

Transversal: International Journal for the Historiography of Science, 2 (2017) 20-35

ISSN 2526-2270

www.historiographyofscience.org

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Dossier Pierre Duhem

The French Roots of Duhem's early Historiography and Epistemology

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Abstract:

Pierre Duhem can be looked upon as one of the heirs of a tradition of historical and philosophical researches that flourished in the second half of the nineteenth century. This tradition opposed the naïve historiography and epistemology of the positivist school. Beside the positivists of different leanings such as Littré, Laffitte, Wyruboff, and Berthelot, we find Cournot, Naville, and Tannery, who developed sophisticated histories and philosophies of science focusing on the real scientific practice and its history. They unfolded elements of continuity and discontinuity in the history of science, and enlightened the complex relationship among experimental, mathematical, logical and philosophical components in scientific practice. In Pierre Duhem we find a systematic and vivid interpretation of these meta-theoretical issues, and a meaningful development of a cultural tradition that re-emerged in the second half of the twentieth century.

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Keywords:

Pierre Duhem; historiography; epistemology; experimental practice; theoretical practice; continuism - discontinuism

Received: 27 March 2017. Reviewed: 26 May 2017. Accepted: 31 May 2017.

DOI: <http://dx.doi.org/10.24117/2526-2270.2017.i2.04>

The originality of Duhem's meta-theoretical researches consisted in the interconnection between historical inquiry and philosophical analysis. The complexity of the natural world and the complexity of scientific practice urged him to go beyond the naïve historiography and epistemology of the positivist tradition. In reality, another tradition had already emerged alongside positivism in the second half of the nineteenth century. Some mathematicians had inquired into the actual scientific practice and its history, and had discovered a plurality of theoretical streams, and stagnations or regressions over time. In their philosophy of science, the positivistic rhetoric of relentless progress, and the cult of a simplified and idealised scientific practice gave way to a mature awareness of inescapable shortcomings and dramatic detours in scientific method and its history.

I would like to focus on the positivist and the *critical* traditions, and then on some historiographical

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and epistemological issues Duhem developed in the early stages of his research. He can be looked upon as the direct heir of the second tradition, which had already put forward a critical historiography and epistemology. Although Duhem has been considered as one of the founding fathers of the modern philosophy of science, I would like to interpret him as the most outstanding follower of an already existing tradition. In some specific issues he discussed between 1892 and 1896, we can find some traces of the previous *critical* tradition. Nevertheless, in the papers he published in this time span we do not find explicit references to scientists and philosophers who had previously put forward a critical analysis of scientific practice.² This seems really surprising when we notice that Duhem always mentioned the scientists who had contributed to the establishment of the mathematical thermodynamics he developed in the same years. The fact is that his interests in history and philosophy of science had emerged from his researches in theoretical physics rather than from an autonomous philosophical research on the track of a specific philosophical tradition. Duhem was objectively in debt to some previous scientists and philosophers, but this debt did not correspond to a direct influence. The content of his scientific researches on thermodynamics led him to the rediscovery and reinterpretation of the Aristotelian tradition, whereas his actual scientific practice led him to the rediscovery and reinterpretation of a subtle epistemological tradition that can be traced back to Pascal (Bordoni 2017, 240-241).³

I find that the historiographical thesis that places the emergence of a mature philosophy of science in France in the last years of the nineteenth century should be updated (Brenner 2003, 1, 2, 4-5, and 7-8; Chimisso 2008, 1-2, and 5-6; Knight 2008, vii; Rheinberger 2010, 1 and 3-4; *MPIWG* 2012, 7; Braunstein 2012, 33; Brenner (ed.) 2015, 5-6). A sophisticated philosophy of science emerged quite earlier. Poincaré, Duhem, and Milhaud were the heirs of a tradition that did not manage to produce any institutional effect in the last decades of the nineteenth century but left long-lasting traces in French intellectual environment. We do not find a direct filiation or an explicitly acknowledged line of descent but a conceptual stream that flowed through an adverse cultural context.

The Context

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The last decades of the nineteenth century saw an “industrial and social revolution,” and the spread of new technologies (Barraclough 1964, 17, 36-8, and 40). A process of professionalization of scientific practice, and a process of specialization, took place in those decades.⁴ Both an optimistic and a pessimistic scientism emerged: science represented the suitable solution for solving technological problems, fostering social progress, and “slowing down the deterioration of the human species” (Bowler and Morus 2005, 147-148 and 150; Olson 2008, 253, 274, 277, and 293).

The intellectual trend that can be qualified as *scientism* rested upon two pillars: the unavoidability of human progress, and the close link between scientific and social progress. In the French context, the most radical scientism can be traced back to the six volumes of the *Cours de philosophie positive* that Auguste Comte published between 1830 and 1842.⁵ He coined the expression “*philosophie positive*” in order to qualify his intellectual commitment. His philosophical system was a “*philosophy of sciences*” that encompassed “every kind of phenomena”, social ones included, because all sciences had to be submitted “to a single method”. At least three strong metaphysical commitments supported his ambitious design: first, the rejection of any question that did not deal with a scientific approach to reality, second, the methodological unification among the different sciences, and third, the faith in human progress (Comte 1830, VII-VIII).

² However, it should be specified that the most complex and questionable of Duhem’s concepts, namely the idea that scientific practice aimed at a *natural classification* of material phenomena stemmed from both traditions.

³ On the relationship between Duhem’s thermodynamics and Aristotle’s natural philosophy, see Bordoni 2012b and the tenth chapter of Bordoni 2012c. Bas van Fraassen pointed out the importance of Pascal’s “underground epistemology” in the history of science (van Fraassen 1989, 151). The deep influence of Pascal on Duhem has been stressed by Jean-François Stoffel (Stoffel 2007, 299 and 301).

⁴ The establishment of definite boundaries between science and philosophy was one of the achievements of scientific practice in the late nineteenth century (Ross 1962, 66, and Morus 2005, 3, 6-7, 20, and 53).

⁵ For the polysemy of the word *scientism*, and its connection with the equally plural meaning of the word *positivism*, see Paul 1968, 299, footnote 2. For the origin of the word in the French context, see Schöttler 2012, 253-254.

