Precompetitive Collaborations

Crisis and devastating policies are already leading pharma explore external alliances to further stimulate the stagnating innovative areas. This seems to offer a new opportunity for a collaboration between academic institutes and industry. Centuries of academic scientific tradition has contributed gigantically to developing better knowledge of hundred of disease states and to the respective therapies: of course this tradition has always been less committed to the practical aim of creating new drugs and at the same time not particularly sensitive to intellectual property protection. During the last twenty years the strong reduction of funds devoted to academic research from government and private agencies has created a new attention of university researchers to industry for support in fundamental research and identifying areas of mutual interest. Steve Carney, editor of the international journal *Drug Discovery Today* thinks that the "[…] days when big Pharma companies operated in glorious isolation, finding their own targets and performing medicinal chemistry in house to find that elusive blockbuster compound are, generally, over" (Carney 2016).

In the previous sections I have amply illustrated that, in a commercialized model of research, creativity is jeopardized certainly because innovation chains and knowledge in motion are humiliated. Given the simple fact that every new idea is built on a previous idea, if the previous idea is protected, the new idea cannot be developed.[33] In presence of an excess of patents it is clear that in some areas of science, continuing research and trying innovation can be guaranteed only by some patent infringement. For example, patents in areas such as DNA diagnostics seem to jeopardize the development of certain kinds of knowledge and certain technological capabilities that have the potential to save lives (Biddle 2012). Patents and property rights constitute

[33] I have described this issue above in Sect. 8.2.1 (cf. p. 170), when dealing with the so-called "Tragedy of Anticommons".

a serious obstacle to perform research (both "normal"—in Kuhnian sense—and innovative) and also to disseminate research results. Recent patent infringement cases in the U.S., such as Monsanto vs. McFarling (2004), Monsanto vs. Scruggs (2006), and Monsanto vs. Bowman (2011) are described in (Biddle 2014)[34]: Monsanto prohibition of seed saving seems to violate the doctrine of patent exhaustion, which states that a patent holder's right to exclude others from using or selling an invention is exhausted after an authorized sale.

Another threat to the epistemic integrity of research can be easily found in the field of ethnopharmacology: astonishingly we see in danger the celebrated rational criterium of falsification, jeopardized by the pressure to publish that afflicts those scientists. In the interpretation of molecular pharmacological data published in ethnopharmacology-related journals a very unsatisfactory level of self-evaluation is observed. The problem is that there has been a rebirth in scientific study of medicinal plants with medical effects, also enriched with new methods for exploration of new drugs candidates for several diseases. We academics all know that various new policies regarding evaluation of researchers have been implemented in the last years to the aim of improving research and its "productivity" and the "merit" of people. Consequently scientists are in general under pressure to publish. In some cases—ethnopharmacology is just a minor example—this fact weakens the commitment to falsify the theories, so generating epistemic irresponsibility.

Gertsch obviously reminds us that we may obviously ascertain when a hypothesis or theory is wrong when it can be "proved" wrong (Popper 1959, 1963; Popper and Miller 1983) and observes

> In an "inflation-driven" scientific environment the currency (scientific publications) is devaluated as the amount of currency increases, which motivates us to publish as many claims as possible. […] The result is the fabrication of unscientific hypotheses and theories. Is it correct to talk about an antimalarial activity of an extract when the readout is derived from an in vitro model? Is a compound an anticancer agent only because it kills cancer cells in vitro? If compound *X* shows anticancer effects in different in vitro models but is completely inactive in vivo because it is not bioavailable or metabolized we have the possibility of improving its chemical properties such that it becomes a therapeutic candidate. […] Only when researchers start to try to falsify or refute their observations and subsequently announce grown-up theories will we see an improvement in scientific quality and a more efficacious promotion of knowledge. In my opinion this is urgently needed in ethnopharmacology (Gertsch 2009, pp. 181 and 182).

Even if the situation of commercialized biopharmaceutical research (and agricultural research, we have to add) presents all the epistemological problems that I have illustrated in this chapter, fortunately there are, still alive, many areas in which commercialization of science is relatively not present and scientific progress very relevant, for example in mathematics, high energy physics, and evolutionary biology, which are patent-free.[35] Of course these areas are considerably damaged in their

[34] In (Biddle 2014) many other examples are illustrated and some possible proposals for overcoming this situation of epistemic hazard advanced: voluntary agreements to make research feasible, elimination of patents, and research exemption.

[35] In these cases Brown observes that "Curiosity, good salaries, and peer recognition are motivation enough" (Brown 2008, p. 209).

intellectual freedom because of a chronic lack of funds and especially because of the obsessive request—addressed to all the academic departments—to organize their courses and their research activities primarily for forging "workers", to be promptly used by the outside market.

To re-create the eco-cognitive conditions for favoring creative scientific abduction pharmaceutical companies have to look outside of their towers to the aim of generating new ideas, identifying targets and reducing redundancy. In this process academy will still play a fundamental role: sharing information early in the scientific cognitive processes will enhance it without compromising the "sacred" intellectual property positions. Some articles recently published in *Drug Discovery Today* have just highlight some of these areas and the benefits of the so-called *precompetitive approaches* or *collaboration*. I have to say that it is really amazing to see invented new neologisms exploiting the adjective "precompetitive" to describe the creation of partnering models comprising both academic department and big and small pharma industry. These unions seem appropriate to develop a better understanding of complicated diseases, identify and validate new therapies, seek and validate novel biomarkers for prediction of efficacy and safety. I was saying that it is amazing to see the adoption of the neologism "precompetitive": it is also very revealing, is not it the admission of a strong failure of the attack to higher education and academic scientific research with its paranoic emphasis on commercialization and competition? The many decision makers who follow neoliberalism are just discovering—I have to say very slowly—that, having killed a great part of the state structures and private financial funds reserved to universities, by concentrating everything in the private sector thanks to the adoption of a totalitarian business oriented model, they have also created and they are still—obstinately—developing an eco-cognitive environment for scientific research in which innovation, creativity, and so good human creative abductive cognition are highly jeopardized.

The partners of these precompetitive unions return to have open access to the data, technology, and training options to utilize in their own research or proprietary projects. Already in 2012 Ish Khanna, experienced pharmaceutical researcher and manager, said that

> With constrained micro economics, new creative deal structures and alliances are emerging with emphasis on partnering to share risk and rewards. Although innovation is a driver in deal making, interest in early collaborations seems to have intensified during the past two to three years. This is a marked shift from previous models wherein biotechs would carry projects to clinical proof-of-concept before partnering with larger companies. Early partnerships, equity holdings, option alliances with non-dilutive funding are emerging as desirable alternates. The risk shared deals (preclinical and clinical) with preferred partners are becoming common place (Khanna 2012, p. 1098).

The so-called "Symbiotic Innovation Model" is related to this new research perspective in terms of early partnership and aims both at benefiting all partners and at being particularly relevant for the so-called novel mechanism based drugs. It

seems that variations of this model will likely be adopted rapidly in pharma industry during coming years.[36]

Reopening the barriers between public and private biopharmacological sectors thanks to the precompetitive collaborations is a first step to favor the "creative scientist", that is the unconventional thinker who currently feels imprisoned under constrictive environment. Human creative abduction can flourish beyond limits only in eco-cognitive open systems.

8.4 Computational Invasive "Subcultures" Jeopardize Human Creative Abduction in Science

In the previous sections I have illustrated how various groups of technical, social, and political-economic forces can attract scientists' attention, constrain research, and stimulate stakeholder interests along particular directions. We have to say that also some computational research is directed by groups that aim at promoting the related business, unfortunately also challenging epistemic integrity, for example trivially contending their capacity to replace with artifacts human scientific creative abduction. To make a paradigmatic example Calude and Longo contend that

> Very large databases are a major opportunity for science and data analytics is a remarkable new field of investigation in computer science. The effectiveness of these tools is used to support a "philosophy" against the scientific method as developed throughout history. According to this view, computer-discovered correlations should replace scientific understanding as a guide to prediction and action. Consequently, there will be no need to give scientific meaning to phenomena, by proposing, say, causal relations, since regularities in very large databases are enough: "with enough data, the numbers speak for themselves". The "end of science" is proclaimed (Calude and Longo 2016).

The authors demonstrate, taking advantage of deep classical results from ergodic theory, Ramsey theory, and algorithmic information theory, how absurd is this contention and that instead very large database[37] present too many arbitrary—and so spurious—correlations, which surely cannot be considered examples of pregnant

[36] One such approach, the European Lead Factory (ELF), a project of the Innovative Medicine Initiative, has recently created a collaborative lead generation platform to share research in the early moments of drug discovery. "The state-of-the-art high-throughput screening (HTS) infrastructure and the industrial-quality Joint European Compound Collection of the ELF are made available at no cost to European research investigators, with a milestone payment system applied to any exploitation projects targeting commercialization (https://www.europeanleadfactory eu/)" (Karawajczyk et al. 2015, p. 1310).The European Lead Factory is a collaborative public-private partnership aiming to deliver innovative drug discovery starting points. Having established the first European Compound Library and the first European Screening Centre, the EU Lead Factory gives free access to up to 500,000 novel compounds, a unique industry-standard HTS platform, and much more.

[37] A special issue on the scientific method and the machine learning approach to Big Data analysis has been recently published by the *International Journal of Knowledge Society Research* (D'Avanzo et al. 2016). Moreover, (Sax 2016) provides a discussion of the so-called libertarian-inspired "finders, keepers" ethics, that is the curious "morality" adopted by the business model of big data

scientific creative abduction, but just uninteresting generalizations,[38] even if made thanks to sophisticated artifacts: "Too much information tends to behave like very little information" (*ibid.*) This study is the correct answer to the implicit challenge to scientific cognition proposed in June 2008 by C. Anderson, former editor-in-chief of *Wired Magazine*, who wrote an article titled "The end of theory: the data deluge makes the scientific method obsolete" contending that "with enough data, the numbers speak for themselves", science as we know will be replaced by robust correlations in immense databases![39]

Amazing examples of the use of these correlations are illustrated. The following is an eloquent example that indicates the extreme spontaneity and naturalness of some types of epistemic irresponsibility, especially in the case of the cognitive performances of rudimentary politicians and mass media journalists:

> A 2010 study conducted by Harvard economists Carmen Reinhart and Kenneth Rogoff reported a correlation between a country's economic growth and its debt-to-GDP ratio. In countries where public debt is over 90 percent of GDP, economic growth is slower, they found. The study gathered a lot of attention. Google Scholar listed 1218 citations at the time of writing, and the statistic was used in U.S. economic policy debates in 2011 and 2012 […]. The study isn't conclusive, though-in fact, it's far from it. As noted by John Irons and Josh Bivens of the Economic Policy Institute, it's possible that the effect runs the other way round, with slow growth leading to high debt. Even more worryingly, the research didn't hold up on replication. But by the time that became clear, the original study had already attracted widespread attention and affected policy decisions (Calude and Longo 2016).

The authors also note that European policy makers largely referred to that paper till 2013. The EU Commissioner for Economic Affairs (2009-2013) referred to the Reinhart-Rogoff correlation as a key guideline for his past and present economic views and the British Chancellor of the Exchequer—since 2010—observed in April 2013 that Rogoff and Reinhart demonstrate "convincingly" that all financial crises have their ultimate origins in the public debt.

(Footnote 37 continued)
companies, which can "legitimately" appropriate (the fruits of) their results. (Frizzo-Barker et al. 2016) also describe large-scale networked genetic material as a disruptive technology. On one hand, clinical genomics advances life-saving innovation through precision medicine. On the other, the digital databases they are built upon raise new concerns for informational risk to personal privacy.

[38] Such as the relation between the orientation of a comet's tail and the Emperor's chances of a military victory. Large database seem to rejoin magic, where underlying rational causes are lacking: but correlations do not supersede causation.

