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Overcoming mind-brain dualism. Constructivism, interdisciplinarity, and psychophysiological parallelism in Piaget's cognitive evolutionary synthesis

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Overcoming mind-brain dualism. Constructivism, interdisciplinarity, and psychophysiological parallelism in Piaget's cognitive evolutionary synthesis

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Abstract: Throughout his life, Piaget's biological theorizing was poorly understood. This is because, among other probable reasons, his proposals ran contrary to the rediscovery of Mendelian ideas regarding particulate inheritance (and thus also against the later Neo-Darwinian "modern synthesis"). However, his theory was one of the sources of embodied cognition by showing the sensorimotor origins of knowledge. Leaning on cybernetics, he also later tried to bring psychological and neurological models closer together. However, this cross-referencing never produced a dialogue. His perspective is also largely absent from the history of biology. We present two main reasons to clarify this difficult history: a) Genetic Epistemology argued against reductionism at a time when few imagined that construction could offer a bridge notion to arrive at complex systems; b) this perspective raised transdisciplinary questions addressed to specialists focused on their own fields, at a time when inter- and trans- disciplinary communication were uncommon. For Piaget, the different facets of the objects of biology and psychology could be studied from different angles of a common matrix, and this proposal encountered serious obstacles with biologists' work agenda, as we will try to show.

Keywords: Jean Piaget; genetic epistemology; biology; interdisciplinarity

Jean Piaget (1896-1980) is now known for his contributions to psychology[1]. During his early adolescence, however, he had passion for zoology – and especially for molluscs – which led him to work as an assistant at the

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[1] Harry Beilin, *Piaget's enduring contribution to developmental psychology*, "Developmental Psychology", 28, 2, 1992, pp. 191-204; Michael Chapman, *Constructive evolution: origins and development of Piaget's thought*, Cambridge University Press, UK 1988.

Natural History Museum of Neuchâtel. His enthusiasm was so great that, by the age of 17, he had become known as a malacologist and belonged to a network of naturalists who exchanged specimens and expertise[2].

It was in this field that Piaget then carried out the empirical research for which he obtained his doctorate in science in 1918. This thesis, published as a pamphlet, surveyed the molluscs he collected in and near lakes in the Canton of Valais[3]. By referring to the polymorphism of different varieties, Piaget then raised the question of the main "influential factors" in the constitution of different species types: justified groupings of individuals that could be referred-to by a collective name[4]. The key question, which recurred in different guises throughout his later work, was fundamental to understanding both evolution and development: whether the distribution of related adult-types was continuous or discontinuous, and why.

From the very beginning, Piaget hoped Biology would provide the key to unlock these problems related to transformations over time. Influenced by Bergson, among others, on the issues of adaptation and evolution, he tried very early to find a third way between Lamarck and Darwin, as he later mentioned in one of his classical books[5]. Indeed, his last publication as a professional biologist, in 1929, was several hundred pages describing species that discovered new adaptive "solutions" when put into new environments[6]. In other words, he provided the first description of what Waddington later called *genetic assimilation*[7]: the adaptation of an organism to the environment through an adjustment of internal functional mechanisms that later stabilize as heritable morphological features[8].

2 Sara Campanella, *Understanding bio-cognitive change, Jean Piaget and the path to epigenetic innovation*, "Paradigmi", I, 2019, pp. 7-22; Jean-Jacques Ducret, *Jean Piaget savant et philosophe*, Droz, Genève 1984; Fernando Vidal, *Piaget Before Piaget*, Harvard University Press, USA 1994; Jacques Vonèche, *Piaget's first theory of equilibrium*, in Les Smith (ed.), *Critical Readings on Piaget*, Routledge, London-New York 2005, pp. 1-19.

3 Jean Piaget, *Introduction à la malacologie valaisanne. Thèse pour l'obtention du grade de docteur en sciences*, Aymon, Sion 1921.

4 J. Piaget, C*orrélation entre la répartition verticale des mollusques du Valais et les indices de variations spécifiques*, "Revue suisse de zoologie", 28, fasc. 7, 1920, pp. 125-133; F. Vidal, J. Piaget, *La vanité de la nomenclature. Un manuscrit inédit de Jean Piaget*, "History and philosophy of the life sciences", VI, 1984, pp. 75-106.

5 J. Piaget, *La naissance de l'intelligence chez l'enfant*, Delachaux et Niestlé, Neuchâtel 1936.

6 J. Piaget, *L'adaptation de la Limnaea stagnalis aux milieux lacustres de la Suisse romande: étude biométrique et génétique*, "Revue Suisse de Zoologie", XXXVI, 1929, pp. 263-531, pp. 368-370.

7 Conrad Hal Waddington, *The Evolution of an Evolutionist*, University Press, Cornell 1975.

8 Jeremy Trevor Burman, *Updating the Baldwin Effect: The biological levels behind Piaget's new theory*, "New Ideas in Psychology", XXXI, 2013, pp. 363-373.