Comte looked upon his philosophical system as the last stage in the history of civilisation. The first stage corresponded to the dawn of human civilisation, when mankind relied on magic and religion: it was “the theological stage”. The second one, “the metaphysical stage”, corresponded to the emergence and development of philosophy, logic, mathematics, and rational practices in general. The last stage was the *positive* one, and corresponded to a widespread scientific development. Comte ventured to qualify his historiographical framework as a law: “direct observation” proved “the exactness of this law”, and rational considerations suggested the necessity of that law or “positive theory” (Comte 1830, 3-8).

He offered a simplified and idealised account of scientific practice based on the possibility of a sharp separation between science and metaphysics, and on the structural difference between the third stage of science and the previous stages of religion and metaphysics. He underestimated the fact that the founding fathers of modern science pursued metaphysical agendas, and modern science was based on explicit and implicit meta-theoretical beliefs. However *positivism* was both a specific philosophy, which can be traced back to Comte’s *Cours de philosophie positive*, and a broader cultural mood. Moreover, Comte’s philosophy went through different stages, as the historian of philosophy Isaac Benrubi pointed out many decades ago. Comte crossed in reverse order the three stages that would describe the development of Humanity: although he had started from what he considered as the positive stage of mankind, he then “advanced or retrograded to the metaphysical and religious stages” that corresponded to the religion of Humanity (Benrubi 1926, 16-17; Bordoni 2017, 11).⁶

Comte’s *Cours de philosophie positive* had an enduring influence in French-speaking countries and abroad. Even when his positivistic philosophy was judged too radical and dogmatic, the enthusiasm for scientific methods could rely on a wide consensus. We find a milder scientism in the book the British philosopher William Whewell published in 1840, *The Philosophy of Inductive Sciences founded upon their History*. He insisted on scientific progress and the paradigmatic role of physical sciences but paid more attention to history and metaphysics. He found that Comte’s reduction of science “to the mere expression of the laws of phenomena, expressed in formulae of space, time, and number” was “historically false”. To exclude any inquiry into the nature of scientific phenomena would have led us “to secure ourselves from the poison of error by abstaining from the banquet of truth”.⁷ Going beyond Comte’s naïve scientism, Whewell explored the essential tension between the structures of thought and sensorial experiences (Whewell 1847a, v-x, 1, 7, and 14; Whewell 1847b, 321-322, 324, 326, and 329).

In the French context, the expression *philosophy of science* had already been used by the mathematician and natural philosopher André Marie Ampère, and the corresponding meaning was not so different from Comte’s. In the *Essai sur la philosophie des sciences* he published in 1834, Ampère specified that his work dealt with “the analytical exposition of a natural classification of all human knowledge”. The adjective *natural* involved the connection among “the objects of our knowledge”, the essential features of the human mind, and the history of cultural development (Ampère 1834, v-vi, xiii-xiv, xix-xx, xxxi, xxxvi, and xl-xlix).

Ampère was not satisfied with the classification of the *Encyclopaedists*, and followed Comte’s hierarchy that started from mathematics and led to “philosophical, moral, and social sciences” through sciences dealing with inorganic matter and life sciences. At the same time, we find a new, dynamic conception of classification: the progress of science involved a continuous rearrangement of old classifications (Ampère 1834, 2-3, 9-10, 13-15, and 18). The second volume of the *Essai* was published after Ampère’s death. The most eminent of Comte’s followers, the physician, lexicographer, and philosopher Émile Littré, added a celebratory scientific biography, but reminded readers that Ampère himself had regretted not having managed to achieve a more ambitious target, namely a detailed account of foundations and methods of sciences, and a critical analysis of competing theories (Ampère 1843, ix, xiii, lxxxi-vii, and xcii).

In 1848, the English philosopher and logician John Stuart Mill published a long and demanding book,

⁶ In 1930, the historian of science Hélène Metzger remarked that *Positivism* was something more than a mere philosophical school: it was rather one of the essential components of “an atmosphere” or a broader intellectual attitude that branched out in different directions in the nineteenth century (Metzger 1987 [1930], 113).

⁷ Whewell acknowledged that sometimes the borderline between facts and interpretations was vague, and scientists were committed to “*interpreting* the phenomena” rather than merely reporting them (Whewell 1847a, 37, 39-41, 44, 48, and 50).

A System of Logic, Ratiocinative and Inductive, where he put forward a philosophy of science that might be looked upon as an intermediate philosophical approach between Comte and Whewell. In Comte’s “admirable speculations” he found the explicit awareness that the causes of natural phenomena were beyond the understanding of scientists and philosophers: only empirical and mathematical laws were attainable. Nevertheless, he did not agree with Comte on the uselessness of “those scientific hypotheses ... which are unsusceptible of being ultimately brought to the test of actual induction” such as the two hypotheses on the nature of light. (Mill 1848, 172, 209-210, 336, 339, and 433).

Mill’s confidence in the empirical foundation of knowledge put him in contact with Comte and distanced him from Whewell. Where Whewell saw “a conception of the mind, which did not exist in the facts themselves”, or “a principle of connexion”, Mill found that our conceptions were always “conceptions of something which really is in the facts” (Mill 1848, 178-179, 390, 561, 576, and 586).

Two Different Traditions

In 1851, the first outline of a more sophisticated philosophy of science appeared in Paris. The author had gained a reputation as a mathematician who had put forward a daring mathematization of economics.⁸ In 1838, he had published a short book, *Recherches sur les principes mathématiques de la théorie des richesses*, which dealt with “applications of mathematical analysis to the theory of wealth” (Cournot 1838, V, VII-VIII). In 1843, he had published a longer book on statistics and probability, wherein he paid attention to philosophical and scientific foundations (Cournot 1843, III-V, 84, 181-184, and 205-206).⁹

After eight years, in the book *Essai sur les fondements de nos connaissances et sur les caractères de la critique philosophique*, he attempted to go beyond Comte and Ampère’s horizon, and undertook a new and sophisticated analysis of scientific practice. Statistics and probability appeared as the most meaningful link between the formal structures of mathematics and the complexity of phenomena: they could encompass both natural and human sciences (Cournot 1851, tome 1, 18-19, 48, 62-65, 82, and 418-419; Faure 1905, 409-410).¹⁰

Cournot also paid attention to tacit meta-theoretical issues that guided scientific research: the confidence in the permanence of scientific laws over time, the confidence in analogy and induction, and the confidence in the simplicity, unity, symmetry, and beauty of scientific laws. Probability was also at stake in this context, because these issues could not share the certainty of logical deductions and empirical experiences, but could only rely on a certain degree of probability. It was “a *philosophical probability*” that allowed scientists to synthetically grasp “the order and reason of things” (Cournot 1851, tome 1, 92-100, 294 and 308; tome 2, 247-248).

