COMPLEMENTING STANDARD ABDUCTION. Anticipative Approaches to Creativity and Explanation in the Methodology of Natural Sciences

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1) THE STRUCTURE OF MY CONTRIBUTION

INTRODUCTION: The debate on the context of discovery in the philosophy of science
PART I: The role of standard abduction in the methodology of natural sciences
PART II: Crossing the frontiers of abduction. Theoretical preduction as a deductive creative practice in natural sciences
PART III: Completing the view on abduction. Sophisticated abduction in theoretical sciences.
CONCLUSION

2) THE DEBATE ON CREATIVITY IN THE METHODOLOGY OF SCIENCE

Is the question of how a new idea is introduced into science, a hypothesis for instance, relevant to the methodology of science? There are two different answers to this question:

1. The negative answer: the *Popper-Reichenbach approach*, according to which the philosophy of science is concerned only with questions of justification or validity. Thus the way in which scientists find theories is methodologically irrelevant: the only relevant thing is how they do test them.

2. The positive answer: The *Peircean approach*

3) SOME CONSEQUENCES OF THE NEGATIVE APPROACH

Following Popper-Reichenbach's view, the methodology of science has focused almost exclusively on synchronic or systematic aspects of science (the justification context), and has neglected for decades the issues of conceiving new ideas (the discovery context). According to the official view, science exclusively applies the deductive testing of hypotheses (e.g. Popperian tests).

Nonetheless, in some natural sciences, for instance in geology, we may find the following viewpoints: Dan McKenzie, one of the creators of the plate tectonics model, confesses (2001:185) that "hypothesis testing in its strict form is not an activity familiar to most earth scientists", and John Sclater (2001: 138) affirms that "Earth scientists, in most cases, observe and describe phenomena rather than conducting experiments to test hypotheses." Thus, deductive testing of hypotheses is not the exclusive methodology of natural sciences.

Moreover, the neglect of the context of discovery by the official philosophy of science has since the 1970s been taken over by cognitive scientists and AI researchers, who have developed computational models of scientific creativity; indeed, they have developed a *computational science of scientific discovery* actually (H. Simon, P. Langley etc).

4) OBSERVATIONAL AND THEORETICAL NATURAL SCIENCES

If we recognize the existence of sciences that do not apply deductive hypothesis testing, then we might accept the distinction between *observational* and *theoretical* sciences in the realm of natural sciences.

- Observational natural sciences are predominantly empirical. They rely on experience, on observation, they apply abduction – inference to the best explanation (IBE) – as a discovery practice, and they do not implement any Popperian deductive testing of hypotheses, only additional evidence tests.
- Theoretical natural sciences rely both on ***abduction*** and ***preduction*** for the introduction of novel hypotheses into science. A typical example of theoretical natural science is mathematical physics.
- Finally, in theoretical natural sciences abduction can be both: standard and sophisticated.

5) PART I: STANDARD ABDUCTION IN THE METHODOLOGY OF SCIENCE.

Thirty years before Popper and Reichenbach neglected the relevance of the processes of conceiving or inventing scientific hypotheses, Charles Peirce had taken up a position on the processes of forming or devising explanatory scientific hypotheses.

Peirce's basic idea was very simple: more often than not scientists stumble over unexpected, surprising, striking facts or phenomena. They try to propose or to introduce new hypotheses which, if true, would account for them.

Peirce gave the name *abduction* to the logical operation of introducing new ideas into science: "All the ideas of science come to it by the way of abduction. Abduction consists in studying facts and devising a theory to explain them" (CP, 5.170).

6) TWO SIDES OF STANDARD ABDUCTION

Abduction has two sides. I completely agree with Lorenzo Magnani (2001:17-18, 2007:294) that abduction both generates plausible hypotheses and that successful abduction provides best explanations of facts.

Gilbert Harman (1965: 88) equated abduction with *inference to the best explanation*, and since the late 1970s abduction has been, for the methodology of science inference to the best explanation.

Paul Thagard (1978: 77), for instance, recognizes that "Inference to scientific hypotheses on the basis of what they explain was discussed by such nineteenth-century thinkers as William Whewell and C. S. Peirce, … To put it briefly, inference to the best explanation consists in accepting a hypothesis on the grounds that it provides a better explanation of the evidence than is provided by alternative hypotheses."

And John Josephson (1994:5) claims that "*Abduction*, or *inference to the best explanation*, is a form of inference that goes from data describing something to a hypothesis that best explains or accounts for the data."