[39] More and more often researchers in different disciplines have been interested in using big data for their applications. Nonetheless, "For big data, spurious correlation refers to uncorrelated variables being falsely found to be correlated due to the massive size of the dataset" (Gandomi and Haider 2015, p. 143). Studies that use big data are thus more likely to achieve the "generalizability" criterion of the findings, yet they are also prone to potentially produce uninteresting and/or insignificant, though generalizable, results due to the mentioned spurious correlations (see e.g. (Fan et al. 2014)).

Let me describe another challenge to human abductive reasoning performed in the area of artificial intelligence (AI), very interesting but exaggeratedly emphasized by mass-media, social networks, and the corporation itself, which proudly made it, that is Google. A long tradition in artificial intelligence—mainly in the area usually called "machine learning"—concerned the epistemologically very impressive computational AI applications that involve the abductive processes in scientific discovery and mathematical reasoning and creativity.[40]

The example I am describing here regards an AI program that was able to play the Game Go very successfully, and so not involved in simulating scientific discovery but certainly human skillful strategic ability and creativity. It is well-known that in 2015 Google DeepMind's program AlphaGo beat Fan Hui, the European Go champion and a 2 dan (out of 9 dan possible) professional, five times out of five with no handicap on a full size 19x19 board. In March 2016, Google also challenged Lee Sedol, a 9 dan considered the top world player, to a five-game match. The program shot down Lee in four of the five games. It seems the looser acknowledged the fact the program adopted one unconventional move—never played by humans—leading to a new strategy, so performing a very "human" capacity, and I have to say, better than the one of the more skilled humans. AlphaGo learned to play the game by checking data of thousands of games, and may be also those played by Lee Sedol, exploiting the so-called "reinforcement learning", which means the machine plays against itself to further enrich and adjusts its own neural networks based on trial and error. Of course the program also implicitly performs what we call "reasoning strategies" to reduce the search space for the next best move from something almost infinite to a more calculable quantity.

Cohleo and Thompsen Primo, de facto testify in the below passage that for an AI program as AlphaGo is relatively easy to reproduce at the computational level what I have called *locked reasoning strategies* (Magnani 2017).[41] In summary, a kind of general reason of this simplicity would be that this kind of human reasoning is less creative than others, even if it is so spectacular and performed in an optimal way only by very skilled and intelligent subjects.

> Let us compare the key ideas behind Deep Blue (Chess) and AlphaGo (Go). The first program used values to assess potential moves, a function that incorporated lots of detailed chess knowledge to evaluate any given board position and immense computing power (brute force) to calculate lots of possible positions, selecting the move that would drive the best possible final possible position. Such ideas were not suitable for Go. A good program may capture elements of human intuition to evaluate board positions with good shape, an idea able to attain far-reaching consequences. After essays with Monte Carlo tree search algorithms, the bright idea was to find patterns in a high quantity of games (150,000) with deep learning

[40] I have discussed the problem of automatic scientific discovery with AI programs in (Magnani 2009, Chap. 2, Sect. 2.7 "Automatic Abductive Scientists").

[41] In this case the strategies which are activated are multiple but all are "locked" because the components of each scenario in which they are applied are always the same (for example in the case of the game Go just the number of present stones and their configurations change), in a finite and unchanging framework (no new rules, no new objects, no new boards, etc.).

> based upon neural networks. The program kept making adjustments to the parameters in the model, trying to find a way to do tiny improvements in its play. And, this shift was a way out to create a policy network through billions of settings, i.e., a valuation system that captures intuition about the value of different board position. Such search-and-optimization idea was cleverer about how search is done, but the replication of intuitive pattern recognition was a big deal. The program learned to recognize good patterns of play leading to higher scores, and when that happened it reinforces the creative behavior (it acquired an ability to recognize images with similar style) (Coelho and Thompsen Primo 2017).

We humans with our organic brains do not have to feel humiliated by these bad news…Human portentous performances with the game Go and other human ways of reasoning, even more creative than the ones involved in a locked strategic reasoning, cannot reach the global echo AlphaGo gained. The reason is simple, human-more-skillful-abductive creative performances—still cognitively gorgeous—are not sponsored by Google, which is a powerful corporation that can easily obtain a huge attention by aggressive media, a lot of internet web sites, and social networks enthusiast ignorant followers, more easily impressionable by the "miracles" of AI, robotics, and in general, information technologies, than by exceptional human knowledge achievements, always out of their material and intellectual reach.

Google managers also believe AI programs similar to AlphaGo could be used to help scientists solve tough real-world problems in healthcare and other areas. This is more than welcome. Of course I guess Google will also expect to implement some business thanks to a commercialization of new AI capacities to gather information and making abductions on it. Marketing aims are always important in these cases.

The Wikipedia entry DeepMind (https://en.wikipedia.org/wiki/DeepMind) [DeepMind is a British AI company founded in September 2010 and acquired by Google in 2014, the company realized the AlphaGo program] reports the following non contested passage:

> In April 2016 New Scientist obtained a copy of a data-sharing agreement between DeepMind and the Royal Free London NHS Foundation Trust, which operates the three London hospitals which an estimated 1.6 million patients are treated annually. The revelation has exposed the ease with which private companies can obtain highly sensitive medical information without patient consent. The agreement shows DeepMind Health is gaining access to admissions, discharge and transfer data, accident and emergency, pathology and radiology, and critical care at these hospitals. This included personal details such as whether patients had been diagnosed with HIV, suffered from depression or had ever undergone an abortion. This led to some public outcry and officials from Google have yet to make a statement but many regard this move as controversial and question the legality of the acquisition generally. The concerns were widely reported and have led to a complaint to the Information Commissioner's Office (ICO), arguing that the data should be pseudonymised and encrypted.

Academic epistemologists and logicians have to monitor the exploitation of these AI and of other computational tools, which could present uses that can be less transparent than the simple and clear—and so astonishing—performance of AlphaGo in games against humans. Good software, which represents a great opportunity for science and data analytics, can be transformed in a tool that does not respect episte-

mological rigor and/or basic western received moral standards. In the different case concerning the management of big data described by Calude and Longo's (Calude and Longo 2016), I have already illustrated above in this section, results can lead to unsubstantial computer-discovered correlations, (may be instead interesting from a commercial point of view), but they are presented—amazingly—as aiming at substituting human centered scientific understanding as a guide to prediction and action.

A strong criticism of another invasive computational "subculture" is provided by (Longo and Tendero 2007), who address their observations to the still widespread metaphor "DNA is a program" (the programming paradigm), used both in molecular biology and in its popularization. The authors contend that the metaphor and the model are fundamentally inadequate not only in biology but also from the point of view of both physics and computer science. Still in this case, analogously to the case of big data I have just illustrated, the programming paradigm is not theoretically sound as a causal framework for relating the genome to the phenotype, a much more complex process than the one which is depicted by an explanation based on this computational paradigm.

8.5 Science Impoverished: Encouraging Epistemic Irresponsibility Through Ignorance

A general taxonomy of ignorance, occasioned by the feminist tradition in epistemology, is usefully provided by (Tuana 2006). The various items below compose the program of the so-called "epistemology of ignorance", which refers to a wide group of problems pertaining human cognitive behavior, beyond the ones strictly referred to science. The list is interesting and some of the items can also regard science. However, I added three items that are more directly related the the relationship between ignorance and scientific cognition:

1. "knowing that we do not know, but not caring to know", in this case ignorance is sometimes the result of the configurations of interest. I have already quoted the case of drug companies that decided research in the area of hormonal contraception for men would not be profitable (cf. (Tuana 2006, p. 4)):
2. "we do not even know that we do not know" because our current interests, beliefs, and theories obscure some issues. A canonical example is provided by the feminists' notes about twentieth-century medical and anatomical illustrations which included careful examinations of male and female genitalia, but the anatomy of the clitoris was not a focus of attention and almost ignored in some mid-century textbooks;

3. "they do not want us to know", when the ignorance of certain groups is systematically cultivated. Some knowledge is rendered secret because of national security or because of business interests. I have to add that sometimes even people that know tend to ignore what they know. Indeed, an important question is not simply whether something is known but also who knows it and whether that knowledge is adequately exploited in the decision making techniques used by those in power: "Selective ignorance is important to emphasize even if it is not a matter of complete ignorance but rather a matter of the relative attention given to particular forms of information and research pathways" (Elliott 2012, p. 335);
4. "wilful ignorance", which is related to the situation of people that do not know and do not want to know, such as in some forms of racism, when a strong ignorance of the lives and histories of those considered inferior is actively cultivated;
5. "ignorance produced by the construction of epistemically disadvantaged identities". In this case we see people that are constructed as untrustworthy or situations in which a deliberate maintenance of ignorance to guarantee privileges and power is activated: "What feminist epistemologists and science studies theorists have carefully demonstrated is that our theories of knowledge and knowledge practices are far from democratic, maintaining criteria of credibility that favor members of privileged groups" (Tuana 2006, p. 13);
6. "loving ignorance", when accepting that it is better to ignore events, people aspects, situations, that can increase conflicts or produce violence or to disfavor good projects; and I would also add three further items, which are of direct interest in the case of science:
7. "faking knowledge to preserve ignorance": I have already quoted the case in which some politicians and decision-makers address the solution of a problem toward scientific or technical fixes rather than social or political solutions. In this case I have to say that scientific knowledge is not precisely faked, but, so to speak, just reverberated as possible (and needed). Thus, before scientists even begin to formulate their own specific questions about a research topic, a significant and value-laden decision may already have been made tacitly by citizens or policy makers-namely, the decision to treat the problem primarily as a set of questions for scientists and engineers to address. Of course there are a number of non-technical solutions to social problems, which instead cannot be solved thanks to science, even imagining for science the most shining future;
8. "epistemic irresponsibility": I have illustrated in the previous sections many ways of jeopardizing science and its epistemological integrity, that is ways of promoting a scientific ignorance that would have been avoided adopting more epistemic rigor;
9. "distributed ignorance" through misinformation, widespread biased beliefs, ideological just-so stories pertaining science and pseudoscience in science-related contexts, such as virtual online communities and—by now extremely degraded—mass-media. This threat to science (and scientific mentality) is illustrated in

(Arfini et al. 2017): the diffusion of not verifiable scientific news through digital media can contribute to the formation of huge bubbles of shallow understanding in the laymen public.

In this chapter I just wanted to provide an analysis, in the light of my eco-cognitive approach to epistemology, of various threats to science, to human creative abduction, and related ways of producing rational knowledge developed in the last few centuries, that I consider extremely negative. These threats seem to design a potential future of decivilization, or at least a future characterized by different forms of "civilization", incommensurable with the one of democracies we have experienced in the last century in the western world. Unfortunately, it is highly difficult to address in a socially responsible manner the problems originated by these transformations. To recognize some of these threats is already making a good intellectual job, even if I am sure that many of these menaces, which are already active, are still difficult to be detected or completely out of intellectual sight. It is for example difficult to criticize the use of models in science and their possible role in hiding important forms of knowledge that would be extremely worthful to construct, for example in case they result less interesting from the point of view of an immediate commercialization.

It is simple to detect and criticize behaviors that testify patent forms of epistemic irresponsibility, for example a corporation that refuses to reveal information about the harmful effects of its products, but it will be more difficult to criticize studies organized in such a way of minimizing the chance of detecting negative effects. It is obvious that selective ignorance is always at stake, and this regards the directions of research science has to adopt, and that often reflect the interest of restricted groups[42]: criticizing it is related to the adoption of a different interest, for example the one of the public goods. Another count is the critique to the threats to the productivity of science itself I have illustrated in the previous sections, which jeopardize the entire way of producing rational knowledge.