He frequently stressed the difference between science and philosophy, and, at the same time the necessity of a fruitful alliance. He found that science was a progressive practice whereas philosophy inquired into a set of problems that persisted over time.¹¹ According to Cournot, a specific philosophical practice stood beside logical, computational and empirical practices in science. The philosophical component spanned both the interpretation of experiments and debates on scientific methods: in some way, it involved both theoretical and meta-theoretical issues. A purely *positive* science, in the sense of a merely empirical practice, could hardly exist (Cournot 1851, tome 2, 216-217, 228, 234-237, 244, 252-253, 255).

The following year, Comte published what he considered the achievement of his human experience

⁸ On Poisson’s recommendation, Cournot was appointed to a chair of mathematical analysis in Lyon in 1834, and in Grenoble the following year. After becoming Dean in Grenoble, in 1838 he replaced Ampère as General Inspector of Public Education (Moore 1905, 528-535; Martin 2017, 3).

⁹ He had also published *Traité élémentaire de la théorie des fonctions et du calcul infinitésimal* in 1841, and *De l’origine et des limites de la correspondance entre l’algèbre et la géométrie* in 1847. For Cournot’s biography, see Moore 1905, 521-543.

¹⁰ In 1905, Fernand Faure, politician, professor of law, and then professor of statistics in Paris, remarked that Cournot’s researches on statistics passed almost unnoticed because they were “too philosophical for statisticians and too statistical for philosophers” (Faure 1905, 396).

¹¹ Cournot warned against “the overconfidence in the possibility of solving typical philosophical problems inside the scientific context” (Cournot 1851, tome 2, 404).

and intellectual enterprise, the *Catéchisme positiviste*; the same pathway that had led him from a sound scientific practice to “a sane philosophy” was leading him from the latter to “the universal religion”. Both philosophical and political issues were at stake: he opposed his “proven religion” to “an anarchic democracy and a retrograde aristocracy”. Political commitment merged with religious inspiration: the new mankind would have marched towards “the conciliation of order and progress” (Comte 1891 [1852], 1, 4-6, 11, 15-17, 21, 26 and 29).¹²

In the same year, Émile Littré, the most sophisticated philosopher of Comte’s entourage, pointed out the necessity of a social order that could assure wealth, justice, order, and stability. The new positivist *dogma* or “spiritual order” required a new regime or a new social order.¹³ Only “the positive philosophy” could help discover the scientific deterministic laws of human societies in order to inspire, encourage, and accompany social progress (Littré 1852, VI-IX, XXX-XXXII, 15-6, 35-36, 48, 311-312, and 327).

Nevertheless, after Comte’s death (1857), Littré progressively distanced himself from Comte’s *religion of Humanity*. In a long book he published in 1863, Littré undertook the extremely demanding task of making use of “Comte’s method to judge Comte himself”, and rejected Comte’s religious commitment (Littré 1863, III-IV, VI, IX, 667-8, 674, and 677-8). Mill put forward the same criticism in 1865, and regretted that Comte had transformed into “the High Priest of the Religion of Humanity”. He agreed with Littré on the necessity of separating the sound foundations of Positivism from the subsequent mystic drift (Mill 1865, 5, 9, and 125-128).¹⁴

Another English philosopher, Herbert Spencer, opposed Comte’s dogmatism, and focused on scientific knowledge in a more pragmatic way than Mill and Whewell: he was interested in human beliefs from the sociological rather than the logical point of view. A sophisticated criticism and relativism led him to inquire into “tacit assumptions” that many different beliefs had in common. Unlike Comte, Spencer saw “a fundamental harmony” between science and religion: both of them were “constituents of the same mind” that corresponded to “different aspects of the same Universe”. Both science and religion tacitly acknowledged that the comprehension of the world required the continuous effort of going beyond common experiences and appearances (Spencer 1862, 10, 17, 21, and 24).

In Spencer’s text, the key words and the key concepts were *change* and “the relativity of all knowledge”: the mind was moulded by the world, and the comprehension of the world was continuously transformed by the mind. Cycles of evolutions and dissolutions led to a “universal” and “omnipresent” metamorphosis (Spencer 1862, 66-8, 96-97, 122-123, 440, and 489-491).

Naïve versus Sophisticated Philosophies of Science

In the meantime, Cournot had published a book on methods and practices in mathematics, physical sciences, natural sciences, and human sciences, *Traité de l’enchaînement des idées fondamentales dans les sciences et dans l’histoire*. He put forward a detailed analysis of the conceptual structure of *positive* science, in order to make its hidden philosophical foundations emerge. He was also interested in understanding how the emergence of modern science had changed our patterns of explanation. Modern science had emerged when time and history had come into play, when Copernicus and Tycho’s purely geometrical models were transformed into physical models. Recent developments had highlighted the differences among “contents, principles, and methods” of the various sciences, and the pivotal role of life sciences (Cournot 1861, II-VII and 118-122).

General principles were interpretations of present and future experiences rather than necessary consequences of experiences. Scientific concepts involved both science and metaphysics, or rather, “a

¹² Comte frequently insisted on the essential contribution of women and proletarians to social progress, and on them as privileged recipients of his catechism. In the conclusion of the *Foreword*, the references to the most important women of his life are intertwined with the evocation of the Supreme Being (Comte 1891 [1852], 11, 16, 21, 24, 26, 28, and 30).