Meanwhile, starting with his better-known psychological books of 1923[9] and 1924[10], he had also begun to publish the work that would ultimately reshape developmental psychology. This came primarily as a result of his invention of methods for collecting and interpreting qualitative data from children[11], and their subsequent popularization in the United States of America in the 1960s[12]. But his own focus was on the subject's exploratory interactions, regarded as the engine driving the development of reasoning. Indeed, he was convinced that this – the basis for his theoretical approach to the genesis of knowledge (represented in textbooks now by the words assimilation, accommodation, and equilibration) – could directly inform his sought-after *third way.*

However, Piaget's knowledge of the underlying physiology was lacking. His training as a naturalist had led him in the opposite direction. And this did not go unnoticed. For instance, the Russian-born French experimental psychologist Nicolas Kostyleff noted that Piaget "started as a biologist and came to psychology without having gone through the physiology of sensations"[13]. The Swiss logician Jean-Blaise Grize, who worked with Piaget to correct his operational logic from the 1940s, also recalled that "if Piaget's thinking is deeply rooted in biology, it ignores the activity of the brain"[14]. But although such criticisms were representative of the majority view, the minority view must also be considered.

Thus, for example, we see that Pierre Naville (a sociologist who followed the cybernetic trend during the post-war period and later became director of research at the *Centre d'études sociologiques* of the French National Centre for Scientific Research [CNRS]) wrote: "I do really believe that Piaget and some cybernetician neurophysiologists revealed some of the articulations between computer science and the structure of the universe"[15]. Simi-

[9] J. Piaget, *Le langage et la pensée chez l'enfant*, Delachaux et Niestlé, Neuchâtel 1923.

[10] J. Piaget, *Le jugement et le raisonnement chez l'enfant*, Delachaux et Niestlé, Neuchâtel 1924.

[11] Marc Ratcliff, *A Temporal Puzzle: Metamorphosis of the Body in Piaget's Early Writings*, "Constructivist Foundations", XIV, 2018, pp. 301-309.

[12] Yeh Hsueh, *Piaget in the United States, 1925-1971*, in Ulrich Müller, Jeremy Carpendale, Leslie Smith (eds.), *The Cambridge Companion to Piaget*, Cambridge University Press, Cambridge, UK 2009, pp. 344-370; Gilbert Voyat, *In tribute to Piaget: A look at his scientific impact in the United States*, "NYASA", CCXCI, 1977, pp. 342-349.

[13] Nicolas Kostyleff, *La réflexologie et les essais d'une psychologie structurale*, Delachaux et Niestlé, Neuchâtel 1947, p. 162.

[14] Jean-Blaise Grize, *Lectures, digression, reactions*, "Revue européenne des sciences sociales", XXXV, 1997, pp. 289-299, p. 298.

[15] Letter by Pierre Naville to Jean van Heijenoort, March 29, 1959, cited by Rémy Pontont, *Lectures et affinités de Pierre Naville*, in Françoise Blum (sous la dir. de), *Les vies de Pierre Naville*, Presses Universitaires du Septentrion, Villeneuve d'Ascq 2006, pp. 17-35.

larly, in a report to the Rockefeller Foundation, Wolfe Mays (a British philosopher now known for having founded the British Society for Phenomenology and its journal) explained of Piaget's research program: "In the *Épistémologie Génétique* we have a field of possible investigation in which logicians, psychologists, neurologists, linguists and historians of science can join together to make a multi-dimensional study of concept formation"[16]. We see this also in Piaget's own unpublished grant proposal to support genetic epistemology, where he included logic, physiology, and cybernetics in the same portfolio (work package)[17].

Texts such as these suggest that the majority view has missed something[18]. It was clearly known, in certain circles, that Piaget was looking for another way forward; his *third way*. And it is also clear that this was relevant to overcoming the traditional dualism used in describing the relations between mind and brain. To understand that, we must therefore delve deeper.

1. *From plasticity to neurology*

Piaget's mollusks changed in their bodies as they adapted to their changing milieu: their shells provided "the most authentic psychological document we have describing the history of its proprietor". In children, these changes must therefore occur in their bodies as well. Piaget then hypothesized that operational structures were constructed first from sensori-motor loops: sensations and movements, building on reflexes inherited through evolution.

1.1. *Plasticity as a first metaphor*

During the 1920s, Piaget explored the boundaries of plasticity. He just did not always use the same words. In writing about psychology in his last biological essay, for example, he exclaimed, "if the word 'psychology' bothers the reader, replace it with 'physiology of the nervous system' or whatever you like: my conclusions will remain the same".

[16] Unpublished report by Wolfe Mays for the Rockefeller Foundation, quoted and discussed by J.T. Burman, *The genetic epistemology of Jean Piaget*, in Wade Pickren (ed.), *The Oxford Research Encyclopedia of Psychology*, Oxford University Press, UK 1953.

[17] Unpublished grant proposal by Jean Piaget for the Rockefeller Foundation, quoted and discussed by J.T. Burman, 1954, *ibidem*.

[18] J.T. Burman, *Neglect of the foreign invisible: Historiography and the navigation of conflicting sensibilities*, "History of psychology", XVIII, 2015, p. 146.

Two years before, Piaget also explicitly defined the structure responsible for the children's explanations of causal phenomena as "plastic"[19].

The reason he gave was required by theory: causal reason in children was "inexplicable if we do not allow that between environment and consciousness there come to be interposed schemas of internal origin, i.e. psycho-physiological schemas"[20]. This psychophysiological layer was then a mediating level embedded in the process of adaptation. In another paper, which reached new audiences when it was reprinted in the expanded edition of *Sociological Studies* nearly fifty years later, he emphasised that "reason is plastic and various types of systematisation are conceivable"[21].