7) ABDUCTION IN THE HISTORY OF SCIENCE

Indeed, abduction in its both aspects – as creative generation of plausible hypotheses and as IBE – has been widely applied in the natural sciences:

- Ancient astronomy applied abductive reasoning in order to model planetary movements by means of geometrical models.
- One of the most celebrated abductions was Kepler's postulation of the elliptic character of Mars' orbit (Peirce CP 1.72, 1.73, 1.74; Hanson 1958, 84-85).
- A particularly interesting case of abduction, to be presented later here, is Alfred Wegener's (1880-1930) *continental drift hypothesis* as defended in his *Die Entstehung der Kontinente und Ozeane*, 1915.
- Darwin's evolutionary hypothesis in *On the Origin of Species by Means of Natural Selection*, 1859: "we accept the Darwinian theory of evolution by natural selection as what Peirce called an 'abduction', or what has recently been called an 'inference to the best explanation'" Putnam (1981: 198)
- Ernest Rutherford's *atomic planetary model* was abductively postulated in 1911 on the basis of the alpha particles scattering experiments. Etc, etc

8) ABDUCTION IN OBSERVATIONAL SCIENCES I. PALEOANTHROPOLOGY

From a methodological viewpoint, palaeoanthropology follows the pattern of a typical empirical science: the recognition of surprising facts, abduction by elimination of mutually exclusive hypotheses, hypothesis revision in the light of additional data, and the beginning of a new cycle. Two examples:

James Noonan, Pääbo *et al.* (2006), in a paper on the comparison of the genomes of Neanderthals and modern humans, claim that "Our knowledge of Neanderthals is based on a limited number of remains and artefacts from which we must make inferences about their biology, behavior, and relationship to ourselves."

Carlos Lorenzo (2005: 103) affirms that "Philogenetic trees are only evolutionary hypotheses built upon a continuously changing empirical basis. It is usual that these hypotheses are tested, and modified, if necessary, on the grounds of new data."

9) FOR INSTANCE: THE POSTULATION OF A NEW HOMININ SPECIES, *Homo antecessor*

1. The surprising fact: The 1995 discovery, at Sierra de Atapuerca, Spain, of a part of the facial skeleton of a young man – the *Gran Dolina Boy* – of an age of nearly 800 kiloyears.
2. This fossil showed neither the primitive features of *Homo ergaster* nor the derived characters of *Homo heidelbergensis* – 500 kiloyears old – which were inherited by *Homo neanderthalensis*.
3. Moreover the skull capacity of the *Gran Dolina Boy* – about 1000 cc, considerably bigger than that of the best preserved skulls of *Homo ergaster* – provided an excellent reason for not considering it to be a member of *Homo ergaster*.
4. Furthermore neither could the *Gran Dolina Boy* be a representative of *Homo erectus*, since this is mainly distributed throughout Asia (as well as in Israel and in Georgia), and these fossils are considerably older.
5. Conclusion: The *Gran Dolina Boy* could only belong to a new species, *Homo antecessor*: "a common predecessor of both the evolutionary line that in Europe led to *Homo neanderthalensis* and of the evolutionary line that in Africa led to the modern populations of *Homo sapiens."* (Bermúdez de Castro 2002: 35)

10) ABDUCTION IN OBSERVATIONAL SCIENCES II. THE EARTH SCIENCES. THE CASE OF THE *CONTINENTAL DRIFT* HYPOTHESIS I

The postulation of this hypothesis has proceeded – confesses Alfred Lothar Wegener (1966:167) – in a purely empirical way: "by means of the totality of geodetic, geophysical, geological, biological and palaeoclimatic data. … This is the *inductive method*, one which the natural sciences are forced to employ in the vast majority of cases."

(Note: the name and the logic and philosophy of *abduction* was completely unknown in 1915, the year of the first edition of *Die Entstehung der Kontinente und Ozeane*.)

11) THE CASE OF THE *CONTINENTAL DRIFT* HYPOTHESIS II

The huge amount of data supporting Wegener's hypothesis is summarily presented here:

1. *Geodetic data*: Observation, on the basis of astronomical, radiotelegraphic and radio-emission measures, of the continuous separation of Europe and America.
2. *Geophysical data*: Compatibility of the *Fennoscandian rebound* and the *isostasy* hypothesis with lateral continental displacements.
3. *Geological data*: Affinities between the plateaus of Brazil and Africa, and between the mountains of Buenos Aires and the Cape region, etc.
4. *Palaeontological data*: The distribution of the Glossopteris flora – a fern fossil register – in Australia, South India, Central Africa and Patagonia, and of Mesosaurus in Africa and South America
5. *Palaeoclimatical data*: The Spitzberg(en) Islands, nowadays affected by a polar climate, must have enjoyed a much warmer climate in the Mesozoic and in the Palaeozoic.

12) ABDUCTION IN THEORETICAL NATURAL SCIENCES I. AMAZING DISCOVERIES IN ASTROPHYSICS: THE CASE OF DARK MATTER

Between the years 1932-1933, Jan Hendrik Oort (1900-1992) and Fritz Zwicky, working independently from each other, found out that stars orbiting at remote distances around their galaxies' centres do move more quickly than expected.