¹³ See Littré 1852, XXXII: “Voilà un dogme, voilà un régime, voilà un culte qu’il s’agit de développer, de propager, de prouver, d’éclaircir !”

¹⁴ Mill qualified Littré as “the only thinker of established reputation” in French positivist environment (Mill 1865, 126)

shared land” where scientific principles had their natural seat.¹⁵ *Philosophy of science* was the name of the borderland between philosophy and science (Cournot 1861, 179 and 181-183). This third component of scientific practice stood besides mathematics and experiments, and was not submitted to “an experimental proof or mathematical demonstration” (Cournot 1861, 189-190).

Chemistry could not be reduced to physics, and life sciences could not be reduced to physics and chemistry. Chemistry was a science of transformations, and chemical transformations could be violent or marked by a sharp discontinuity (Cournot 1861, 191-2, 208, 210-212, and 214).¹⁶ In a living structure, the action of one part on another was affected by the systematic link with “the structure and the functions of the system” as a whole. Moreover, living species had appeared and then disappeared over time: *Nature* was not compelled “to act always in the same way in the same situations”, and “time was involved in an intrinsic way in the laws ruling Nature” (Cournot 1861, 223, 272-273, 277, and 284).

In 1867, Littré and the mineralogist Gregoire Wyruboff¹⁷ published a booklet on the philosophical relationship between Comte and Mill. Littré insisted on the validity of Comte’s intellectual enterprise, and separated Comte’s philosophical core from his later intellectual decay, which was inconsistent with “his principles and his methods”. Definitely less refined than Littré from the philosophical point of view, Wyruboff defended “the new dogma” of Positivism, and defended Comte against Mill’s criticism: he found that Mill was too pragmatic and not prone to ideological scientism and sharp reductionism (Littré 1867, 5; Wyruboff 1867, 59-62, 68, and 84).¹⁸

The following year, Littré insisted on the concept of “positive science”, wherein every *a priori* was excluded. This naïve epistemology led to a likewise naïve historiography and sociology: the disappearance of metaphysics was looked upon as tightly linked to the disappearance of war and the emergence of industry in the history of mankind (Littré 1868, 11, 31, 39-40, 49-50, and 74).

Nevertheless, it seems that Littré was not enough radical as a positivist. The most radical among them, who had followed Comte even in the late mystic drift, sharply criticised Littré. Jean François Robinet, Comte’s former physician and one of his literary executors, charged Littré with having belittled and betrayed Comte. A political controversy was also involved: Littré was blamed for having endorsed “parliamentarism and plutocracy” (Robinet 1871, 3-4 and 10-14).

Cournot’s anti-reductionist attitude was restated in 1872, in the book *Considérations sur la marche des idées et des événements dans les temps modernes*. It is worth remarking that, in the same year, the renowned German physiologist Emile Du Bois-Reymond claimed that scientific knowledge consisted in “reducing all transformations taking place in the material world to atomic motions”. A strict reductionism led him to a strict determinism: the universe was ruled by mechanical necessity (Du Bois-Reymond 1872, 441-444 and 446).

Cournot’s concept of *chance*, and adjectives such as *accidental* and *contingent* were at the core of his philosophy of history. He stressed that chance did not mean ignorance or unreliability: chance had its laws, and those laws were no less reliable than the laws of physics and astronomy.¹⁹ His probabilistic turn

¹⁵ In 1858, in the book *La métaphysique et la science ou principes de métaphysique positive*, the French philosopher Étienne Vacherot had attempted to revive metaphysics as a free practice of “analysis and critics”, which allowed philosophers to protect themselves against “unreasonable dogmatism and regrettable scepticism”. Metaphysics needed to be updated, and he ventured to “reconcile metaphysics with science” (Vacherot 1858, V-VI, XV, XXXV, 52, and 94).

¹⁶ Different kinds of discontinuity emerged from chemistry: discontinuity in the sense of abrupt and energetic transformations, discontinuity in the sense of qualitative transformations, and discontinuity in the sense of rearrangements of chemical substances in accordance with integer ratios between their weights (Cournot 1861, 215).

¹⁷ Wyruboff, a scholar of Russian origin, got in touch with Littré when attending Comte’s lectures, and in 1867 they founded the journal *La Philosophie Positive*, which was published until 1883.

¹⁸ Wyruboff’s philosophical naivety was also displayed in a booklet he published in 1865. He stated that “every philosophical debate can be reduced to a matter of fact”, and scientific laws were nothing else but a collection of facts that continuously occurred “in the same way under the same conditions” (Wyruboff 1865, 1).

¹⁹ In 1812 the mathematician Pierre Simon de Laplace had published *Théorie analytique des probabilités*, and two years later a less demanding *Essai philosophique sur les probabilités*. In the latter he had claimed that “the most important problems of life” dealt with probability: in his words, “l’induction et l’analogie se fondent sur les probabilités” (Laplace 1825, 1-2). Comte considered the theory of probability as “false sciences”: in general, he did not rely on the application of mathematics to social sciences.

encompassed both necessity and contingency. History could be overturned by sudden revolutions: his historiographical framework rested upon the continuity of ordinary processes and the discontinuity of extraordinary processes or revolutions. During revolutions, apparently meaningless contingencies could lead to long-term effects (Cournot 1872, 1-6).

In reality, Cournot’s historiographical framework involved two different traditions. On the one hand he saw systematic sciences, which had been systematic since the age of Greek civilisation, and had experienced “a revolutionary crisis” in the sixteenth and seventeenth centuries. On the other hand, he saw scattered bodies of knowledge, such as “theories of heat, magnetism, and electricity”, that had preserved their “childish condition” of semi-empirical sciences throughout the seventeenth century and even afterwards (Cournot 1872, 292-294). This historiographical and epistemological perspective was not in tune with positivist historiography and epistemology.²⁰

On the positivist shore, Littré criticised Spencer for having dared to replace the Comtian hierarchical order of sciences with a more pragmatic interconnection, and remarked that ancient civilisations were aware and proud of their past but less interested in their future, whereas “modern civilisations” focused mainly on their future. Actually, it was just Littré and other positivists that celebrated the cult of progress, and underestimated the complex dynamics of historical transformations (Littré 1873a, 13; Littré 1873b, IV-VII).