In his final 1929 paper on molluscs, plasticity was also used as a suggestive hypothesis to qualify a new biological *character*. There, though, plasticity was also hereditary: "plasticity is a character like any other"[22]. This reflected a move away from Bergson: plasticity, or the capacity for adaptation, replaced *élan vital* as a general property of living entities. In the case of the molluscs, "the various species, according to their biological characteristics, react with different speeds and plasticities"[23]. In this sense, the characters are conceived as fluctuating and situational, and not as something static. (Later, in passages that Piaget would cite in turn, Waddington called this property *homeorhesis*[24]).

All of this, however, was in conflict with the emerging modern synthesis: development and embryology were left out of the synthesis in favour of a focus on population genetics. Considerations of plasticity were thus moved from the level of the organism to that of the genes but considered from the perspective of their changing inter-generational distribution across the entire species-grouping. Needless to say, this was not the assumption that Piaget made in his psychological research (his use of the term "genetic" meant the opposite: genesis or generation, not genes[25]). As

[19] J. Piaget, *The Child's Conception of Physical Causality*, Adams & company, Littlefield 1960, p. 273 [or. ed.: Id., *La causalité physique chez l'enfant*, Alcan, Paris 1927, p. 307].

[20] Ivi, p. 272, or. ed. p. 306.

[21] J. Piaget, *Logique génétique et sociologie*, "Revue Philosophique de la France et de l'Etranger", LIII, 1928, pp. 168-205, p. 174 [our translation].

[22] J. Piaget, *L'adaptation de la Limnaea stagnalis*, cit., p. 366.

[23] *Ibidem*.

[24] J.T. Burman, *Development*, in R. Robert Sternberg, Wade Pickren (eds.), *The Cambridge Handbook of the intellectual history of psychology*, Cambridge University Press, UK 2019, pp. 287-317.

[25] J. Piaget, "Programme et méthodes de l'épistémologie génétique", in *Épistémologie et recherche psychologique. Etudes d'épistémologie génétique*, Presses Universitaires de France, Paris 1957, pp. 1-37.

a result, his pre-synthesis biological meta-theory led his psychological theorizing in dissident directions that he later described as "hazardous".

1.2. *Object permanence, realism, and reductionism*

To understand the invisible role of neuropsychology in Piaget's theory, we must consider that he managed several research programs in parallel. Ducret gave a picture of the first three decades of his work – before the creation of the International Center for Genetic Epistemology – to identify the periods devoted to the various general themes (fig. 1)[26].

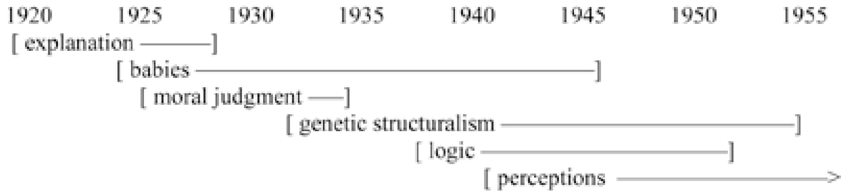

Fig 1. Piaget's research programs overlapping, between 1920 and 1955, inspired by Ducret 2011.

As early as 1925, he and his wife Valentine embarked on a program to observe sensory-motor development, first in their daughter Jacqueline, and then in their two other children[27]. The parents systematically studied the development of sensorimotor intelligence through thousands of careful observations of the three babies' daily activities. But the interest for the physiological mechanisms was brushed aside, both by the focus on the autonomy of adaptive mental processes and by the brilliant discovery of the object permanence. Establishing that the object was not permanent in infants before the age of 8 months – in other words, that objects' existence only become independent from the subject's activity after eight months of age – was more than a factual finding: it was the source for a study on a multifaceted object. Hence it was integrated into multiple series of observations which corroborated it and contributed to a double criticism: on one hand, of realism, because the object was considered as something absolutely different from what it is for the adult and, on the

[26] J.-J. Ducret, *Jean Piaget, un parcours à travers l'oeuvre*, in Merete Amann Gainotti, Jean-Jacques Ducret (a cura di), *Jean Piaget psicologo epistemologo svizzero all'avanguardia*, AEMME Publishing, Roma 2011, pp. 2-41.

[27] See on this research program M.J. Ratcliff, *A Temporal Puzzle*, cit.

other hand, of reductionism, because the object that exists beyond the activity that the subject carries out with it, is not the precipitate of sensation or perception.

But how can one explain the relation between absence of permanence and neurological process? Are there neurological processes responsible for this *absence* when the object is or is not permanent? The answer that Piaget developed was that adaptation, as an equilibrium between the functional mechanisms of assimilation and accommodation, is the source of the co-construction of both, subject and object, or, in another terms, mental instruments and reality. Thus, biology, from this approach, is a necessary but not sufficient dimension to explain this achievement of child development. And, in a sense, explanations based exclusively on neuronal maturation or habit acquisition were considered by Piaget as forms of reductionism. Consequently, the double criticism to realism and neurological reductionism set the tone of his interest in neuropsychology from the time of the war.

1.3. *The turn toward neurology in the 1940s*

For several reasons, and, in particular, to test the idea that the *Gestalt* were weaker structures than the structures of intelligence (the group and reversibility), in 1941 Piaget launched a research program on child perception. Almost 20 years later, while he had published 50 co-authored papers on that, the major outcome was his book *The Mechanisms of Perception*[28]. This study of lower processes brought him closer to scholars who worked on psychophysiology – such as André Rey, Marc Richelle, and Grey Walter – with whom he engaged or argued. This experimental program showed his growing interest for the neurological field, developed since WWII.