According to Kepler's Third Law $P^2 = \left(\frac{4\pi^2}{G_N M} \right) D^3$

the orbital velocity of the star should behave like $v_{orb} \propto \sqrt{1/D}$

i.e.: $v_{orb} \propto D^{-1}$.

This means that it is inversely related to the star's distance: the larger the distance, the smaller the star orbital velocity.

Instead of concluding that Kepler's Law is wrong, physicists hypothesized that a much greater quantity of matter must exist than that which is being directly observed, and which is responsible for the rapid orbit of faraway stars. They called it *dark matter*.

13) ABDUCTION IN THEORETICAL NATURAL SCIENCES II. AMAZING DISCOVERIES IN COSMOLOGY: THE CASE OF DARK ENERGY

In 1998, observations of supernovae of type A (Ia class), situated 4300 Mpc (mega parsec [1 parsec = 3.26 light years]) away from us, show that they are more distant than would be expected if the Universe were to contain only matter – both ordinary, baryonic, or dark matter – since the gravitational attraction would slow down its expansion.

These observations thus suggest that the Universe is not only expanding, but that it is also accelerating.

In order to provide an explanation for this unexpected phenomenon, physicists proposed the hypothesis of the existence of some *dark energy*. For this discovery Saul Perlmutter, Brian Schmidt and Adam Riess were awarded the Nobel Physics Prize in 2011.

14) PART II: COMPLEMENTING ABDUCTION. THE ROLE OF PREDUCTIVE REASONING IN THE CREATIVE PROCESSES OF THEORETICAL NATURAL SCIENCES

According to Peirce (CP, 5.145) "Induction can never originate any idea whatever. No more can deduction." Indeed, "deduction merely evolves the necessary consequences of a pure hypothesis" (CP, 5.171)

My main concern is: *Can deductive reasoning be used in the context of scientific discovery?* My answer will be: Yes, it can.

I maintain that in the methodology of theoretical physics, we can implement deductive reasoning in the context of discovery, beyond its ordinary uses in the context of justification. This is possible because theoretical physics uses mathematics as an indispensable tool.

Theoretical physicists apply at will Leibniz's principle of *substitutio salva veritate*: dimensional analysis guarantees *substitutio salva legalitate*, i.e. the legitimacy of the undertaken substitutions.

Thus a new form of reasoning in scientific methodology, which I call *theoretical preduction* or simply *preduction*, can be identified.

15) ARTHUR EDDINGTON ON THE KNOWABILITY OF STELLAR INTERIORS

"At first sight it would seem that the deep interior of the sun and stars is less accessible to scientific investigation than any other region of the universe…, the interior of a star is not wholly off from such communication. A gravitational field emanates from it …; further, radiant energy from the hot interior after many deflections and transformations manages to struggle to the surface and begin its journey across space. From these two clues alone a chain of deduction can start, which is perhaps the more trustworthy because it is only possible to employ in it the most universal rules of nature –the conservation of energy and momentum, the laws of chance and averages, the second law of thermodynamics, the fundamental properties of the atom, and so on. There is no more essential uncertainty in the knowledge so reached than there is in most scientific inferences." (*The Internal Constitution of Stars.* Cambridge Univ. Pr, 1926:1)

16) SOME FEATURES OF THEORETICAL PREDUCTION

1. *Preduction* consists in resorting to the available results of theoretical physics as a whole, in order to *anticipate* new ideas by mathematical combination and manipulation of these results, in a form which is compatible with dimensional analysis – although not every combination need be heuristically fruitful.
2. The results postulated *methodologically* as premises proceed from differing theories, and any accepted result can serve as a premise – on the understanding that *accepted* does not imply *accepted as true.*
3. This suggests the notion of a hypothetic-deductive method. Indeed, *preduction* is an implementation of the deductive way of reasoning.
4. The specificity of preduction is that it is an extension of deductive reasoning into the contexts of scientific discovery (and explanation).
5. Since the results, which are the premises of the preductive way of reasoning, derive from different theories, preduction is *transversal* or *inter-theoretical* deduction.
6. This is what makes it possible to anticipate new ideas in physics.
7. Physicists apply preductive reasoning in a spontaneous way in order to anticipate as yet unavailable ideas, hypotheses or theoretical results.