Although the adjectives *naïve* and *sophisticated* cannot be formally defined, it seems to me that they can help us understand what really happened at the dawn of modern philosophy of science in the second half of the nineteenth century. Naïve approaches can be associated with a simplified account of scientific practice, the celebration of a simplified scientific method, and the uncritical mythology of scientific progress. Sophisticated approaches managed to grasp the complexity of scientific practice, the complex interaction among rational, empirical, and intuitive components in scientific research, the plurality and pliability of scientific methods, and the existence of different scientific traditions which had developed throughout history. However, I must warn against any dogmatic application of my tentative, dichotomic classification: *naïve* and *sophisticated* are only provisional labels that help us interpret the emergence, the history, and further developments of modern history and philosophy of science (Bordoni 2017, 189).

Further Debates

In 1874, the young philosopher Émile Boutroux published his doctoral dissertation, *De la contingence des lois de la nature*, wherein he focused on the relationship between scientific theories and experiences. The emergence and development of natural philosophy had involved the transition from “a purely descriptive science” to “an explicative knowledge”. According to Boutroux, this development had widened the gap between the disorder of experiences and the order of laws that should explain those experiences (Boutroux 1874, 2-4). In Boutroux’ radical anti-reductionism, variability and instability replaced invariance and stability of mathematical laws. Boutroux’ philosophy was not antiscientific but was based on the assumption that sharp reductionism and determinism were not necessary foundations for a natural science. He did not despise science, and kept abreast of recent scientific achievements but he firmly opposed the positivistic trend.²¹

Boutroux’ theses were put forward in a context where positivism was hegemonic; nevertheless, the following year, Cournot published another book where his anti-reductionist attitude was further developed. Nevertheless, his philosophy of science was more cautious and pliable than Boutroux’s. The development of life sciences required a new epistemology: statistics and probability allowed scientists to replace certainty with probability. Cournot pursued a new alliance between determinism and contingency, between the stability of laws and the contingency of facts. In the late 1870s we find that some physiologists and physicians rejected reductionism (Egger 1877, 193-196, 197-198, 200-201, 209-211) but the majority was less cautious than Cournot, and put forward a radical reduction of psychology, anthropology, and sociology

²⁰ It is worth remarking that, in the twentieth century, Thomas Kuhn inquired extensively into the two traditions (Kuhn 1976, 4-22).

²¹ Benrubi stressed that Boutroux’ contingency should not be confused with chance: it was close to the idea of natural freedom, in the sense of free and unpredictable unfolding of natural laws. In other words, contingency occupied the intermediate place between chance and necessity (Benrubi 1926, 154-157).

to brain physiology (Luys 1876, VIII-XI; Boëns 1878, 345-347, 349-354, and 359-360; Boëns 1879, 5-9, and 14-15).

Cournot pointed out the impossibility of getting rid of meta-theoretical practices that “*positivist* philosophers” had discarded together with metaphysics (Cournot 1875, 371 and 373-5). His words echoed what Whewell had written some decades before: he stressed that “a body of purely empirical knowledge is not a real science” (Cournot 1875, 371-376). On the other hand, Pierre Laffitte, one of Comte’s most passionate followers, and the head of the community that accepted the whole of Comte’s doctrine, insisted on empiricism in scientific practice, determinism in history, and the “universal religion” as the necessary achievement of “*western evolution*” (Laffitte 1876, 1, 13-14, 18, and 30)

In the late 1870s, the debates on reductionism were accompanied by debates on determinism, and in both cases the problematic link among mechanics, life sciences, and philosophy was at stake. The mathematician Cournot put forward a sophisticated approach to reductionism, and another mathematician put forward a sophisticated approach to determinism. In 1878, Joseph Boussinesq published the booklet *Conciliation du véritable déterminisme mécanique avec l’existence de la vie et de la liberté morale*. His commitment was mathematical, physical, and philosophical: some differential equations led to “*branch points (points de bifurcation)*”, and a material system could evolve towards unpredictable directions (Janet 1878, 3 and 12-13).

Boussinesq reminded readers that mathematicians and engineers had inquired into concepts such as guiding principle in life sciences. In 1861, the mathematician Cournot had spoken of “a principle of harmonic unity, global direction, and homogeneity”, whereas in 1877 the mathematician and engineer Adhémar Barré de Saint-Venant had introduced a vanishing “trigger action (*travail décrochant*)”, which was not so different from the small amount of force required to pull a gun trigger. Boussinesq specified that a guiding principle was not in need of a corresponding mechanical force, however negligible it might be. Those “bifurcations in the integrals of the equations of motion” offered a structural analogy and a mathematical model for physical instabilities and complex systems such as living structures (Cournot 1861, 364, 370, and 374; Saint-Venant 1877, 421-422; Boussinesq 1878, 31-33; Bordoni 2015, 28-29).²²

It seems that the first mathematician who raised the question of *determinism* in connection with singular solutions of differential equations was really Boussinesq himself, in a brief *Note* he published in the *Comptes Rendus* of the *Académie des sciences* in 1877. In reality, in 1872 Cournot had briefly discussed the instability stemming from a cone in equilibrium upon its top (Cournot 1872, 276). In 1875 Cournot envisaged a more general kind of determinism where both deterministic and non-deterministic processes were submitted to the normative role of mathematics (Cournot 1875, 113-120 and 128). This is exactly the pathway that Boussinesq followed two years later.