Indeed, in a 1948 conference he discussed the relation between intelligence and neurological maturation. The meeting was held by the Swiss Psychological Society with an audience which was mostly medical. Against his adaptation model that established the autonomy of mental processes, someone claimed the development of intelligence was but "a hierarchical layering of behaviours determined by the stages of maturation of the nervous

[28] J. Piaget, *Les mécanismes perceptifs*, PUF, Paris 1961; M.J. Ratcliff, Claude-Alain Hauert, *Un programme de recherche piagétien ignoré: les recherches sur le développement des perceptions 1943-1962*, in M.J. Ratcliff, Martine Ruchat (sous la dir. de), *Les laboratoires de l'esprit, une histoire de la psychologie à Genève*, Musée d'histoire des sciences, Genève 2006, pp. 103-116.

system"[29]. This was a recurring reductionist criticism, especially from doctors, such as Henri Wallon[30]. In the 1930s, against Piaget, the latter considered that child development was but the product of interactions between neurological maturation and social situations[31].

In his 1948 talk, Piaget reduced nervous maturation to one of the factors of development for three reasons:

1. A hierarchy of structure does not exclude functional continuity, provided by the internal organisation. The development of intelligence and the evolution of nervous functions show analogies, therefore, the structural approach called for a functional approach.

2. Maturation "often requires a certain exercise or certain functional stimulation"[32] such as remyelinisation after injury, or neurobiotaxy: Piaget cited MacGraw (1947) in Carmichael's *Manual of Child Psychology*. Hence the second argument was: there is no maturation without exercise.

3. Maturation "is an outcome and not a cause", it obeys the laws of organisation and equilibrium: "It is these laws that matter for psychology more than the static layering of devices that reached the state of maturity"[33]. This was argument 3: we need a comprehensive approach exploring the laws of development of both the nervous system and cognition, without reducing one to another.

Piaget thus declared himself to be against reductionism, which subordinated mental states to nervous phenomena.

During this period, his interest in neurology sprang up. One year after, in 1949, he discussed some criticisms in a paper on "the neurological problem of the interiorization of actions in reversible operations"[34]. André Rey was a Swiss psychologist, a colleague of Piaget who had worked in Lashley laboratory before the war. In 1948, he accounted for the genesis of mental

[29] J. Piaget, *L'intelligence et la maturation nerveuse*, "Revue suisse de psychologie", VII, 1948, p. 308 [Autoréféré from 11th meeting of the Swiss Psychological Society, Olten, October, 10, 1948].

[30] Henri Wallon, *L'autisme du malade et l'égocentrisme enfantin: intervention dans les discussions sur la thèse de Piaget*, "Bulletin de la Société Française de Philosophie", XXVIII, 1928, pp. 131-136; Id., *De l'acte à la pensée, Essai de psychologie comparée*, Flammarion, Paris 1942.

[31] Emile Jalley, *Wallon lecteur de Sigmund Freud et Jean Piaget*, La Dispute, Paris 1981; Marcel Turbiaux, *Le cercle de craie piagétien ou Henri Wallon, lecteur de Piaget*, "Bulletin de psychologie", LI 1998, pp. 673-685.

[32] Ivi, p. 307.

[33] J. Piaget, *L'intelligence et la maturation nerveuse*, cit., p. 308.

[34] J. Piaget, *Le problème neurologique de l'intériorisation des actions en opérations réversibles*, "Archives de psychologie", XXXII, 1949, pp. 241-258, p. 241.

images with an inhibition theory[35]. Piaget discussed Rey's paper with modelling the relation between nervous system and operations. According to Rey, motor skills were not limited to functional execution and were interiorized as representation during the development. Rey discussed "the coordination of afferences [from periphery to the center] and efferences [the reverse] undertaken in the central areas, always engaging less actively the peripheral systems in the course of evolution"[36]. He identified a gradual inhibition of the peripherical areas. Piaget took up the issue, wondering "how to neurologically interpret this break or interiorization of action as the perceptual and motor circuits are subordinated to central areas"[37].

Indeed, according to his research, children from 2 to 7 years-old "only interiorize, as imaged representations, that simple and short actions ready for effective realizations"[38], therefore, showing an uncompleted interiorization. Later on, at the approximate age of 12, the mental operations detach themselves entirely from their motor reference, and come to rely on each other, "which implies a set of circuits momentarily closed in on itself, therefore a possible return to the starting points"[39]. It should be noted that the language had changed: Piaget talked about circuits and would soon use words from engineering, microphysics, and graph theory. The circuits were not Rey's coordination of afference and efference, but "connections between the associative paths which require a reversible scheme".

After using the neurological language, Piaget was inspired by "the microphysicist" who describes reality with diagrams, operators and transformations, "while ignoring their real causality". He first defined some observables – experimental reactions and physiological circuits – and operators – bifurcations and inhibitions. Lower systems were regarded as progressively integrated to higher systems, nesting basic closed circuit into larger ones, which he formalized: if A is a reflex – partially myelinized – and B a circuit of which A is part, we obtain: $A < B < C$. He then translated the structures of intelligence into neurological diagrams, and drew up a distinction between two structures, reversible or not.