In conclusion, political and academic strategies can be implemented to restore epistemic responsibility when needed (for example (Elliott 2012) quotes political activism and deliberative forums for both steering science toward public goods and identifying public goods thanks to democratic policies). The success of these processes will exclusively depend on the decisions and actions the human beings will adopt (or will be able to adopt).

[42] Sometimes it is the mere neoliberal organization of universities and research centers which inhibits freedom and that eco-cognitive openness and optimization of eco-cognitive situatedness I have introduced in this book. For example: idiot pressure to produce science that can be published in disciplinary important journals, huge bureaucratization of academic departments that inhibits creative collaborations and, so to speak, both "enthusiasm for understanding" and needed times for "concentration", lack of funds, funds that compel to study certain themes, obsession for increasing profits, etc.

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Conclusion

In place of a formal conclusion, I offer here a sort of summary and a few final comments about what I see as the most important elements of *The Abductive Structure of Scientific Creativity*. My hope is to have established a compelling rationale for making a serious commitment to further increasing knowledge, both logico-epistemological and cognitive, on scientific reasoning thanks to the concept of abduction. It is certainly through new knowledge on this important way of thinking that we can increase our chances of success in maintaining the epistemological commitment to studying human "rational" attitudes, keeping research lively and fruitful. At the same time, given the importance of scientific hypothetical reason in human cognition, study on abduction helps to maintain the importance of scientific mentality, also beyond the strictly intellectual scientific community. The knowledge about abductive cognition in science I passionately endorsed in this book also aims at supplying researchers with the rational poise required to handle controversial issues regarding creative and hypothetical reasoning, now and in the future.

In 1998 Jaakko Hintikka had already stressed the philosophical importance of abduction in "What is abduction? The fundamental problem of contemporary epistemology". At that time many articles about abductive reasoning were already available, especially related to the history of philosophy, artificial intelligence (for example, in the case of knowledge-based medical systems and in planning), and logic. Those articles already characterized the field as constitutively interdisciplinary: (1) articles written by the historians of philosophy and researchers studying philosophical and semiotic aspects of abduction related to the work of Charles Sanders Peirce; (2) articles concerning research on abductive reasoning stimulated by the development of artificial intelligence (AI), which immediately recognized its importance; (3) articles written by logicians engaged in building non-standard logical models of abduction (such as nonmonotonic systems), in turn promoted by the new AI ideas.

In that intellectual atmosphere I published the pioneering book *Abduction, Reason, and Science* (Kluwer Academic/Plenum Publishers, New York, 2001), in which I presented a new interdisciplinary perspective on abduction. The book illustrated a novel philosophical and cognitive perspective able to introduce an unconventional

L. Magnani, *The Abductive Structure of Scientific Creativity*,
Studies in Applied Philosophy, Epistemology and Rational Ethics 37,
DOI 10.1007/978-3-319-59256-5

approach taking advantage of the research available in epistemology, cognitive science and artificial intelligence and proposing an interdisciplinary treatment. The book also introduced the following main concepts: creative and selective abduction, model-based and manipulative abduction, and the notion of the epistemic mediator, all concepts which were then usefully exploited and discussed within the international scientific community.

Later on in 2009 I published another book on abduction, *Abductive Cognition* (Springer, Heidelberg/Berlin), which was the manifesto of my eco-cognitive perspective on hypothetical reasoning, and illustrated what I more recently called eco-cognitive model (EC-model) of abduction,[1] a model further described and elaborated in the present book. In *Abductive Cognition* I clearly explained that at the center of my perspective on cognition is the emphasis on the "practical agent", of the individual agent operating "on the ground", that is, in the circumstances of real life. In all its contexts, from the most abstractly logical and mathematical to the most roughly empirical, I always emphasized the whole cognitive nature of abduction. Reasoning is something performed by cognitive systems. At a certain level of abstraction and as a first approximation, a cognitive system is a triple (A, T, R), in which A is an *agent*, T is a *cognitive target* of the agent, and R relates to the *cognitive resources* on which the agent can count in the course of trying to meet the target-information, time and computational capacity, to name the three most important. I linked the concept of abduction to that cognitive science tradition that see agents as *embodied distributed cognitive systems*: cognition is embodied and the interactions between brains, bodies, and external environment are its central aspects. Cognition is occurring taking advantage of a constant exchange of information in a complex distributed system that crosses the boundary between humans, artifacts, and the surrounding environment, where also instinctual and unconscious abilities play an important role.

It seems these books also opened up new research opportunities, still to be further exploited in international scientific debates, and which I am honored to offer again through this new book from a fresher perspective. Over the last decades I have benefited from several international relationships with researchers, been involved in and taken advantage of the direct organization of international events, of the publication of edited books, conference proceedings, and articles in international journals and I expect this book to enhance this type of social activity which I consider so precious to academic work.

The main tenet of the present book is that guessing scientific hypotheses is one of the most important cognitive activities of human beings. We have seen in this book that this cognitive activity occurs in a multimodal way, which involves all sensori-motor modalities and happens with the help of visualizations, simulations, analogies, emotions, etc., and external resources. Consequently, multimodal and manipulative abductive cognition in humans is fundamentally hybrid, and does not occur only with the help of natural or artificial languages, as supposed from the traditional epistemological perspectives. Its hybridity is also at the root of several high-level

[1] (Magnani 2015, 2016).

creative skills. All sensorimotor modalities are involved in this performance. Culture and science represent the main fruit of that important human endowment—i.e. the capacity to guess hypotheses—which has also presented an astonishing evolutionary success. I always thought the concept of abduction, already studied by Charles Sanders Peirce in XIX Century, is the best philosophical and intellectual tool to afford the study of that human "rational" capacity which is often very creative. In the second half of the last century this concept suddenly acquired a great importance in logic, cognitive science, artificial intelligence, neuroscience, and biology demonstrating both a ground-breaking nature and a strong interdisciplinary character.

Studying multimodality embedded in model-based reasoning further offers the chance to stress the role of models in scientific reasoning and thus in the case of hypothesis formation capabilities. Furthermore, joining abduction and model-based reasoning in the present book allowed me to further clearly acknowledge the fact that hypothesis guessing is not only multimodal but also distributed, as I have already explained few lines above. I also stressed that, when active in science, modeling cognitive processes cannot be considered fictional at all. Cognitive agents distribute in—and delegate to—natural entities and artifacts various cognitive roles. In this way the activity of building the so-called "epistemological niches" plays an important role also, and especially, in abductive cognition. Thus the study of abductive cognition opens up new horizons and opportunities for research, mainly because of its interdisciplinary nature, which crosses the boundaries between different fields of research, but also because the consideration of model-based and abductive aspects of reasoning permits an analysis of cognition capable to understand it in a broader way: (1) cognition is shown as an activity which involves models and so we can acknowledge that it is present in various organisms, not only in humans; (2) cognition is distributed, so the door is opened to the fundamental analysis of epistemic and cognitive roles of artifacts; (3) "creative"—abductive—aspects of cognition have to be studied and possibly enhanced, given the ethical importance of knowledge in our technological world.[2] The various chapters all are committed to stress the role of manipulative abduction, showing how we can find methods of constructivity based on external models, cognitive epistemic mediators, and hybrid representations in scientific and everyday reasoning (but also in technological innovation).

Those who are suspicious of interdisciplinarity—this book is mainly interdisciplinary—invoke the conviction that we must "focus" and restrict our research in order to honor the target of producing scientific results, which can only be reached through specialist commitment. Even if it is undoubtedly true that specialist research is an optimal way to reach scientific answers, that conviction becomes dogmatic and intellectually dangerous when used to proscribe different approaches. Here in the increasingly complex twenty-first century, that conviction alone can sometimes seem too simplistic and general to do us much good in the face of the excessive specialization of research and of the lack of unify-

[2]I was engaged in stressing the importance of studying the role of artifacts from both a cognitive and an ethical point of view when I wrote my book *Morality in a Technological World* (Cambridge University Press, Cambridge, 2007).

ing and broader perspectives. But we can build on that dogmatic conviction: by moderating its mandate—and by encouraging researchers of all non scientific disciplines to seriously take into consideration the results of scientific research—we can begin to make peace with that exclusive mentality that inevitably transforms other approaches into "deviant" approaches. Indeed, defending the interdisciplinary approach we are simply re-engaged in one of the basic tenets of the philosophical mentality, now enriched by a naturalistic commitment, which acknowledges the relevance of scientific results. By endorsing this view I am just following the lesson of the neopositivist philosophers who already taught, at the beginning of the last century, the importance of scientific research and results but "also" the importance of a basic profound philosophical interdisciplinary openness. This commitment always characterized the life of that part of philosophical reflection which is interested in the structure of knowledge and of cognition. How could we deal with a concept like abductive cognition in science abandoning the philosophical spirit of openness to every kind of knowledge, and without taking into account the results of many modern disciplines?

Thinking of abductive cognition as a valuable and central topic of contemporary epistemology and cognitive science is also a modest but useful way to navigate the murky waters of that "virtuosity" (the term is taken from John Woods) of many modern logical technicalities aiming at modeling abduction, which are looking for a more fruitful cultural life. Faced with these virtuosities, even as a trained logician, and not only a philosopher, I felt myself compelled to approach abduction in a broader way. I think my extended method is appropriate if we wish to live as philosophers of cognition, now and, especially, in the future, still committed to scientific mentality and to rational methods, in that future when magical, mythical, and mystical knowledge—i.e. that knowledge which is for example always hidden in religion, everyday thinking, social networks, and mass-media—could be more common than today and intertwined with an unwelcome triumph of conflictual and violent contrasting and irreducible beliefs. Conflicts and violence that tomorrow could otherwise increase, in the absence of a more widespread intellectual dedication to scientific mentality and "notwithstanding" the further welcome growth of specialization in science and technology. In my book of 2011 *Understanding Violence*, my studies on abduction also helped me not only to clarify the concept of violence, in its relationships with morality, but also reflect upon the entanglement of epistemology and morality, which is at the basis of the treatment of the last chapter of this book, dedicated to the recent dangerous and disturbing threats to human abductive scientific cognition and epistemic rigor.

Furthermore, the increasing hybridization between the human and the artificial, a process fueled, of course, by scientific knowledge, makes an interdisciplinary philosophical "rational" attitude to human hypothetical cognition increasingly relevant to our everyday lives; similarly, it demands greater understanding of this new hybrid human condition. I would also hope that readers come away from *The Abductive Structure of Scientific Creativity* with a renewed appreciation for the astonishing human capacity of guessing more or less creative hypotheses, which I believe addresses important issues about the relevance of cognition and knowledge in our

scientific and technological era, vexed by tumultuous outbursts of irrationality, backwardness, and increasing commodification of the human scientific activities. Overall, I would say that the study on how we as individuals deal (or fail to deal) with the attainment of appropriate hypothetical knowledge needs much greater attention in scientific research and in the interdisciplinary arena of philosophical discussion.

Scientific abductive cognition is so pervasive, so much a part of human life, that it is not easy to imagine how to live and flourish without it. Guessing scientific hypotheses is a complicated cognitive mechanism, which is intertwined with that optimization of eco-cognitive situatedness I have illustrated in this book and has to be seriously protected and defended. Acknowledging our "condition" as "hypothetical beings" ("Popperian creatures", as Daniel Dennett says), and increasing knowledge about this astounding capacity to guess so typical of a scientific stance, is a form of accepting epistemic responsibility—it will hopefully weaken errors and could be of help in further improving our freedom and the ownership of our destinies.

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Lexicon of Abductive Cognition in Science

Abductive logic programming. Abductive logic* programming (ALP) is a high level knowledge-representation framework that can be used to solve problems declaratively based on abductive reasoning. It extends normal logic programming by allowing some predicates to be incompletely defined, declared as abducible predicates. Problem solving is accomplished by deriving hypotheses on these abducible predicates (abductive hypotheses) as solutions of problems to be solved. These problems can be either observations that need to be explained (as in classical abduction) or goals to be achieved (as in normal logic programming). It can be used to resolve problems in diagnosis, planning, natural language and machine learning. It has also been used to handle negation as failure as a way of expressing some forms of abductive reasoning.