Cournot first reflections on foundations and methods of scientific practice were put forward in the 1860s, in an adverse intellectual environment.²³ Still in 1881, after Cournot’s death, in a summary of Comte and Laffitte’s doctrines, Robinet insisted on a naïve philosophy of science which was based on a strict empiricism, and on a naïve historiographical framework wherein Positivism was looked upon as the crowning achievement of “a mental revolution triggered off by Thales and Pythagoras” (Robinet 1881, 6-7 and 10). However, in the same decade, Cournot’s theses reappeared and found new implementations. In 1883, the philosopher and theologian Ernest Naville put forward a sophisticated conception of science as a dynamic body of knowledge rather than a naïve accumulation of empirical procedures and rational truths. On the track of Cournot, whom Naville mentioned only occasionally, we find an epistemology marked by fallibility

²² During the nineteenth century, singular integrals had sometimes attracted the attention of mathematicians. Boussinesq mentioned Siméon Denis Poisson, Jean-Marie Constant Duhamel and Cournot’s, and briefly commented on their texts (Boussinesq 1878, 121-130). In 1841, in the second volume of his *Traité élémentaire de la théorie des fonctions et du calcul infinitésimal*, Cournot had devoted a whole chapter to the subject (Cournot 1841, II vol., 271-292).

²³ According to the historian of philosophy Isaac Benrubi, Cournot’s philosophy eluded any attempt to describe it by means of “a definite summary and a sharp classification” (Cournot 1851, 1 vol., 171-172; Benrubi 1926, 89-90). According to the philosopher François Mentré, Cournot’s *discreetness* was both a personal leaning and an epistemological commitment (Mentré 1905, 483; Mentré 1908, 644 and 646). See Martin 2017, 18: “le style de sa pensée, la prudence et la rigueur avec lesquelles il construit ses analyses n’ont pas la puissance séductrice des grands systèmes de pensée de la tradition occidentale”.

and probability, and intertwined with a dynamic historiographical framework (Navelle 1883, 28, 32-35, 41-47, and 50-55).

According to Navelle, theories represented the pivotal stage in scientific practice: they occupied the “intermediate region” between experimental laws and general principles: that intermediate position was consistent with their nature of “changeable and provisional” entities. Physical laws corresponded to an empirical necessity, and guiding principles corresponded to a rational necessity, whereas theories could only rely on a problematic correspondence between the empirical and rational domains. The dynamic process of emergence, development, and replacement of physical theories was the essential feature of scientific progress: it was just the caducity of theories that protected science from involution and decadence (Navelle 1883, 54-55).

A completely different meta-theoretical attitude can be found in the book the authoritative chemist and influential politician Marcelin Berthelot published in 1886. He focused on “positive science”, which started from facts, and connected them by means of “immediate relations”. Science had led mankind to “the explanation of a huge number of phenomena” merely on the basis of “the coarsest facts”. We find here both confidence in a continuous scientific progress and in a simplified empiricism. Not only could “physics and chemistry be reduced to mechanics”, but also the process of reduction was an empirical necessity rather than a rational option. (Berthelot 1886, V, VII, 4-5, and 9-11).²⁴ The previous year he had published a history of the ancient alchemy. He saw a continuous line of descent that led from antiquity to the late Renaissance. Broad and simplified analogies also emerged: Heraclitus' world-view was associated with modern “transformation of forces and the mechanical theory of heat” (Berthelot 1885, 78-9, 248, 250, 252, 262-265, 267, 271, and 275).

After two years the engineer and mathematician Paul Tannery published a very different history of ancient science, *Pour l'histoire de la science Hellène*: he could rely on mathematical competence, philosophical sensitivity, and the study of ancient languages (Duhem 1905, 216). The accuracy of his historical reconstructions, the careful and detached analysis of original texts, and the presence of a cautious but definite historiographical perspective, makes his history of science a milestone in the intellectual landscape of the late nineteenth century. He did not manage to gain an academic position in France even though he was acknowledged as one of the most competent European scholars in the history of ancient science.²⁵ He contributed to the establishment of a modern history of science, where the adjective *modern* means a history of science that is not pursued from the point of view of present-day scientific theories and beliefs, and does not confine itself to a list of cumulative successes (Brenner 2003, 184-185).

He stressed the necessity of separating “philosophical history” from “scientific history”. Historians of philosophy had naturally leant towards an abstract classification of theories in accordance with modern linguistic and conceptual standards: they had tacitly assumed a sort of ideal continuity between different contexts in order to safeguard the unitary structure of philosophy. On the contrary, a history of science required the analysis of both historical filiations and discontinuities. Another question involved the sources: many original texts had been lost, and the history of subsequent loans and influences had to be analysed. In reality Tannery's history was both a history of original ideas and a history of historical reconstructions and misunderstandings (Tannery 1887a, 10-11, 14, and 18-19).²⁶

²⁴ I find that a short passage deserves to be quoted: “Une généralisation progressive, déduite des faits antérieurs et vérifiée sans cesse par de nouvelles observations, conduit ainsi notre connaissance depuis les phénomènes vulgaires et particuliers jusqu'aux lois naturelles les plus abstraites et les plus étendues.” (Berthelot 1886, 10).

²⁵ For a reconstruction of the events that prevented him from being appointed to a Chair of “Histoire Générale des Sciences” at the *Collège de France*, see Milhaud 1906, 14, Sarton 1948, 30, GUSDORF 1966, 43-4, 62, 98-101, and 104-6, Canguilhem 1979, 63, Stoffel 1996, 416, Brenner 2003, 5 and 101, and Chimisso 2008, 85, fn 1. That chair was looked upon as “a fiefdom of the positivist school (or church)” (Sarton 1938, 690). It is worth remarking that Berthelot had supported Tannery's nomination.

²⁶ On the influence of German history of philosophy on Tannery, and more specifically on the philosophical background of the conception “of history of science as *complementary* to history of philosophy”, see Catana 2011, 517-523. In the same year Tannery also published a book on Greek geometry wherein he stressed that a reliable history of mathematics had to account for “*the events and the causes*” that had led to stages of “*past decadence*” (Tannery 1887b, V-VI, 4, and 8-9).