The structures were translated into integrated circuits, for which Piaget defined two operators: a positive operator that opens the circuit

[35] André Rey, *L'évolution du comportement interne dans la représentation du mouvement*, "Archives de psychologie", XXXII, 1948, pp. 209-234.

[36] J. Piaget, *Le problème neurologique de l'intériorisation*, cit., p. 243.

[37] Ivi, p. 244.

[38] *Ibidem*.

[39] *Ibidem*.

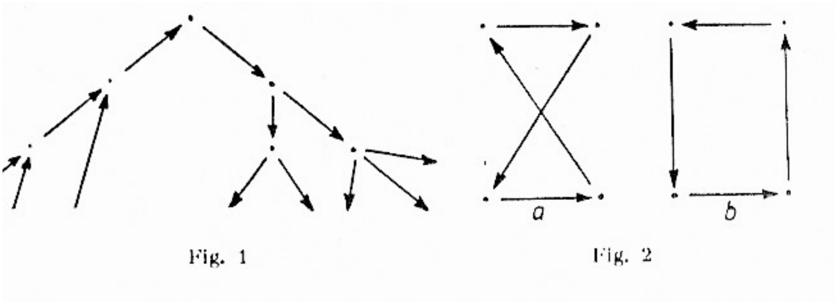

Fig. 2. The first figure shows a non-reversible structure, the second, reversible structures. From: Jean Piaget, *Le problème neurologique de l'intériorisation*, cit. 1949, p. 249.

(flow) and a negative one that closes it (inhibition). In order to model psychological phenomena, he endorsed the language of signal processing as early as 1949 and spoke of inhibitions and facilitation. The goal was to turn into circuits the structures of intelligence he had formalized in his works on natural logic[40]. He therefore complied with the neuropsychological and cybernetic approach when describing "a series of structures of increasing complexity corresponding the successive interiorizations"[41], bound to physiological structures relevant to the levels of neural complexity.

He could then identify three types of structures that characterize as many stages in the development:

1. *Rhythm* presents little plasticity: there are few flows and inhibitions, non-reciprocal relations, mainly located in the peripheric areas (motor skills), and Piaget called here for Sherrington's ideas.

2. *Regulations* show alternate flows and inhibitions, without periodicity, with a set of anticipations and consequences, with new reciprocal relations due to major integration of the lower circuits into the higher. It is, for instance, the perceptual and motor regulations of the visual perception which are not fully reversible. Here the level of control is higher than previously as is the role of the brain.

3. *Reversible coordinations* mark the period when the central areas have become independent of the peripheral territories. Access to the non-reversible previous systems is always available, therefore exteroceptive perception still leads to a motor outcome.

[40] J. Piaget, *Classes, relations et nombre, Essai sur les groupements de la logistique et sur la réversibilité de la pensée*, Vrin, Paris 1942; Id., *Traité de logique*, Colin, Paris 1949.

[41] J. Piaget, *Le problème neurologique de l'intériorisation*, cit., p. 251.

This model suggested how, during the first seven years of life, the importance of the brain increased while peripheral areas declined (fig. 3). It was a developmental response to the debate between centralists and peripheralists that engaged physiologists and neurologists since the nineteenth century[42]. Finally, considering the complexity of the phenomenon, Piaget synthesized the relationships between neurological and psychological structures in this table:

Stage	Structure	Neurological system	Systems integration
Sensorimotor	Rhythm	Peripheral	Low
Preoperatory	Regulation	Central-Periphery	Medium
Operatory	Reversibility	Central	Strong

Fig. 3 Integrating stages, structures, and neurological systems, a synthetic view of Jean Piaget, *Le problème neurologique de l'intériorisation*, cit.

2. *Interdisciplinarity during the fifties*

2.1. *The interdisciplinary context*

While exploring languages, models and ideas from other disciplines, Piaget was developing new methodologies. Indeed, after WWII, his way of dealing with that issue – articulate logic, psychological and neurological processes – was in the spirit of the time. Psychologists, physicians, cyberneticians, neurologists, physicists, mathematicians, and other scholars, collaborated in the post-war atmosphere of the European reconstruction. Piaget was also looking for interdisciplinary contexts to expand his project. Along with the anthropologist Claude Lévy-Strauss' and the physicists Destouches-Février' groups in Paris, with Arne Naess' group in Oslo, one of these circles was the Zurich meetings led by the mathematician and philosopher of science Ferdinand Gonseth and assisted by Bachelard and the physicist Bernays. Piaget was close to all of them, especially to Gonseth, whom he knew from the early 1920s. Around 1950, in the Zurich meeting a physicist mentioned Ashby's homeostat, a device that adapts itself to the environment. This was close enough to Piaget's thesis on adaptation,

[42] Denis Forest, *Bain et les théories centralistes de l'action et de la conscience d'agir*, "Revue d'histoire des sciences", LX, 2007, pp. 357-374.

something that he considered, in his autobiography, a milestone. As he put it, he suddenly heard someone speaking "his language"[43].

From the 1920s Piaget looked for joint areas where scholars from different disciplines shared enough concepts and language to establish a collective heuristic environment. This contrasted with the dynamics of specialization proper to psychology where a shared language was sometime missing. Piaget benefited from the social dynamics of the post-war period and the collaborations with mathematicians who explored biological and human sciences: "Some neurologists […] started to build mechanical models and […] taking advantage of the astonishing technological advances in the computing machines, they shaped a 'mecanophysiology'"[44].