AKM-schema. The AKM-schema illustrates the explanatory dimension of abduction. That is, it describes abduction as the kind of reasoning which aims at generating hypotheses, which are related to considerations of plausibility, relevance and characteristicness. In this perspective abduction is immediately considered a generation/selection of "plausible" hypotheses. However, the AKM model does not exhaust the concept of abduction, which also presents a non-explanatory, instrumental, and manipulative dimension, possibly considered as not intrinsically consequentialist.

Anomalies and abduction. Anomaly refers to unexpected and uncharacteristic events that create problems which demand a solution. Anomalous events are marked by both an epistemic disadvantage and an emotional rating. Philosophers of science in the last century have illustrated that inconsistencies and anomalies

*A previous "Lexicon of abductive cognition" considering certain aspects of abduction not illustrated in this book, is included in my earlier book *Abductive Cognition. The Epistemological and Eco-Cognitive Dimensions of Hypothetical Reasoning* (2009).

L. Magnani, *The Abductive Structure of Scientific Creativity*,
Studies in Applied Philosophy, Epistemology and Rational Ethics 37,
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often play an important role in the growth of scientific knowledge. Hence, contradictions and inconsistencies are fundamental in abductive reasoning, and abductive reasoning is appropriate for "governing" inconsistencies.

Aristotle's ἀπαγωγή. Aristotle clearly states that in syllogistic theory local/environmental cognitive factors—external to that peculiar inferential process, for example regarding users/reasoners—are given up. At the same time in chapter B25 of the *Prior Analytics* Aristotle presents a seminal perspective on abduction: some of the current well-known distinctive characters of abductive cognition, and of abductive cognition in science, are already expressed, which are in tune with the EC-Model. By referring to the role of the method of analysis and of the middle terms in Plato's dialectic argumentation, considered as related to the diorismic/poristic process in ancient geometry, Aristotle is still pointing to the fundamental inferential and "distributed" role in reasoning of those externalities that substantiate the process of "leading away" (an expression which also translates what Aristotle calls ἀπαγωγή, that is "abduction").

Creative abduction. Creative abduction is the process in which a completely new hypothesis is created. An example of creative abduction is scientific discovery: the discovery of a new disease and the manifestations it causes in the field of medical knowledge or the Kepler's discovery of the elliptic orbit of the planets.

Deduction and abduction. Deduction is that kind of truth-preserving reasoning which starts from reasons and looks for consequences. In doing so deduction does not produce any new idea. New ideas are due to abduction that involves the generation and evaluation of hypotheses. In the process of hypothesis generation and evaluation, deduction plays a fundamental role in deriving the consequences of hypotheses, which, in turn, are compared with the available data by induction.

Diagnosis. Conjectures can be either the fruit of an abductive selection in a set of pre-stored hypotheses or the creation of new ones. "Creative" abduction deals for example 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. In this case abduction selects hypotheses; from these hypotheses consequences are derived by deduction that are compared with the available data by what Peirce called induction, in this case considered a method of evaluation.[1] Often the information available does not allow a physician to make a precise diagnosis. Therefore, she has to get further data, or even try some different manipulations to uncover symptoms otherwise hidden.

[1] Peirce was right in denying the role of "naked" induction in forming new hypotheses and considered the term to indicate processes of evaluation. However, Hintikka usefully warns us about the use of the word induction in the case of the testing of hypotheses: "[…] I do not think that it is instructive to call such reasoning inductive, but this is a merely terminological matter" (Hintikka 2007, p. 55).

EC-model and knowledge enhancing abduction. The backbone of the new approach illustrated in this book can be found in the original manifesto of my EC-Model of abduction in (Magnani 2009). This model always emphasizes the cognitive nature of abduction. Reasoning is something performed by cognitive systems. At a certain level of abstraction and as a first approximation, a cognitive system is a triple (A, T, R), in which A is an *agent*, T is a *cognitive target* of the agent, and R relates to the *cognitive resources* on which the agent can count in the course of trying to meet the target-information, time and computational capacity, to name the three most important. The agents are also considered as *embodied distributed cognitive systems*: cognition is embodied and the interactions between brains, bodies, and external environment are its central aspects. Cognition is occurring taking advantage of a constant exchange of information in a complex distributed system that crosses the boundary between humans, artifacts, and the surrounding environment, where also instinctual and unconscious abilities play an important role. This interplay is especially manifest and clear in various aspects of abductive cognition. The EC-model of abduction provides the opportunity to illustrate the knowledge enhancing character of abduction, beyond its ignorance preserving character, stated by the GW-schema: through abduction, knowledge can be enhanced, even when abduction is not considered an inference to the best explanation in the classical sense of the expression, that is an inference necessarily characterized by an empirical evaluation phase, or an inductive phase, as Peirce called it.[2]

Eco-cognitive openness and abduction. A new formal perspective on abductive processes, in terms of the effort to naturalize the logic of its special consequence relation, leads to the emphasis on the importance of the following main aspects: "optimization of eco-cognitive situatedness", "maximization of changeability" of both input and output of the general form of an inferential abductive problem, and high "information-sensitiveness". Furthermore, a naturalized logic of abduction must acknowledge the importance of keeping record of the "past life" of abductive inferential praxes, contrarily to the fact that traditional demonstrative ideal systems are prototypically characterized by what I call "maximization of memorylessness". In this perspective it is important to stress what can be called *maximization of abducibility*, which is typical of science. Constraints, methods, cognitive virtues, etc. which characterize scientific cognition certainly substantiate limitations of the cognitive behaviors but at the same time they are clearly finalized to the maintenance of the optimization of eco-cognitive openness, that solely can grant the flourishing of abductive scientific creativity. Situatedness is

[2]Peirce provides various justifications of the knowledge enhancing role of abduction: these justifications basically resort to the conceptual exploitation of *evolutionary* and *metaphysical* ideas, which clearly show that abduction is constitutively akin to truth, even if certainly always ignorance-preserving or mitigating in the sense that the "absolute truth" is never reached through abduction. Examples that indicate the knowledge enhancing role of abduction are: (1) abducing conventions in empirical science and (2) the process of abducing those models which play the "constitutive" function of enhancing scientific knowledge.

related to eco-cognitive aspects: to favor the solution of the abductive problem input and output of the formula

$$\Lambda_1, ..., \Lambda_i, ?_I \Vdash_L^X \Upsilon_1, ..., .\Upsilon_j$$

have to be thought as *optimally positioned*.[3] This optimality is in turn made possible by a *maximization of changeability* of both input and output. Not only inputs have to be enriched with the possible solution but, to do that, other inputs have usually to be changed and/or modified. Consequently, abductive inferential processes are highly *information-sensitive*, that is the flux of information which interferes with them is continuous and systematically human(or machine)-promoted and enhanced when needed. This is not true of traditional inferential settings, for example proofs in classical logic, in which the modifications of the inputs are *minimized*, proofs are usually taken with "given" inputs, and the burden of proofs is dominant and charged on rules of inferences, and on the smart choice of them together with the choice of their appropriate sequentiality; indeed, in the eco-cognitive perspective, an "inferential problem" can be enriched by the appearance of new outputs to be accounted for and the inferential process has to restart. This is exactly the case of abduction and the cycle of reasoning reflects the well-known nonmonotonic character of abductive reasoning. Abductive consequence is ruptured by new and newly disclosed information, and so defeasible. In this perspective abductive inference is *not only* the result of the modification of the inputs, but, in general, actually involves the intertwined modification of both input and outputs.

Embodied and distributed cognition. Extra-theoretical aspects and manipulations of "external" objects in reasoning are very important in hypothetical reasoning. Paying attention to the perceptual and manipulative dimension of cognition, Peirce already reminded us that human cognitive systems are not "isolated" and autonomous entities. Cognition is embodied and the interactions between brains, bodies, and external environment are its central aspects. Cognition is occurring taking advantage of a constant exchange of information in a complex distributed system that crosses the boundary between humans, artifacts, and the surrounding environment. This interplay is especially manifest and clear in various aspects of abductive cognition.

Emotion as abduction. Emotion furnishes immediate abductive appraisals of the bodily states, and provides a kind of explanation of them. Happiness, sadness, fear, anger, disgust, and surprise all can be viewed as judgments about a person's general state; a man who unexpectedly comes across a tiger on the loose, for example, would be understandably afraid because the large carnivore threatens his instinct to stay alive. In this sense, all emotions are connected to goal accom-

[3] This formula is illustrated in Chap. 3, p. 137.

plishment: people become angry when they are thwarted, for instance, and feel pleased when they are successful.

Epistemic responsibility and irresponsibility, and creative abduction. The examination of some important aspects of the current organization of Research and Development (R&D), for example in the case of biopharmaceutical companies, represents a prototypical case of creation of the so-called impoverished epistemic niches. In these cases I see a challenge to the epistemic integrity and rigor of modern science and to the productivity of scientific abductive creativity. Currently a hot problem is the emergence of various kinds of "*epistemic irresponsibility*", such as in the case of the increasing commodification and commercialization of science, the marketing of technoscientific products, the emergence of computational invasive "subcultures", and the unwelcome effects of selective ignorance. The subsequent impoverishment of the so-called epistemological niches shows that human fruitful abductive cognition is increasingly assaulted, and at the same time human creativity seriously endangered.

Fallacies and abduction. In the perspective of classical logic abductive reasoning can be defined as fallacious. More precisely, abduction is classified as the fallacy of affirming the consequent. In the light of an agent-based approach to logic the fallacious character of abduction can be further clarified and weakened: abduction is recognized as a very precious method of explanation and discovery in science and in everyday reasoning. Hence, in an agent-based perspective this kind of fallacious reasoning can be redefined and considered as a fundamental and good way of reasoning.

Fallacy of affirming the consequent. Abduction appears to be a formal fallacy that can be recognized in the perspective of classical logic: it is the fallacy of affirming the consequent. Basically it is an invalid inference, which assumes the form: "if A, then B, B; then A. From the classical logic point of view this inference is fallacious and not truth preserving.

Fictionalism, distributed model-based science, epistemic warfare, and abduction. Fictionalism sees scientific models as fictions: we need revise and criticize this view—also reframing the received idea of abstractness and ideality of models—with the help of recent results coming from the area of distributed and abductive cognition (manipulative). In science we do not have to confuse the process of abducing models with the process of abducing fictions: the recent epistemological conundrum concerning fictionalism help us to see, on the contrary, that models abduced by scientists reveal themselves not to be "airy nothings" at all (cf. the epigraph I have added to the present book), and certainly different in their gnoseological status from literary fictions. Scientific models instead play fundamental "rational" knowledge enhancing roles: in a static perspective (for example when inserted in a textbook) scientific models can appear fictional to the epistemolo-

gist, but their fictional character disappears if a dynamic/abductive perspective is adopted. Abduction in scientific model-based reasoning is not a suspicious process of guessing fictions. Furthermore, scientific modeling activity can be better described also 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.