Mature Historiographies and Epistemologies

The cult of progress, historiographical and epistemological simplifications, and even positivist religion did not fade away. As late as 1891, the editor of a new reprint of Comte’s *positive* catechism paid tribute to “the saint Father” of the new cult, and insisted on the necessity of putting “the cult before the dogma”, namely the religious commitment before the philosophical one. He regretted that some former followers disdained the cult, and confined themselves to a purely philosophical commitment. Not only did he address his criticism to Littré but also to Laffitte, who was charged with having relinquished Comte’s religious and political preaching (Lagarigue 1891, V and VII-XI)

However, Tannery’s style of research left a meaningful heritage, and inspired the mathematician Gaston Milhaud.²⁷ The book he published in 1893, *Leçons sur les origines de la science grecque*, consciously pursued the setting up of a tradition of research that could rely on Tannery’s innovative and authoritative researches (Milhaud 1893, 3-5 and 8-9).²⁸ He stressed the creative power of the human mind: scientific progress consisted of “a linguistic evolution”, or in other terms, “a new explanation of the same phenomena”. This epistemological and historiographical perspective was in conflict with Comte’s positivistic faith in the mighty pressure of *facts* (Milhaud 1893, 11-3, 16-8, and 21-28).

In the late 1880s and early 1890s, we find three different histories of science. At first we find Berthelot’s positivistic history wherein both the march of scientific progress and the naivety of ancient science were emphasised. Tannery’s histories offered a different intellectual landscape: the historiographical reference frame included regressive stages and centuries of stagnation besides progressive trends. Milhaud’s histories were embedded in more explicit historiographical and epistemological frameworks. In contrast with the empiricism of the Comtian tradition, he insisted on scientific practice as an act of mathematisation and linguistic reinterpretation. He attempted to merge history of science and philosophy of science into each other in order to establish a new sophisticated discipline.

Berthelot, Tannery, and Milhaud had been trained in science, engineering or mathematics: their historical and philosophical interests stemmed from a scientific background. This is also true for the younger physicist Pierre Duhem. Since the late 1880s he envisaged a unified mathematical framework for mechanics, thermodynamics, and chemistry, which was based on analytical mechanics, and founded this unified theory on the two principles of thermodynamics. His *Energetics* was different from Georg Helm and Wilhelm Ostwald’s *Energetics*: the latter mainly focused on the universality of the principle of the conservation of energy, whereas Duhem also developed a sophisticated mathematical theory.²⁹

Struggling against the old physics of qualities, modern science had set aside the complexity of the physical world, and put forward a simplified geometrical world. Duhem found that, at the end of the nineteenth century, that complexity, and more specifically dissipative effects, could scientifically be addressed. In terms of the ancient Aristotelian natural philosophy, Duhem’s unified theory could go beyond *local motion* in order to describe all kinds of transformations.³⁰

In the meantime, in the early 1890s, he published the first paper explicitly devoted to meta-theoretical issues.³¹ On the track of Cournot and Naville, he stressed that theoretical physics was something more than the mere alliance between “experience and mathematical analysis”, and allowed scientists to go beyond “the confused and inextricable accumulation” of laws derived by experience (Duhem 1892 (1987), 175). He

²⁷ Milhaud set up “a programme of study in philosophy of science” at Montpellier University in the 1890s. A Chair of *History of Philosophy in its Relation to Science* was then created for him at the Sorbonne in 1909. He was one of the first scholars of Jewish origin to be appointed to a Chair in Paris (Chimisso 2008, 25-26; Brenner and Gayon 2009b, 5).

²⁸ In 1906, after Tannery’s death, Milhaud underscored the deep influence exerted by Tannery (Milhaud 1906, 4).

²⁹ On Duhem’s design of a rational thermodynamics, see Bordoni 2012a, 2012b, 2012c, and 2013. The warm relationship between Duhem and Ostwald cannot be interpreted as an agreement on the meaning of *Energetics*. On their friendship, see Brouzeng 1981, vol. 2, 226-228.

³⁰ Duhem’s theoretical and meta-theoretical design was explicitly unfolded in a book he published in 1903, *L’évolution de la mécanique* (Duhem 1992 [1903]), 199 and 218-219).

³¹ At that time, Duhem was “maitre de conférences” at Lille University: for further biographical details, see Brouzeng 1987, 54.

pursued a critical overview of scientific practice that was not so different from Poincaré’s: I find that the “important differences” between them that some historians and philosophers of science have pointed out should not be overestimated (Brenner 1996, 389-390).³² They criticised the mechanistic view, and were aware of the intrinsic historicity of scientific achievements.

In 1893, Duhem devised a four-level scientific practice that, starting from phenomena, led to mathematical laws, theories, and then a plurality of metaphysical foundations. The four levels were mutually independent: a plurality of theories could stem from a definite set of laws, and a plurality of metaphysical assumptions could stem from a theory or set of theories (Duhem 1893a, 65-66 and 68-71). Once more, we find here a meta-theoretical analysis of scientific theories that had much in common with what Cournot and Naville had previously put forward.

In the same year, he published another paper wherein he introduced the concept of “*natural classification of laws*” that had already appeared in the tradition of French philosophy of science. He qualified the concept as a “perfect and ideal theory” or a “complete and appropriate metaphysical explanation of the nature of material things”. Actual physical theories had to “strive for perfection”, even though perfection could not be attained. This commitment dealt with practices that eluded any definite definition, but Duhem insisted on further, fruitless philosophical specifications (Duhem 1893b (1987), 136-137).³³

Unlike Comte, Duhem’s concept of natural classification made reference to the essential features of a scientific theory. Comte’s natural classification was a relationship among different bodies of knowledge that was in tune with logical and historical genealogies (Comte 1830, 60-61, 76-8, and 86). Cournot’s concept was not so different from Comte’s: a natural classification could grasp some essential features of reality even though he specified that every classification was provisional and incomplete (Cournot 1861, 423 and 425-426). Boutroux rejected the concept itself: every classification was intrinsically artificial (Boutroux 1874, 46).