17) INTERIOR STELLAR MODEL

The *discovery* of the interior structure of main sequence stars amounts to preducing a theoretical model of the stellar interiors. This model consists of five basic differential equations: Hydrostatic equilibrium, mass conservation, interior luminosity, temperature gradient for radiative transport and adiabatic convection (Cfr. Ostlie & Carroll 1996: 365):

$$\frac{dP}{dr} = -G\frac{M_r \rho}{r^2}$$
$$\frac{dM_r}{dr} = 4\pi r^2 \rho$$
$$\frac{dL_r}{dr} = 4\pi r^2 \rho \varepsilon$$
$$\frac{dT}{dr} = -\frac{3}{4ac}\frac{\bar{\kappa}\rho}{T^3}\frac{L_r}{4\pi r^2}$$
$$\frac{dT}{dr} = -\left(1-\frac{1}{\gamma}\right)\frac{\overline{m}}{\kappa}\frac{GM_r}{r^2}$$

18) THE PREDUCTIVE PROCESS OF THE STELLAR INTERIOR MODEL

The idealisations needed for hydrostatic equilibrium are those of a spherically symmetric and static star. The corresponding *preductive* procedure consists in the *combination of three theories*: Newtonian mechanics (second and third laws, and the universal gravitation law), classical statistics mechanics (the Maxwell-Boltzmann distribution of the ideal gas pressure), and quantum physics (Planck's radiation law of the radiative pressure of a black body), being the total pressure the combination of both the ideal gas pressure and the radiation pressure: $P = \rho kT / \overline{m} + (1/3)aT^4$.

The idealisations, assumed for the obtaining of the temperature gradient, are also that of a static sphere with black body conditions plus the conditions of adiabatic expansion. The corresponding *preductive* procedure consists in the *combination of following disciplines*: classical physics and quantum physics for the temperature gradient of radiative transfer (combination of the equation of radiative transfer with the equation of the black body radiation pressure); and classical statistical mechanics and thermodynamics of adiabatic processes (for the obtaining of the temperature gradient of a monoatomic ideal gas expanding adiabatically).

The full account of the theoretical model of stellar interiors is completed with the mass conservation equation and the equation of the luminosity gradient, with the latter depending on the energy generated by both nuclear and gravitational processes.

19) PART III: SOPHISTICATED ABDUCTION

In PART II have focused mainly on the creative aspect of abduction.

When concerned with *inferences to the best explanations*, sometimes the available empirical data do not directly suggest an attractive explanation, as we might imagine they would for Rutherford's postulation of the planetary atomic model or Wegener's continental drift hypothesis.

Very frequently, hard (mathematical) work is needed for instance in theoretical physics. In these cases, preductive reasoning serves abduction for the purposes of providing satisfactory explanations for as-yet unexplained constructs.

I say that in such cases, the theoretical explanation takes place *more preductivo*. Since in such cases the inference to the best explanation depends on the implementation of preductive reasoning on the context of theoretical explanation, it is not standard abduction which is being applied here. I name this procedure *sophisticated abduction*.

20) ONE CASE OF SOPHISTICATED ABDUCTION IN THE HISTORY OF PHYSICS: PLANCK'S RADIATION LAW

The search for a theoretical explanation of the black body radiation (Kirchhoff) was one the most urgent tasks theoretical physicists were faced with at the end of the nineteenth century.

With the contributions by Stefan (1879), Boltzmann (1884) and Wien (1894), empirically confirmed by Lumer and Pringsheim in 1897, classical thermodynamics had exhausted its explanatory possibilities.

Further contributions by Rayleigh and Jeans (1900) combining statistical mechanics and electrodynamics were only partially satisfactory (ultraviolet catastrophe).

Finally, in December 1900, Max Planck, combining electrodynamics with Boltzmann's statistical mechanics and with Wien's first law (classical thermodynamics), plus the formal supposition E=hν, produced – preduced – his famous *Black Body Radiation Law.*

Planck's procedure is unquestionably preductive. But since his purpose was to offer a theoretical explanation of a challenging empirical result, Planck provided a Best Explanation of the black body radiation, thus performing a characteristic abductive explanation.

Abduction + preduction= sophisticated abduction

21) FURTHER EXAMPLES OF SOPHISTICATED ABDUCTION

- Einstein's explanation of the photoelectric effect
- Planck's Radiation Law, as it obtains in the framework of Bose-Einstein quantum statistical physics
- The explanation of the variability of *Cepheids* or *pulsating stars*
- The construction of theoretical models for *cataclysmic explosive variables: novae* and *supernovae* (for instance SN1987A).
- The theoretical explanation of neutron stars.
- The theoretical explanation of pulsars. Etc, etc

22) CONCLUSION

- In Part I, have shown the fruitfulness of standard abduction in the methodology of both observational and theoretical natural sciences.
- In Part II, I have crossed the frontiers of abduction for the postulation of theoretical preduction as a deductive practice of creativity in theoretical natural sciences.
- Finally, in Part III, I complete the view on Inference to the Best Explanation by the assessment of sophisticated abduction as a specific form of abductive reasoning that relies on theoretical preduction.
- To sum up: I join the very many contemporary philosophers who have tried to overcome this major error of methodologists over recent decades, that of neglecting the relevance of the context of discovery for the philosophy of science.

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