GW-schema. Focusing attention on basic cognitive aspects of abduction, and adopting a logical framework centered on practical agents, (Gabbay and Woods 2005) contend that abduction (basically seen as a *scant-resource* strategy, which proceeds in absence of knowledge) presents an *ignorance-preserving* (or, better, an *ignorance mitigating*) character. Woods says that of course "[...] it is not at all necessary, or frequent, that the abducer be wholly in the dark, that his ignorance be total. It needs not be the case, and typically is not, that the abducer's choice of a hypothesis is a blind guess, or that nothing positive can be said of it beyond the role it plays in the subjunctive attainment of the abducer's original target (although sometimes this is precisely so)" (Woods 2013, p. 249). In this perspective, abductive reasoning responds to ignorance-problems. Ignorance-problems are defined as the impossible attainments of certain cognitive targets with the knowledge at one's current disposal. In response to ignorance-problems one can adopt three strategies: one can attain some additional knowledge (subduance), overcoming one's ignorance; one can yield to ignorance (at least for the time being) (surrender); or one can abduce, acquiring a new viewpoint for action, without getting rid of the constitutive ignorance. One of the virtues of the GW-schema also resorts to its capacity to provide the opportunity to illustrate non-explanatory and instrumentalist aspects of abductive cognition. Examples of the non-explanatory features of abduction are for example present in logic and mathematical reasoning. Furthermore, physics often aims at discovering physical dependencies which can be considered explanatorily undetermined. In this case abduction also exhibits an instrumental aspect.

Heuristic strategies. We can usefully see selective and creative abduction as performed by the application of "heuristic procedures" (often called "heuristic strategies") that involve all kinds of good and bad inferential moves, beyond the simple mechanical application of rules. It is only by means of these heuristic procedures that the acquisition of new truths is guaranteed. Also Peirce's mature view on creative abduction as a kind of inference seems to stress the strategic component of reasoning. Strategic rules are smart rules, even if they fail in individual cases, and show a propensity for cognitive success. When there is a problem to solve, we usually face several possibilities (hypotheses) and we have to create or select the suitable one. In this situation we can rely on heuristics, that are for example rules of thumb expressed in sentential terms and that help us reach satisfactory choices without considering all the possibilities.

Hybrid abducers. The various abductive activities human agents are engaged in drastically rely on external supports. For instance, human agents create mimetic external representations which mirror concepts and problems that are already represented in the brain and need to be enhanced, solved, further complicated, etc. so they can sometimes creatively give rise to new concepts and meanings. In the process of distributing the mind into the material world around them, human agents develop new abductive skills, which would not be exhibited without the continuous interplay with the various external supports. In doing so, human agents can be described as hybrid abducers. Organic agents are spontaneous inducers and abducers but human beings also construct logical and computational (ideal) systems both able to mimic human inductions and abductions and to create new and more "rational" ways of inducing and abducing. These systems are in turn used by human agents: they consequently have to be seen as hybrid reasoners.

Ignorance-preserving abductive cognition. Abduction is a procedure in which something that lacks classical epistemic virtue is accepted because it has virtue of another kind. For example: let S be the standard that you are not able to meet (e.g., that of mathematical proof). It is possible that there is a lesser epistemic standard S' (e.g., having reason to believe) that you do meet. Focusing attention on this cognitive aspect of abduction we can contend that abduction (basically seen as a scant-resource strategy, which proceeds in absence of knowledge) presents an ignorance preserving (but also an ignorance mitigating) character. Of course it is not at all necessary, or frequent, that the abducer be wholly in the dark, that his ignorance be total. It needs not be the case, and typically is not, that the abducer's choice of a hypothesis is a blind guess, or that nothing positive can be said of it beyond the role it plays in the subjunctive attainment of the abducer's original target (although sometimes this is precisely so). Abductive reasoning is a response to an ignorance-problem: one has an ignorance-problem when one has a cognitive target that cannot be attained on the basis of what one currently knows. Ignorance problems trigger one or other of three responses. In the first case, one overcomes one's ignorance by attaining some additional knowledge (subduance). In the second instance, one yields to one's ignorance (at least for the time being) (surrender). In the third instance, one abduces, and so has a positive and reasoned basis for new action even if in the presence of the constitutive ignorance.

Induction and abduction. Since the time of John Stuart Mill, the name given to the most important kinds of conjectural non deductive reasoning has been induction, considered as an aggregate of many methods for discovering generalizations and casual relationships. Consequently induction in its widest sense is an ampliative process of generalization of knowledge. By using induction it is possible to synthesize individual statements into general laws—inductive generalizations—in a defeasible way, but it is also possible to evaluate (confirm or discount) hypotheses (on induction as a form of evaluation cf. the considerations contained in the

footnote 45 at p. xxx.) In the case of the relationship between abduction, deduction, and induction, illustrated by Peirce and exploited in the ST-model, induction does not deal with the problem of individuating the ways of "generating" inductive hypotheses but refers to a logic of hypothesis "evaluation". Abduction creates or selects hypotheses; from these hypotheses consequences are derived by deduction that are compared with the available data by induction. In the ST-model induction is used as the process of reducing the uncertainty of established hypotheses by comparing their consequences with observed facts.

Inference to the best explanation. There are two main epistemological/cognitive meanings of the word abduction: (1) abduction that only generates plausible hypotheses (selective or creative)—this is the meaning of abduction accepted in my epistemological ST-model—and (2) abduction considered as an inference to the best explanation, that also evaluates hypotheses by induction. In the latter sense the classical meaning of abduction as an inference to the best explanation (for instance in medicine, to the best diagnosis—selective abduction) is described by the complete abduction-deduction-induction cycle.

Instinct as abduction. An example of instinctual (and putatively "unconscious") abduction is given by the case of animal embodied kinesthetic/motor abilities, capable of leading to some appropriate cognitive behavior; Peirce says abduction even takes place when a new born chick picks up the right sort of corn. This is another example, so to say, of spontaneous abduction—analogous to the case of some unconscious/embodied abductive processes in humans. Therefore, instinct vs. inference represents a conflict we can overcome simply by observing that the work of abduction is partly explicable as a biological phenomenon and partly as a more or less "logical" operation related to "plastic" cognitive endowments of all organisms.

Instrumental abduction. Abduction exhibits an instrumental and strategic aspect, for instance, when intertwined with the exquisite epistemological problem of the role of unfalsifiable hypotheses in scientific reasoning. In this case, an abductive hypothesis can be highly implausible from the "propositional" point of view and nevertheless it can be adopted for its instrumental virtues, such as in the Newtonian case of action-at-a-distance. Highly implausible hypotheses from the "propositional" point of view can be conjectured because of their high "instrumental" plausibility, where a different role of characteristicness is at stake. We have to note that in some sense all abductions embed instrumental factors. In the general case, one accepts a hypothesis because doing so enables one's target to be attained, notwithstanding that lacks the relevant epistemic virtue of plausibility.

Logical abductive agents. Logical agents have to be seen as ideal "demonstrative environments", which in turn are suitable tools for the creation of logical/deductive models of abductive reasoning itself. They are the fruit of cognitive

externalizations in objective logical systems, endowed with symbolic, abstract and rigorous cognitive features, which are also potentially exploitable at the computational level.

Manipulative abduction. Manipulative abduction 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 the case of the human use of the construction of external diagrams in geometrical reasoning, useful to make observations and "experiments" to transform one cognitive state into another for example to discover new properties and theorems.

Maximization of cognition and abduction. When dealing with abduction in a logical perspective, as an "inferential problem", it is be appropriate to adopt the more general concepts of input and output instead of those of premisses and conclusions. From this perspective abductive inferences can be seen as related to logical processes in which input and output fail to hold each other in an expected relation, with the solution involving the modification of inputs, not that of outputs. The chance of finding an abductive solution still appears to depend on the Aristotelian concept of "leading away" (ἀπαγωγή), that is, on the starting of the application of a supplementary logic implementing an appropriate formal inference engine. In this perspective—and given the fact science produces and "maximizes" cognition through a process in which affirming truths implies negating truths—the most important consequence for epistemology is that in scientific creative abductive reasoning irrelevance and implausibility are not always offensive to reason. For example, we cannot be sure, more broadly, that our guessed hypotheses are plausible (even if we know that looking—in advance—for plausibility is a human good and wise heuristic), indeed an implausible hypothesis can later on result plausible.

Model-based abduction. Inaugurating the new semiotic perspective, Peirce stated that all thinking is in signs, and signs can be icons, indices, or symbols and that all inference is a form of sign activity, where the word sign includes "feeling, image, conception, and other representation" (Peirce 1931–1958, 5.283). In this light it can be maintained that a considerable part of the abductive processes is model-based. That is, a considerable part of hypothesis creation and selection is model-based: it is occurring in the middle of a relationship between brains and model-based aspects of external objects and tools that have received cognitive and/or epistemological delegations.

Multimodal abduction. Multimodal abduction depicts hybrid aspects of abductive reasoning. Abductive inference can be visual as well as verbal, and consequently we have to acknowledge the sentential, model-based, and manipulative nature of abduction. Both evidence and hypotheses can be represented using various sensory modalities. Some basic aspects of this constitutive hybrid nature of multimodal abduction involve words, sights, images, smells, etc. but also kinesthetic experiences and other feelings such as pain, and thus all sensory modalities.

Naturalized logic (of abduction). A complete revision of mainstream logic is an urgent task to be achieved. This revision will be able to bring logic into a creative rapprochement with cognitive science. This can be achieved by trying to do for logic what over forty years ago Quine and others attempted for epistemology. It is necessary to propose a "naturalization" of the logic of human inference and of the so-called *third-way reasoning*, which refers to those kinds of inference that owe their rightness to the meeting of standards other than deductive validity and inductive strength, certainly overworked and overvalued by logicians, and that instead show the capacity to reach good and reliable results. Third-way reasoning refers to those cases of human reasoning such as abduction, but also to many other kinds of the so-called fallacies, disregarded or simply considered irremediable errors by logic since its ancient and modern beginnings. To understand the naturalization of logic it is very useful to take advantage of the case of a naturalized logic of abduction, which leads us to the emphasis on the importance of the following main aspects: "optimization of eco-cognitive situatedness", "maximization of changeability" of both input and output, and high "information-sensitiveness". Furthermore, a naturalized logic of abduction must acknowledge the importance of keeping record of the "past life" of abductive inferential praxes, contrarily to the fact that traditional demonstrative ideal systems are prototypically characterized by what I call "maximization of memorylessness".

Niche construction and abduction. The theory of cognitive niches describes the environment as a sort of "global market" that provides living creatures with unlimited possibilities. Indeed, not all the possibilities that the environment offers can be exploited by the human and non-human animals that act on it. For instance, the environment provides organisms with water to swim in, air to fly in, flat surfaces to walk on, and so on. However, no creatures are fully able to take advantage of all of them. Through the activity of niche construction all organisms try to modify their surroundings in order to better exploit those elements that suit them and eliminate or mitigate the effect of the negative ones. This activity is highly related to the hypothetical virtues provided by abductive cognition. That is, the relevant aspects of the environment are appropriately abductively selected and/or reconstructed so as to turn the local environment—inert from a cognitive point of view—into a cultural mediating structure able to deliver suitable chances for behavior control. Through cognitive niche construction organisms

not only influence the nature of their world, but also in part determine the Darwinian selection pressure to which they and their descendants are exposed (and of course the selection pressures to which other species are subjected). It is in this perspective that any abduced hypothesis potentially introduces a change (and an opportunity) in the cognitive processes to advance new perspectives in the coevolution of the organism and the environment.

Non-explanatory abduction. Abduction is not intrinsically explanationist, like for example its description in terms of inference to the best explanation would suggest. If we maintain that E explains E' *only if* the first implies the second, certainly the reverse does not hold. This means that various cases of abduction are consequentialist but not explanationist. Other cases are neither consequentialist nor explanationist. Non-explanatory modes of abduction are clearly exploited in the "reverse mathematics" where propositions can be taken as axioms because they support the axiomatic proofs of target theorems. Furthermore, often in physics the target is the discovery of physical dependencies which we consider explanatorily undetermined. In this case abduction can exhibit an instrumental aspect. Non-explanatory abductions deal with those situations in which the plausibility of certain hypotheses involves less "propositional" and more "strategical" and instrumental aspects, so that propositional plausibility is lower and strategic plausibility higher. These cases are far from the clear ones of explanatory abduction that are for example occurring in science and in various kinds of diagnosis.