The following year Duhem focused on experimental practice. Every experiment involved a wider body of knowledge that dealt with general assumptions and concepts, and specific laws: when a science progressed, the role played by theory increased progressively. He put forward the fundamental thesis that “*a physical experiment can never condemn an isolated hypothesis, but only a theoretical system*”. When an expected prediction did not take place, a definite source of the mismatch could not be found. The complex relationship between theory and experiment required a specific sensitivity or some kind of flair that involved “*the esprit de finesse rather than the esprit de géométrie*”. (Duhem 1894a, 153-155, 157, 179 and 188).³⁴

In a following paper, Duhem stressed the extra-logical concept of the *fruitfulness* of a physical theory. Philosophers and scientists have traditionally focused on the concepts of truth or falsity, but truth was the outcome of a historical process, and therefore it was a provisional value. On the contrary, the fruitfulness of a theory was a permanent value (Duhem 1894b, 124-5). On the track of Cournot and Naville, Duhem outlined a complex historiography where both linear progress and cyclical processes were at stake.³⁵ Theories emerged, were successfully upheld, suffered a dogmatic drift, then they were overwhelmed by their flaws, and were eventually replaced by new theories. This process left behind a permanent and valuable heritage: the long-term progress of key concepts, mathematical structures, and empirical laws (Duhem 1894b, 122 and 125).³⁶ A striking metaphor followed:

³² According to Milena Ivanova, both Duhem and Poincaré “expressed a form of structuralism”, namely structural realism, but they adopted different epistemological views with regard to “how knowledge of the structure of the world is reached” (Ivanova 2015, 88). I stress the sterility of philosophical labels when complex research programmes are involved, and when they are applied to historical contexts quite different from the context that has generated those labels. Can we find essential differences between what might be labelled as structural realism or pragmatism in the late nineteenth century?

³³ Going beyond the debates on Duhem as an instrumentalist or a realist, I agree with Sindhuja Bhakthavatsalam that Duhem’s concept of natural classification deals with “the pragmatic rationality of a physicist” (Bhakthavatsalam 2015, 11 and 21).

³⁴ This fundamental thesis is known as Duhem’s holistic thesis: it has been widely discussed and criticised under the misleading label “Duhem-Quine thesis”. I have discussed it in Bordoni 2017, 292-300.

³⁵ Obviously, this is only a brief outline of the emergence of Duhem’s historiographical and epistemological frameworks. A more detailed analysis can be found in my recent book (Bordoni 2017, chapters 8 and 9).

³⁶ The original passage deserves to be quoted: “Ainsi, sous les théories qui ne s’élèvent que pour être abattues; sous

When waves go towards the beach, a water layer ripples and swarms into the dry sand before retreating from the beach giving up its conquest. Waves fade away and let the sand dry up before new waves come one after the other. This superposition of waves that rise and then collapse seems a shallow effort of the sea, an idle combination of foam and noise. Nevertheless, two hours later, the beach that had been trodden by our footsteps is now sleeping under deep water: during the relentless oscillations of water back and forth, the Ocean tide has really gone up (Duhem 1894b, 125).³⁷

Concluding Remarks

Duhem has been looked upon as one of the founding fathers or ancestors of twentieth-century history and philosophy of science in France. My thesis is that Duhem accomplished an intellectual stream that had emerged considerably earlier. The awareness of the complexity of scientific practice and scientific tradition can be found in some historical and philosophical studies from Cournot to Duhem through Naville and Tannery. They had analysed the superposition of cyclic and linear processes, and the persistence of structural continuities throughout scientific transformations.

Cournot, Boussinesq, and Duhem put forward bold mathematisations of new research fields such as economic processes, physical and chemical instabilities, and thermodynamics of irreversible processes. Cournot, Tannery, and Duhem attempted to cast light on the plurality of scientific methods and their histories. Suspicious of every rigid philosophical system, they were in search of a third way between scepticism and dogmatism. The dissemination of Cournot, Naville, Tannery, and then Duhem and Milhaud’s researches in the history and philosophy of science contributed to the professionalisation of the field in the French context, and the establishment of a research tradition that is known as *historical epistemology*.³⁸

Duhem always mentioned the scientists who had contributed to the development of his research field, and put forward a historical reconstruction of those researches. On the contrary, in his historical and philosophical papers we do not find explicit references to previous researches. The fact is that his interests in history and philosophy of science stemmed from his practice in theoretical physics rather than from the study of previous literature. Duhem was objectively in debt to Cournot and other scholars, but a direct influence is questionable. His scientific researches led him to the rediscovery and reinterpretation of Aristotle, and another influence was exerted by Pascal’s epistemology.³⁹ Duhem found in Aristotle the awareness of the complexity of natural processes, and in Pascal the awareness of the complexity of scientific practice.

les hypothèses qu’un siècle contemple comme le mécanisme secret et le ressort caché de l’Univers, et que le siècle suivant brise comme des jouets d’enfant, se poursuit le progrès lent, mais incessant, de la physique mathématique” (Duhem 1894b, 125).

³⁷ Stoffel pointed out the striking analogy between Duhem’s passage and one of Pascal’s *Pensées* on cyclic, historical processes (Pascal 1951, 417; Stoffel 2007, 292-293). I point out the analogy with Naville’s passage on the slow, scientific progress underlying the appearance and disappearance of theories: “Les théories passent, la science demeure: ... à un système détruit en succède un autre dont les conceptions sont plus solides et plus vastes” (Naville 1883, 55).

³⁸ The emergence of this tradition has frequently been associated with Gaston Bachelard and Georges Canguilhem. I find in them some scientist nuances that Cournot, Tannery, Milhaud, and Duhem would not have endorsed. Canguilhem agreed with Bachelard on the existence of “two kinds of history of science”, namely the history of the out-of-date scientific knowledge, and the history of *legitimate* science that satisfied contemporary standards (Canguilhem 1979, 13 and 20-21). At the same time, I must acknowledge that Canguilhem suitably criticised Cournot and Duhem’s unhistorical concept of *precursor*, which had already been criticized by Hélène Metzger in 1939 (Metzger 1987 [1939], 79 and 83).

³⁹ As already pointed out in fn. 2, van Fraassen stressed the role played by Pascal’s epistemology (van Fraassen 1989, 151). Other scholars have stressed the deep influence of Pascal on Duhem [Picard 1922, CXXX and CXXXV-CXXXVII; Paul 1979, 3 and 159; Maiocchi 1985, 13; Martin 1991, 68, 90 and 115; Stoffel 2002, 196 and 345; Stoffel 2007, 299 and 301).

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