Piaget's appointment as a professor in Paris Sorbonne in 1952 enabled him to spread his ideas to a new audience. In his inaugural lecture, among ideas on equilibrium, he also talked about neurological maturation. For sure, he was not interested in the brain *per se*, but in the brain processes and their impact on development. Up to date with recent research by Arnold Gesell, Carmichael and Wallon, who drew on neurological development, he also referred to many neuroscientists: Tournay on the neurological conditions for coordination of vision and prehension, Flechsig's on myelogenesis, Ariens Kappers on neurobiotaxy – i.e. the migration of neurones during the genesis of neural pathways – Gesell and MacGraw on the laws of maturation in infants, etc. He concluded that "maturation is itself subject to the laws of equilibrium. Each phase of formative instability is followed by a gradual movement towards stability"[45]. Identifying comparable laws of equilibrium in both mind and neural structures, he suggested a new interpretation: the correspondence between mind and brain revealed an isomorphism – and not a causal relation – between the operations of the mind and neurological causality.

2.2. *The contribution of cybernetics*

During the 1950s, Piaget was much concerned with the relations between logical models and psychophysiological and cybernetic interpretations of Grey Walter, Ashby, McCulloch and Bertalanffy, who were

[43] J. Piaget, *Les modèles abstraits sont-ils opposés aux interprétations psycho-physiologiques dans l'explication en psychologie?*, "Bulletin de psychologie", XIII, 1959, pp. 7-13, p. 12.

[44] *Ibidem.*

[45] J. Piaget, *Équilibre et structures d'ensemble*, "Bulletin de psychologie", VI, 1952, pp. 4-10, p. 5.

shaping the modern notion of system[46]. As a sign of this growing interest, in a symposium on the relation between neurology and psychology, held in Paris in 1952, he referred to himself as "the French-speaking psychologist who seems to care less about the nervous system and who hardly ever talks about it"[47]. Conversely, he took this opportunity to show the convergences between the development of logical structures and both nervous maturation and cybernetic models. Yet he was far from just following a trend *à la mode*. Rather he anticipated it, for if Shannon brought out his "lattice theory of information" in 1950, Gonseth and Piaget published four years *before* a paper on "grouping, groups and lattice" that compared psychological and mathematical structures[48]. It is moreover through exchange of ideas with cybernetics interpreted by the mathematicians Mandelbrot and Schutzenberger as a "formal study of behaviour in the face of the unknown" that Piaget took the inspiration for his first model of equilibration[49]. The change was radical for it provided the equilibrium factor with a statistical and not a simple causal status.

Thus, Piaget was at the forefront of efforts to bridge the gap between psychology and hard disciplines, as Seymour Papert recalled in his preface to *Morphisms and categories*, where he brought back Piaget's use of grouping, structures and categories to the vanguard models of 20th century mathematical research. The latter's concern with cybernetics and neurology in the 50s should probably be read as a response to the fact that cybernetics had boosted neurological models. Consequently, meetings with Grey Walter, von Bertalanffy and others such as Huxley, took place in the 1953-1957 World Health Organization Session of the study group on the psychobiological development of the child, and McCulloch was invited to join the International Center for Genetic Epistemology of Geneva.

In 1959, in an autobiographical style, Piaget explained to his French students the origins of his interest on mind and brain relations. Since the 1940s, he said, his central idea

[46] Alex Mucchielli, *La naissance des concepts de système et d'interaction et les débuts du constructivisme: contribution à l'histoire des sciences de la communication*, "Quaderni", XXIII, 1994, pp. 77-96.

[47] J. Piaget, *Structures opérationnelles et cybernétique*, "L'année psychologique", LIII, 1953, pp. 379-388, p. 379.

[48] Ferdinand Gonseth, Jean Piaget, *Groupements, groupes et lattices*, "Archives de psychologie", XXXI, 1946, pp. 65-73.

[49] J. Piaget, *Logique et équilibre dans les comportements du sujet*, in Léo Apostel, Benoît Mandelbrot, Jean Piaget, *Logique et équilibre*, PUF, Paris 1957, pp. 27-117, p. 28.

> […] was, and still is, that development is not rectilinear, but each set of construction must be reconstructed on the next stage before being efficient. According to this perspective, it was possible, without invoking preformation, to assume the operatory structures already at work in the brain function. Therefore, I imagined associative circuits necessarily shaped as mathematical groups or networks, and since then, the works by McCulloch and Ashby clearly demonstrated that there was nothing chimerical about this[50].

Yet while exploring the reductionist ideas, a crucial counterargument emerged: "it is pointless to expect from neurology an explanation of the logico-mathematical structures, for instance to teach us why two plus two make four"[51]. A neat frontier was drawn between classical neurophysiological explanation, accounting, for instance, for emotions reduced to the paleencephalum, and what occurred "in the field of the operations scaffolding the mind"[52]. In that case, one deals with logical necessity[53].