Nonmonotonic reasoning. A logical system is monotonic if the function *Theo* that relates every set of wffs to the set of their theorems holds the following property: for every set of premises S and for every set of premises S', $S \subseteq S'$ implies $Theo(S) \subseteq Theo(S')$. Traditional deductive logics are monotonic: intuitively, adding new premises (axioms) will never invalidate old conclusions. In a nonmonotonic system, when axioms, or premises, increase, their theorems do not. For example, following this deductive nonmonotonic view of abduction, we can stress the fact that in actual abductive medical reasoning, when we increase symptoms and patients' data [premises], we are compelled to abandon previously derived plausible diagnostic hypotheses [theorems], as already—epistemologically—illustrated by the ST-model. If new information emerges, hypotheses not previously considered can be suggested and a new cycle takes place. In this case the nonmonotonic character of abductive reasoning is clear and arises from the "classical" logical unsoundness of the inference rule: it draws defeasible conclusions from incomplete information.

Perception as abduction (and visual abduction). Perception is viewed by Peirce as a fast and uncontrolled knowledge-production procedure. Perception, in this philosophical perspective, is seen as a vehicle for the instantaneous retrieval of knowledge that possibly was previously structured in our mind through more structured inferential processes. By perception, knowledge constructions are so instantly reorganized that they become habitual and diffuse and do not need any further testing. By perception, knowledge constructions are so instantly reorganized that they become habitual and diffuse and do not need any further testing: "[. . .] a fully accepted, simple, and interesting inference tends to obliterate all recognition of the uninteresting and complex premises from which it was derived" (Peirce 1931–1958, 7.37). Many visual stimuli—that can be considered the "premises" of the involved abduction—are ambiguous, yet people are adept at imposing order on them. For example we readily form such hypotheses as that an obscurely seen face belongs to a friend of ours, because we can thereby explain what has been observed. This kind of image-based hypothesis formation can be considered as a form of what I have called visual (or iconic) abduction.

Selective abduction. Selective abduction is the process in which a hypothesis is abductively selected from a pre-stored encyclopedia of "abducibles". An example of selective abduction is diagnostic reasoning in medicine: it starts from patient data that is abstracted into clinical features to be explained. Then, selective abduction generates plausible explanatory diagnostic hypotheses.

Sentential abduction. Sentential abduction—related to logic and to verbal/symbolic inferences—refers to those situations in which a hypothesis is formed and evaluated relying to the sentential aspects of natural or artificial languages, like in the case of logic. Sentential abduction can be rendered in different ways. For example, in the Peircean syllogistic framework abduction is considered like something propositional and as a type of fallacious reasoning. The sentential models of abduction are powerful but limited, because they do not capture various reasoning tasks which involve creative, model-based, and manipulative aspects.

ST-model of abduction. The so-called Select and Test Model (ST-model) is an epistemological model of medical reasoning, which can be described in terms of the classical notions of abduction, deduction and induction; it describes the different roles played by such basic inference types in developing various kinds of medical reasoning (diagnosis, therapy planning, monitoring). The model is consistent with the Peircean view about the various stages of scientific inquiry in terms of "hypothesis" generation (abduction), deduction (prediction), and induction. The model has been used to implement medical knowledge-based systems of medical reasoning.

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Index

A
AASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development), 169
Abducibles, 144
Abduction (ἀπαγωγή), 96–98, 120, 131
  ampliative, 54
  and *arche*-validity, 89–91
  and belief revision (BR), 146, 147
  and central information, 127, 128
  and consistency, 4
  and conventions, 48–53
  and definitory rules, 156
  and diagrams, 156, 157
  and dialectics, 102, 103, 105
  and eco-cognitive openness, 96–100, 119
  and embodied distributed cognitive systems, 9
  and enthymemes, 109–111
  and evaluation, 12, 22
  and fictions, 54–56
  and genealogy of logic, 89–91
  and geometry, 100–107
  and ignorance, 127, 128
  and induction, 5, 6, 12
  and information sensitivity, 138
  and instinct, 15–18
  and maximization of changeability of inputs and outputs, 138
  and middle terms, 100–107
  and minimality, 4
  and modern science, 14
  and multimodality, 139, 149
  and nonmonotonic reasoning, 14
  and optimization of situatedness, 138
  and perception, 8, 9
  and peripheral information, 127, 128
  and reliabilism, 13
  and signs, 109–111
  and strategic rules, 156
  and subconceptual levels of cognition, 150
  and testability, 5
  and the production of a deduction, 129–132
  as a case of consequence drawing, 121
  as ampliative inference, 12
  as an inference, 147
  as ignorance-preserving reasoning, 1
  as inference to the best explanation, 6, 13, 14, 147
  as knowledge-enhancing, 14, 15, 19, 21, 22
  as leading away, 89, 92, 96–107, 119, 150
  as the fallacy of affirming the consequent, 85, 96, 97, 107, 121, 123, 138, 147, 148, 153
  as thought experiment, 85
  creative, 7, 111, 147, 152
  instrumental, 8
  logic of, 135–138
  manipulative, 11, 39–42, 143, 150, 156
  maximization of (in science), 135–148
  model-based, 147
  multimodal, 154–156
  multimodal logics of, 139

L. Magnani, *The Abductive Structure of Scientific Creativity*,
Studies in Applied Philosophy, Epistemology and Rational Ethics 37,
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non-explanatory, 8
non-plausibilist, 48
on-line manipulative, 39–42
perceptual, 9
selective, 7, 11, 147
simple, 13
virtues of, 13
Abductive inferences
and deductive inferences, 61
and traditional demonstrative inferences, 148–151, 153–157
Abductive Logic programming (ALP), 144
Abstract models, 36
Academia
and creative abduction, 182–187
Adams, J., 164, 165
Ad hoc hypotheses, 53
Ad ignorantiam fallacy, 22
Adobor, H., 182
Affordances, 38
Agenda
and relevance, 128
Agents
practical, 149
theoretical, 149
Agricultural research, 185
AKM-schema of abduction, 4, 122, 124, 136
Albert the Great, 130
Alchourrón, C., 146
Alexander of Aphrodisias, 130
Aliseda, A., 4, 123, 136, 137, 144, 146, 154, 156
Allwein, G., 149, 150
AlphaGo, 189, 190
Amado, R., 177
Ampliative abduction, 54
Ampliative inference, 12
Anagkion, 91, 94, 118
Anderson, A., 128, 129
Anderson, C., 188
Angius, N., 9
Animal experimentation, 171
Animal models, 171
Anson, B. D., 171
Anthropomorphization
of the logic of abduction, 138, 139
Apellicon, 97, 100
Applied epistemology, 173
Arcangeli, M., 84
Archai, 93
Arche-validity, 95, 119
and abduction, 89–91
and genealogy of logic, 89–91
and knowledge-enhancing abduction, 91–93
Arfini, S., 2, 127, 182
Aristotle, 89, 92–102, 106–111, 116–120, 129–131, 206
Artificial Intelligence (AI), 7, 8, 18, 96, 120, 121, 145, 147, 153, 189, 190
Atran, S., 16
Aust, U., 148
Automatic scientific discovery, 189
Averroes, 130
Avorn, J., 180, 181

B

Baars, B, J., 24
Barsalou, L. W., 39
Batens, D., 136
Bayh-Dole Act, 166
Bayle, P., 130
Becher, V., 146
Belief Revision (BR)
and abduction, 146, 147
Belnap, N., 128, 129
Benacerraf, P., 142, 143
Benacerraf's dilemma, 142
and the logic of abduction, 142–144
Bennani, Y. L., 171, 174–176, 183
Berlin, B., 16
Bertolotti, T., 26, 38, 39, 86, 122, 127, 173
Beth, E. W., 154, 155
Betz, G., 130
Biddle, J., 20, 21, 162–164, 166–170, 180, 185
Big data
and scientific method, 187–191
Big pharma, 166, 167, 170, 172–176, 179, 180, 182–184, 186, 187
Bivens, J., 188
Bochenski, I. N., 130
Bohr, N., 56
Bokulich, A., 69
Boumans, M. J., 73
Boutilier, C., 146
Brandom, R., 90
Bricot, T., 130
Brighton, H., 156
Brown, J. R., 166, 168–170, 176–179, 181, 186
Bruyaka, O., 183
Bruza, P. D., 150
Bueno, O., 70, 76

Buridan, J., 130
Business oriented medicalization, 179–181, 183–187
Butterworth, B., 148
Bybee, M. D., 92, 110

C
Calabrese, E., 177
Callaway, H., 125
Calude, C. S., 187, 188, 191
Campos, D. G., 131
Caplovitz, A., 180
Carney, S., 184
Carrera, M., 172
Cartwright, N., 32, 75, 77, 80, 81, 84–86
Caterina, G., 154
Cellucci, C., 130
Central information
  and abduction, 127, 128
  and ignorance, 127, 128
Chakravartty, A., 32, 79
Chandrasekharan, S., 36, 37, 39, 40, 42, 66
Charro, F., 77
Châtelet, G., 148
Civilization
  and decivilization, 193
Clark, A., 69, 144
Clark, K. L., 52
Coady, D., 173
Coelho, H., 189, 190
Co-exact properties, 106
Cognition
  and morality, 26–28
  subconceptual level of, 150
Cognitive niches, 18, 37
Colapietro, V., 18
Colomina, J. J., 77
Commercialization of science, 167–170, 175, 176, 178–181, 183–187
Commodification of scientific abduction
  and big pharma, 168–182
  as epistemic irresponsibility, 168–173
Commodisme, 49
Computational invasive subcultures
  and creative abduction, 187–191
  and scientific abduction, 187–191
Computational Logic (CL), 145
Consequence drawing, 121, 142
Consequence drawing vs. consequence having, 96
Consequence having, 142
Consequence having vs. consequence drawing, 96
Consistency
  and abduction, 4
Constructions
  and geometry, 100–107
  and logic, 100–107
  as middle terms, 100–107
Contentual axiomatics, 156
Contessa, G., 32, 66, 74
Conventionalism
  and negation as failure, 52
  and nominalism, 50
  generalized, 49
  geometric, 49
  in physics, 50
Conventions
  and abduction, 48–53
  withdrawing, 48–53
Coopersmith, J., 49
Corporations
  and creative abduction, 182–187
Counterinduction, 7, 125
  and resemblance, 78–81
Cozzo, S., 117
Creative abduction, 7
  and academia, 182–187
  and corporations, 182–187
  and the optimization of eco-cognitive situatedness, 182–187
Creativity, 131, 168, 170, 182, 184
  and strategic rules, 155
Crippa, F., 105
Curie, M., 51
Cutdown problem, 123
  and fill-up problem, 6, 7, 9, 10

D
Da Costa, N. C., 70
D'Avanzo, E., 187
Decivilization
  and civilization, 193
De Cruz, H., 41, 42
Deduction
  abductive production of, 129–132
  and eco-cognitive immunization, 93–96
  and manipulative abduction, 60–63
  and mathematics, 60–63
  and validity, 91
  as *syllogismos*, 93
Deductive consequence
  repels information, 144, 145
Deductive inferences
  and abductive inferences, 61

Deductive validity, 91
Deep blue, 189
Deep learning, 189
DeepMind, 189, 190
Defeasibility, 92
Definitory rules, 155, 156
  and abduction, 156
  and strategic rules, 155, 156
Dehaene, S., 148
Demarcation problem, 36, 59
  and scientific models as fictions, 57–59
  in epistemology, 53
Demonstrative environments, 143
De-moralization of truth, 116–118
Denialism, 22
Dennett, D., 23, 27
De Regt, H. W., 70
Descartes, R., 126
De Smedt, J., 41, 42
Dialectical logic, 108
Dialectical logic vs. syllogistic logic, 107–109
Dialectics, 107–109
  and abduction (ἀπαγωγή), 102, 103, 105
  and logic, 102, 103, 105
Diorisms, 101, 104
Disciplinarity, 164, 165
Disembodiment of the mind, 18, 60, 142
Dismissing conventions, 51–53
Distributed cognition, 144
  and logic, 156
Distributed ignorance, 192
Distributed scientific models, 36–39
  and understanding, 37
Distributive justice, 177
D'Mello, B., 179, 182
Dorp, J., 130
Douglas, H., 20, 21
Dranitsaris, G, 173
Dunbar, R., 26, 27
Dynamic arguments
  and situatedness, 95
Dynamic aspects of scientific enterprise
  and scientific models, 74, 76, 78
  and static aspects of scientific enterprise, 74, 76, 78
Dynamic view of scientific models
  and static view of scientific models, 57–59