3. *The integrated answer: Biology and Knowledge (1967)*

3.1. *A cognitive evolutionary synthesis*

After the war Piaget had fallen out of touch with advances in the theory of evolution, citing Roux but omitting the authors of the modern synthesis – such as Huxley and Dobzhanski – in the third volume of his *Introduction à l'épistémologie génétique* that dealt with biology. Conducted first in the field during the 60s, the research program that led to *Biology and Knowledge* gave a new look into that topic. To fill the gap, Piaget achieved a second biological study in the mid-60s, after his work on molluscs of the late 1920s. In the latter, plasticity had been regarded as a possible new stabilised character, claiming that "there are no isolated characters in biology, only webs of characters"[54]. In the second, Piaget followed the evolution of a vegetable, the genre *Sedum*, and welcomed Waddington's approach in these words:

> In the spirit of contemporary cybernetic conceptions as used in biology by C. H. Waddington […] the phenomena that we will seek to describe would be at-

[50] J. Piaget, *Les modèles abstraits*, cit., p. 11.

[51] Ivi, p. 12.

[52] *Ibidem.*

[53] Leslie Smith, *Necessary Knowledge: Piagetian Perspectives on Constructivism*, Erlbaum, Hillsdale NJ 1993.

[54] J. Piaget, *L'adaptation de la Limnaea stagnalis*, cit., p. 451.

tributable neither to genotypic programming nor to phenotypic accommodations, but to an 'epigenetic system' responsible for morphogenesis[55].

He thus endorsed Waddington's networks of creodes, "in line with the most current cybernetic thinking"[56] which allowed as well to omit finalist interpretations[57]. And so Piaget layered the new biology on top of a system with which he was already familiar[58].

Cybernetics provided a diagram language, a systemic outlook to causality and a dynamic approach to systems, all which Piaget had dreamed up since his earlier work. Feed-back and reversibility were thus close to each other as were structures and dynamic systems or equilibration and stable states. During the 1950s, coupled with cybernetics, neurology made breakthroughs, especially at the Paris congress in January 1951 on calculating machines and human thought where Norbert Wiener, Ashby, Gray Walter and McCulloch met together. Moreover, for Piaget, it was useful to get rid of classic dead-end directions for example the biologist Lucien Cuénot's forced choice between chance and finality[59] – an issue that anticipated the controversy with Jacques Monod[60].

Among the arguments invoked in the book to refine constructivism as a *tertium quid*, plasticity drew now on the "plastic reason" studied in 1926 more than on the "hereditary plasticity" of 1929. According to Piaget, the logico-mathematical structures could not

> […] be caused by mere hereditary transmission, for if they were attached to the genes in the same way that the shape of the cranium […] they would be neither necessary nor general, nor would they have the extraordinary constructive plasticity which they do[61].

Behaviours attached to genes was a naive view that neglected the power of human construction of structures, as a determinant of actions. For Piaget, indeed, the beliefs of many scholars in the life sciences revealed a tacit realist epistemology. Still, he discussed the effects of brain development

55 J. Piaget, *Observations sur le mode d'insertion et la chute des rameaux secondaires chez les Sedum*, "Candollea", XXI, 1966, pp. 137-239, p. 142.

56 Ivi, p. 211.

57 Ivi, p. 143.

58 J.T. Burman, *Development*, cit.

59 J. Piaget, *Observations sur le mode d'insertion et la chute des rameaux secondaires chez les Sedum*, cit., p. 216.

60 J. Piaget, *Hasard et dialectique en épistémologie biologique*, Hermann, Paris 1969.

61 J. Piaget, *Biologie et connaissance*, cit., p. 368-369.

during evolution on increasing learning capacities, reported on the ethological experiments on superseding of instinct in paramecia to mammals (Bramstedt, Soest, Grassé). But, once classic learning is showed to be driven by an adaptive construction of new structures, there is a need to understand it as a dynamic system of equilibrium between the subject and the environment where top-down (assimilation) and bottom-up (accommodation) adaptive regulations build a stabilized reality. Hence, considering reality as the product of an adaptive construction and the outcome of both evolution and development had major consequences on the interpretation of the species relations with its environment. Since the 1930s, Piaget ascribed to the construction of reality a decisive antireductionist role which resurfaced in the 1960s. This is why several pages from *Biology and Knowledge* ruled out the behaviourist learning model to replace it with the constructivist model of schematic adaptation, in order to overcome innatism and associationism.

A second argument rested on the difference between biological functioning and programming. The functioning is inherent to any living organisation and "carries on its construction process wherever there is an organization". But, as he puts it, the cortical functioning has "almost no hereditary programming by way of cognitive structures"[62]. Functioning is not programming, which is limited to instinct and elementary structures, physiological and perceptual. Hence, higher functions shall be conceived as not strictly programmed, but constructed by the action of the subject:

> In fact, the functioning of the brain is hereditary, since the progress made in cerebral and cortical development among primates and hominids, including man, rather precisely determines the progress of intelligence; but this is only a functioning and not a programming in any sense of the word, since it engenders neither 'innate ideas' nor particular 'knowing how' instincts, and even McCullch's 'neuron logic' is in no way reflected in a congenital logic in the child[63].