E

EC-model of abduction, 1, 4, 6, 9–12, 60, 110, 116, 120, 122, 124, 136, 152
  and logic, 120–131
Eco-cognitive discipline of logic, 135–138
Eco-cognitive immunization, 116–118
  and deduction, 93–96
Eco-cognitive openness
  and abduction, 162–165, 167, 168
  and abduction (ἀπαγωγή), 96–100, 119
  and knowledge in motion, 162–165, 167, 168
  and neoliberalism, 193
Eco-cognitive shutdown of creative abduction
  and epistemic irresponsibility, 173–176
Eco-cognitive situatedness, 122
  optimization of, 135–148
Einstein, A., 126
Eisenberg, R. S., 170
Elliott, K., 21, 42, 43, 167, 169, 170, 180, 193
El Skaf, R., 37
Embodied distributed cognitive systems
  and abduction, 9
Enthymemes
  and abduction, 109–111
  and signs, 109–111
Epistemically beneficial dissent vs. epistemically detrimental dissent, 20, 21
Epistemically detrimental dissent vs. epistemically beneficial dissent, 20, 21
Epistemic integrity, 177
  and neoliberalism, 177–182
Epistemic irresponsibility, 20, 162
  and big pharma, 168–176
  and commodification of abduction in science, 168–173
  and epistemic integrity, 177–182
  and ignorance, 191, 193
  and neoliberalism, 177–182
  and science impoverished, 191, 193
  and the eco-cognitive shutdown of creative abduction, 173–176
Epistemic mediators, 54
Epistemic quality, 166
Epistemic responsibility, 165
Epistemic virtues, 117
Epistemic warfare, 32, 65–69, 73, 74, 76, 78, 80
  and fictions, 68
  and propaganda, 68
Epistemic weapons
  and fictionalism, 65–69
  as scientific models, 65–69
Epistemological niches, 162–164

impoverished, 168–174, 176, 178–182, 187–191, 193
Epistemology
and ethics, 173
applied, 173
moral, 175
of ignorance, 191
wide and restricted meaning of, 173
Estrada-González, L., 120, 123, 125, 127, 136, 137
Ethics
and epistemology, 173
Ethnopharmacology
and epistemic integrity, 185
Euclid, 73, 76, 101, 130, 131
Evans, J. S., 157
Evidentially inert knowledge-enhancing abduction, 54–56
Expensive drugs, 171, 172, 178
External models, 38
External observations
and logic programs, 144, 145
External representations
creative, 60, 143
mimetic, 60, 143
External scientific models, 41
External systems
and scientific models, 37

F
Façons de parler
and scientific models, 69–72
Fallacies, 109
ad hominem, 96
ad ignorantiam, 22, 96
ad populum, 96
ad verecundiam, 96
base rate, 96
begging the question, 96
denying the antecedent, 96
gambler's, 96
hasty generalization, 96
many question, 96
of affirming the consequent, 107, 121, 123, 147, 148, 153
of equivocation, 96
post hoc, ergo propter hoc, 96
of the affirming the consequent, 85, 96, 97, 121
Faller, M., 100, 102, 104, 106
Fallibilism, 2
Falsifiability, 50
Falsificationism
and the theory of research programs, 53
Fan, J., 188
Feyerabend, P., 7, 32, 68, 79, 125, 164
Fictionalism
and epistemic weapons, 65–69
Fictions
and abduction, 54–56
and geometrical diagrams, 72–74, 76, 78
and in-vitro models, 72–74, 76, 78
as scientific models, 69–72, 86
Figueroa, A. R., 149
Fill-up problem, 129, 130
and cutdown problem, 6, 7, 9, 10
Financial crisis, 172
Fine, A., 32
Fischer, H. R., 147
Food and Drug Administration (FDA), 173, 175, 180
Formal axiomatics, 156
Franco, P. L., 21
Frege, L. G., 156
French, S., 70, 76
Fresnel, A. J., 49
Freud, S., 70
Frigg, R., 32, 62, 66, 68, 72
Frizzo-Barker, J., 188

G
Gabbay, D., 1–4, 48, 53, 94, 95, 116, 118, 128, 135, 136, 144, 151–153, 155, 210
Gálik, D., 93
Galilei, G., 4, 32, 79, 82, 86
Game (GO), 189
Gandomi, A., 188
Gangle, R., 154
Gärdenfors, P., 146, 150
Gedankenexperiment, 82–85
Gendler, T. S., 82–84
Genealogy of logic, 91–96
and abduction, 89–91
and *arche*-validity, 89–91
Genetic Modification (GM), 167, 168
Gennari, R., 14
Gentzen, G., 157
Geometrical diagrams
and fictions, 72–74, 76, 78
Geometry
and abduction, 100–107
and constructions, 100–107
and logic, 100–107

and middle terms, 100–107
George of Brussels, 130
Gertsch, J., 185
Gewertz, N. M., 177
Gibson, J. J., 38
Giedymin, J., 49, 50
Giere, R., 31, 34, 69, 78, 80
Gigerenzer, G., 156
Ginsberg, M. L., 14
Girard, R., 157
Giroux, H. A., 182
Globalization
and neoliberalism, 178
Gödel, K., 8
Godfrey-Smith, P., 32, 75
God's creation of human instinct, 18
Gossip, 173
and abduction, 122
Grassi, O., 86
Grialou, P., 157
Gross, L. J., 43
GW-model of abduction, 13
GW-schema of abduction, 3–6, 8–10, 14, 116, 122, 124, 126, 136, 138

H
Haider, M., 188
Hamblin, C. L., 130
Hamilton, W. R., 49
Hanson, N. R., 55
Hautamäki, A., 77
Heller, M. A., 170
Hempel, C. G., 20
Herzfeld, C., 148
Heterogeneous logics, 136, 149
Heuristics, 11, 57
Hilbert, D., 156, 157
Hintikka, J., 5, 12, 13, 32, 57, 58, 61, 62, 101, 108, 129, 143, 154–157, 176, 206
Hippocrates of Chios, 101–103, 106
HIV/AIDS research, 164, 165
Hoffmann, M. H. G., 17
Hui, F., 189
Human abduction jeopardized
and the impoverishment of epistemological niches, 168–174, 176, 178–182, 187–191, 193
Hutchins, E., 37, 144
Hypothesis
ad hoc, 52, 53
auxiliary, 53
unfalsifiable, 53

I
Iconicity
in theorematic reasoning, 73
Icons, 131
Idealization, 69
Galilean, 82, 84
Ignorance, 2
and agent's central information, 2
and central information, 127, 128
and epistemic irresponsibility, 191–193
and faking knowledge to preserve ignorance, 192
and peripheral information, 2, 127, 128
and plausibility, 126–129
and "they do not want us to know", 192
as "knowing that we do not know, but not caring to know", 191
as "produced by the construction of epistemically disadvantaged identities", 192
as "we do not even know that we do not know", 191
distributed, 192
epistemology of ignorance, 191
loving, 192
model-based, 42, 43
preservation of, 2
selective, 43, 169, 180, 193
wilful, 192
Ignorance-preserving reasoning, 1, 8, 116
Imagination
and scientific models, 42
Imbert, C., 37
Implausibility
and abduction, 170
and irrelevance, 125–129
Indexes, 131
Individual diagrams
and abduction, 156, 157
in deduction, 156
in problem solving processes, 156
Induction
and abduction, 5, 6, 12
Aristotelian, 92, 93
as leading in, 92, 93
Inductive risk, 19–22, 167
Inference
ampliative, 12
and abduction, 147
Inference to the best explanation, 6, 13

and meta-syllogisms, 130
Inference vs. instinct, 18
Inferential problems, 120–124
Infinitely remote falsehoods, 59
Infinitesimals, 41
Information dissemination, 167
Information sensitivity
of abductive inferences, 138
Innovation ASAP, 174–176
Inputs and outputs
of inferences, 137–139
vs. premisses and conclusions, 120–124, 137–139
Instinct, 15
and abduction, 15–18
Instinct vs. inference, 18
Instrumental abduction, 8
Interdisciplinarity, 164, 165
Internal assimilation
and logic programs, 144, 145
Inventio medii, 130
In-vitro models
and fictions, 72–74, 76, 78
Irons, J., 188
Irrelevance
and abduction, 170
and implausibility, 125–129

J
Jeffrey, R. C., 20
Jennings, R. E., 59
Johnson-Laird, P. N., 155
Jordan, A. M., 184

K
Kant, I., 27, 73
Karasmanis, V., 100–102, 107
Karawajczyk, A., 187
Keil, F., 16
Kelp. C., 37
Khanna, I., 183, 186
Kirsh, D., 40
Kitcher, P., 164
Knowledge assimilation, 145
Knowledge-enhancing abduction, 14, 15, 19, 21, 22, 116
and *arche*-validity, 91–93, 48–56
Knowledge in motion
and eco-cognitive openness, 162–165, 167, 168
and scientific abduction, 162–165, 167, 168
Kölher's monkey, 74
Kourikoski, J., 32, 76
Kowalski, R. A., 4, 144–146
Kralemann, B., 38
Kraus, M., 97, 99, 100, 109, 110
Kuhn, T., 55, 58, 77, 164
Kuipers, T. A., 4, 136
Kuorikoski, J., 37

L
Labelled deductive systems, 152
Lakatos, I., 53, 55, 164, 170
Laland, K. N., 18
Lanigan, R. L., 110
Large database
and scientific method, 187–191
Lattmann, C., 38
Lazonick, W., 166
Leading away
as abduction, 92, 96–107, 119, 150
Leading in
as induction, 92, 93
Leibniz, G. W., 41, 42
Leo Chang, P., 183
Lestel, D., 148
Leuschner, A., 20, 21, 168
Levy, A., 42, 131
Leyton, M., 149
Liberal arts education
and neoliberalism, 169
Light, R., 164, 165
Livio, M., 126
Liz, M, 77
Locked reasoning strategies, 189
Logic
and constructions, 100–107
and dialectics, 102, 103, 105
and distributed cognition, 156
and geometry, 100–107
and the EC-model of abduction, 120–131
eco-cognitively disciplined, 135–138
of abduction, 135–138
Logical agents, 149
Logical reasoning
as a discursive process, 156, 157
Logic of abduction
and abstractness, 150
and Benacerraf's dilemma, 142–144
and multimodality, 139
and rigor, 151
and the modification of its language and rules, 151

and the multimodality of its language and rules, 151
anthropomorphization of, 138, 139
distributed, 142–144
does not maximize memorilessness, 151
naturalization of, 140, 141
Logic programming, 147
Logic programs
and external observation, 144, 145
and internal assimilation, 144, 145
as agents, 144, 145
as information-sensitive, 144, 145
Longino, H. E., 162–164
Longo, G., 148, 187, 188, 191
Loving ignorance, 192
Lukaszewicz, W., 14
Lume naturale
and Galileo, 4, 15, 16
Lundberg, J. M., 175

M
Mackonis, A., 10
Maglio, P., 40
Magnani, L., 2, 4, 6, 8, 10, 11, 14, 18, 20, 22, 26, 27, 32, 38, 48, 52, 56, 60, 68, 69, 83, 96, 101, 110, 121, 122, 127, 128, 131, 136, 147, 156, 173, 174, 189, 207
Mäki, U., 32, 75, 78–80
Manders, K., 76, 105
Manifest model, 36
Manipulative abduction, 11, 62
and deduction, 60–63
and mathematics, 60–63
Marietti, S., 131
Marion, M., 108
Marketing technoscientific results, 165–168
Material validity, 90, 122
Mathematical discovery, 60, 62
Mathematics
and deduction, 60–63
and manipulative abduction, 60–63
Matter
and mind, 16
Maximization of changeability of inputs and outputs, 138
Maxwell, J. C., 49
Mayer, J. R. von, 49, 51
Meheus, J., 4, 136
Mental models, 155
Meredith, L., 178–180
Meynell, L., 42
Michaels, D., 22
Michelson, A. A., 53
Middle terms, 89, 97–100, 131, 132
and abduction, 100–107
as constructions, 100–107
Military intelligence, 67
Miller, D., 185
Miller, G. A., 81
Mill, J. S., 162, 211
Mind
and matter, 16
Minimality
and abduction, 4
Mizrahi, M., 31, 34, 74
Model-based abduction, 147
Model-based ignorance, 42, 43
Model construction, 155
Models, 31–35
Model-theoretic approach to logic
and pragmatic approach to logic, 145
Moral epistemology, 175
Morality
and cognition, 26–28
and tracking human behavior, 26–28
in the predictability of human behavior, 26–28
Moreno, G. A., 172
Morley, E. W., 53
Morrison, M., 60, 76, 77, 79, 80
Multidisciplinarity, 164, 165
Multimodal abduction
and traditional deductive proofs, 154–156
Multimodality, 149
Multimodality of logic, 139
Mumma, J., 76, 105

N
Naturalization
of logic, 121, 122
of the logic of abduction, 140, 141
Naturalized Logic (NL), 96, 140, 141
and its naturalistic account of normativity, 141
and the negation of the priority of deductive validity, 141
as a data-rich logic, 140
as agent-centered, 140
as empirically sensitive, 140
as relationally pluralistic, 140
Naylor, R., 32
Necessity

and deduction, 92
Negation as failure, 52, 69
and conventionalism, 52
Negative freedom
and positive freedom, 167
Neoliberalism, 166, 167, 177–179, 181, 186
and eco-cognitive openness, 193
and globalization, 178
and liberal arts education, 169
Neopositivism, 48
Nersessian, N. J., 36, 37, 66, 84
Newton, I., 33
Nguyen, J., 68
Niiniluoto, I., 154
Nominalism
and conventionalism, 50
Non-Euclidean geometries, 101
Non-explanatory abduction, 8
Nonmonotonicity, 95, 139
Nonmonotonic reasoning, 14
Non-plausibilist abduction, 48
Nous, 93

O
Odling-Smee, F. J., 18
Okada, M., 157
Olver, I., 172
On-line manipulative abduction, 39–42
Optical illusion
of logical reasoning as a discursive process, 156, 157
Optimization of eco-cognitive situatedness, 135–148, 162–165, 167, 168
and academia, 182–187
and corporations, 182–187
and creative abduction, 182–187
Oracles, 176
Origins of truth, 93–96
Orphan drugs, 183
Otte, M., 98
Outsourcing of biomedical research, 176, 181, 182

P
Paavola, S., 17, 18
Papadopoulos, G., 173
Pappus, 101
Paraconsistency, 7
Parke, E. C., 37
Park, W., 11, 39, 127
Paul, S. M., 173
Peirce, C. S., 1, 2, 4–6, 8, 9, 12–19, 38, 39, 42, 48, 57, 61, 62, 72, 73, 92, 95–97, 100, 105, 107, 109, 110, 116, 119, 131, 141, 147, 152, 155, 206–208, 210, 212, 213, 216
Perception, 38
and abduction, 8, 9
Perceptual abduction, 9
Perception-action common coding, 39–42
Peripheral information
and abduction, 127, 128
and ignorance, 127, 128
Pharmaceutical research
and epistemic integrity, 177–182
Philanthropic groups
and science, 169
Phillips, J., 99
Philoponus, J., 130
Piazza, M., 125
Planck, M., 54
Plato, 100–106, 117, 119, 130
Plausibility, 92, 124
and ignorance, 126–129
and relevance, 120–131
in a diachronic dimension, 126–129
strategic, 52
Playfair, J., 101
Poincaré, H., 48–53
Poitras, G., 178–180
Pons Asinorum, 130, 131
Popper, K. R., 53, 55, 58, 59, 77, 170, 185
Porisms, 101, 104
Pors, K., 184
Portides, D., 31, 78, 84
Positive freedom
and negative freedom, 167
Possibility, 92
Practical agents, 149
Practical reasoning
and scientific reasoning, 17
Pragmatic approach to logic
and model-theoretic approach to logic, 145
Prawitz, D., 121, 125
Precompetitive collaborations, 184–187
Predictability of human behavior
and morality, 26–28
Prediction
and tracking the external world, 22–24
Premisses and conclusions
vs. input and output, 120–124
Probability, 92
Proclus, 102, 105, 119

Proctor, R. N. 22, 169
Properties
co-exact, 106
Publication bias, 168
Pulcini, G., 125

Q
Quine, W. V. O., 121

R
Rabelais, F., 130
Raftopoulos, A., 38
Ramsey, F., 13
Rawls, J., 177
Reduction
and *reduction ad absurdum*, 104
reduction ad absurdum, 104
Reilly, C., 175
Reinhart, C., 188
Reiss, J., 164, 178, 182
Relevance, 124
and agenda, 128
and ignorance, 126–129
and plausibility, 120–131
in a diachronic temporal dimension, 126–129
Reliabilism
and abduction, 13
Religion
and science, 170
Remes, U., 101, 154
Rescher, N., 17
Research and Development (R&D), 165, 174, 179
Resemblance
and counterinduction, 78–81
Reward and punishment
and the enhancement of knowledge, 19
Rivera, F. D., 6
Robinson, A., 42
Robotics, 190
Rogoff, K., 188
Rosales, A., 32, 56, 70, 71
Rossi Becker, J., 6
Rouse, J., 69
Rowbottom, D. P., 37
Rudner, R., 20
Rules of interrogation, 107–109
Russell, B., 59, 156

S
Sabre, R. M., 110
Saito, K., 104
Sarsi of Siguenza, 86
Sax, M., 187
Schiebinger, L., 169
Schotch, P. K., 59
Schurz, G., 147
Science maximize abducibility, 135–148
Scientific abduction
and knowledge in motion, 162–165, 167, 168
Scientific method
and big data, 187–191
and large database, 187–191
Scientific models
abstract, 36
and animal models, 171
and dynamic aspects of scientific enterprise, 74, 76, 78
and imagination, 42
and mathematics, 60
and semiosis, 60
and static aspects of scientific enterprise, 74, 76, 78
and the demarcation problem, 57–59
as constitutive of new scientific frameworks and empirical domains, 55, 58
as credible worlds, 32
as distributed, 36–39
as epistemic actions, 32
as epistemic weapons, 65–69
as external systems, 37
as *façons de parler*, 69–72
as fictions, 31–35, 66, 69–72, 86
as functional, 32
as idealizations, 31
as make believe, 32
as parables, 32
as pedagogical devices, 32
as revealing capacities, 32
as surrogates, 32
external, 38, 41, 63
for explanatory functions, 32
for testing hypotheses, 32
ideal, 36, 69
manifest, 36
mental, 155
the inferential function of, 55
Scientific reasoning
and practical reasoning, 17
Sedol, L., 189
Select and Test Model (ST-model), 7

Selective abduction, 7, 11, 180
Selective ignorance, 43, 169, 180, 193
Selten, R., 156
Semantic tableaux, 138, 144, 146, 154, 155
Semiophysics, 63
Semiosis, 60
Seth, A. K., 24
Shah, S., 182
Shelley, C., 171
Shimojima, A., 150
Shkreli, M., 172
Shrader-Frechette, K., 177
Shulman, S., 168
Sidoli, N., 104
Signs
  and abduction, 109–111
  and enthymemes, 109–111
Simple abduction, 13
Simson, S., 101
Situatedness
  and dynamic arguments, 95
Smadya, I., 156
Social epistemology, 164
Socrates, 101–106, 109
Spinello, R. A., 177
Static aspects of scientific enterprise
  and dynamic aspects of scientific enterprise, 74, 76, 78
  and scientific models, 74, 76, 78
Static view of scientific models
  and dynamic view of scientific models, 57–59
Steel, L., 32
Stefanov, A., 77
Stevenson-Wydler Technology Innovation Act, 166
Stjernfelt, F., 41
Straight necessitation, 94
Strategic rules, 155, 156
  and abduction, 156
  and creativity, 155
  and definitory rules, 155, 156
Strategies, 13
Suárez, M., 32, 35, 55, 56
Subconceptual levels of cognition, 150
Sufficiency, 92
Sugden, R., 32, 74, 79, 80, 84–86
Swoboda, N., 149, 150
Syllogisity, 91, 95, 118
Syllogismos, 91, 93–100, 118
Syllogisms, 107–109
  of the first figure, 132
  of the second figure, 131
  of the third figure, 132
Syllogisms-as-such, 95
Syllogisms-in-use, 95
Syllogistic logic, 108
Syllogistic logic vs. dialectical logic, 107–109
Syllogistic necessitation, 94
Symbiotic model of innovation, 184–187
Symbols, 131
Synechism, 15, 18

T
Tartaret, P., 130
Technoscientific results
  and market, 165–168
Tendero, P.-E., 191
Testability
  and abduction, 5
Tetris, 40
Thagard, P., 74
The argument of imperfect fit
  and scientific models, 33–35
Theissier, B., 148
Theistic hypothesis, 18
Third way reasoning, 96
Thom, R., 63, 67, 72, 74
Thompsen Primo, T., 189, 190
Thomson, J. J., 55
Thomson-Jones, M., 32, 38, 75
Thought experiment, 82–85
Thought experiment of Galileo, 82
Tiercelin, C., 18
Tolstoy, L., 69
Toon, A., 32, 37, 41
Toth, I., 52
Tracking human behavior
  and morality, 26–28
Tracking the external world, 23, 24
  and prediction, 22–24
  through scientific knowledge, 25
Trade Related Intellectual Property Rights, 172
Traditional deductive proofs
  and multimodal abduction, 154–156
Traditional demonstrative inferences
  and abductive inferences, 148–151, 153–157
  are abstract, 148
  are characterized by a maximization of memorylessness, 149
  are rigorous, 148
  are symbolic, 148

Tragedy of the anticommons, 170, 184
Trajkovski, M., 131
Transdisciplinarity, 164, 165
Tuana, N., 169, 191
Turing Universal Practical Computing Machines, 153
Turing, A. M., 153
Turner, E., 181

U
Unconscious cognition, 39
Understanding
and distributed scientific models, 37

V
Vaihinger, H., 35
Validity, 91, 118
material, 90, 122
recognizing, 118, 119
Van Benthem, J., 137, 153
Van Hilten, L., 168
Vázquez, M., 77
Vorms, M., 38
Vortices
Cartesian, 126

W
Walton, K. L., 41
Weisberg, M., 31, 77, 82
Whitehead, A. N., 42
Whyte, K. P., 162
Wilful ignorance, 192
Wilholt, T., 20
Wittgenstein, L., 157
Woods, J., 1–7, 9, 15, 31, 32, 48, 53, 54, 56, 59, 70, 71, 77, 91–96, 100, 108, 116–119, 121, 123, 128, 129, 131, 135, 136, 138, 140, 142, 144, 151–153, 155, 210

Y
Yerkovich, S., 26
Ylikoski, P., 32, 37, 76

Z
Zardini, E., 125