Thus, it came back to including the contribution of cybernetics and especially how to interpret what McCullochs and Pitts described in their famous paper on logical calculus in nervous activity[64]. For Piaget, "the logic of neurons [...] naturally remains inherent in nervous functioning, which cannot of itself constitute a cognitive mechanism"[65]. But there is a gap be-

[62] Ivi, p. 3.
[63] Ivi, pp. 327-328, or. ed. 1967, pp. 375-376.
[64] Warren S. McCulloch, Walter H. Pitts, *A logical calculus of the ideas immanent in nervous activity*, "Bulletin of Mathematical Biology", V, 1943, pp. 115-133.
[65] J. Piaget, *Biologie et connaissance*, cit., p. 257.

tween the logical formalisation of the neural functioning and cognitive mechanisms, and such an answer determined the borders of reductionism. Indeed, if the logic of neurons were comparable to adult logic – as a cognitive mechanism – then describing what happens at the neural level would be sufficient; but then, why is this mental logic absent in children? Why is the number, or the identity principle absent in children? Therefore, hypothesizing that the logic of neurons fitted cognition relied on a tacit empiricist copy of neuronal logic by the mind. But for Piaget, there was nothing like that, because human systems gave rise to many complex logical systems. (Should we believe that Hilbert's, Gödel's, or Grice's brains were different in kind from others'?) Therefore, if the logic of neurons was incommensurable with cognitive mechanisms, the relation between the brain's and the mind's logics might be reconsidered:

> […] it is not by any direct reference to the logic of neurons that the logic of propositional operations – admittedly isomorphic – will be built up, but rather by an uninterrupted series of constructions that may have been oriented by structures inherent in the nervous functioning[66].

Eventually, Piaget explained that "cognitive functions are an extension of organic regulations and constitute a differentiated organ for regulating exchanges with the external world"[67]. If cognitive functions were such an organ, their relation with the brain functioning could only be understandable through an isomorphism between the *causal* level on which operate the neural functioning and the *implication* level run by the operations of the mind. The idea, between encephalization and construction, would be voiced in the French 1973 new edition of *Biology and Knowledge*, of which the cover page gathered a brain and an embryo. Up to date with neurology, cybernetics, biology and non-conformists evolutionary thinking, Piaget ventured there to shape a cognitive evolutionary synthesis.

3.2. *Constructivism and interdisciplinarity against reductionism*

The big project of *Biology and Knowledge* did not spring up just in Piaget's head alone but took place within a specific locus of knowledge which he also devised. After the war, Piaget developed ideas about merging scientific disciplines. For instance, the circle of sciences was a core concept to sustain a scientific epistemology, for it conferred a "unity

[66] Ivi, p. 223, or. ed. 1967, p. 258.
[67] Ivi, p. 369, or. ed. 1967, p. 422.

thanks to the interdependence between the various sciences"[68]. Yet this remained an abstraction, far from genuine interdisciplinarity as a social dynamic. It is only after having experienced in many places during the 50s the collaboration of specialists from many fields that Piaget put it into practice and created in Geneva in 1955 the *International Centre of Genetic Epistemology*[69]. Even more, Piaget will say later, about his early logical (1949) and epistemological (1950) books, that the lack of the interdisciplinary compliance experienced in the Centre explained the gaps of these works "because I was then alone at attempting to write it"[70] and because if the "*Traité de Logique* had been issued ten years later, it would have been the work of a team"[71]. That was the spirit in which he wrote *Biology and Knowledge* grounded on interdisciplinary exploration since Piaget was putting together matters usually deeply dissociated. In the *Centre*, a strong culture of interdisciplinarity had been implemented[72], intended to fill the gaps and explore the blind spots left out by specialization. Therefore, keeping in mind the multiple facets of the psycho-biological object, *Biology and Knowledge* brought together close issues discussed separately in specific fields, with the scope of avoiding reductionism and building a shared grammar of the relations between hierarchical levels and fields of knowledge. To cover such a wide scope, information had to be gathered from many disciplines, i.e. from biology, psychology, cybernetic, philosophy, logic, mathematics, as much as from biological specialties: molecular biology, zoology, ethology, synthetic theory of evolution, population genetics, embryology, neurology, etc. With the help of people from the Centre, Piaget synthesized a mass of biological, neurological and evolutionary data reshaped within the constructivist scheme, in terms of adaptation, agency, behaviour and equilibrium. The book fit-

[68] J. Piaget, *Du rapport des sciences avec la philosophie*, "Synthèse", VI, 1947, pp. 130-150, p. 148.

[69] J.-J. Ducret, *Jean Piaget 1968-1979: une décennie de recherches sur les mécanismes de construction cognitive*, Service de la Recherche en Education, Genève 2000; M.-J. Ratcliff, Ramiro Tau, *A networking model, The case of the International Center for Genetic Epistemology*, "Estudos e Pesquisas em Psicologia", XVIII, 2018, pp. 1215-1238; M.J. Ratcliff, *La cité utopique: Origine et genèse du centre international d'épistémologie génétique*, "Philosophia scientiae", XXIII, 2019, pp. 3-26.

[70] J. Piaget, *Introduction à l'épistémologie génétique*, second ed. (or. ed. 1950), three volumes, PUF, Paris 1973, preface to the second ed., p. 10.

[71] J. Piaget, *Traité de logique, Essai de logistique opératoire*, second ed. (or. ed. 1949), Dunod, Paris 1972, preface to the second ed., p. XII.

[72] M.J. Ratcliff, J.T. Burman, *The mobile frontiers of Piaget's psychology. From academic tourism to interdisciplinary collaboration*, "Estudios de psicología", XXVIII, 1, pp. 4-36.

ted that scheme as showed by the frequency of authors cited in the book that confirmed their multiple disciplinary origins, therefore grounding Piaget's deep epistemological project into an interdisciplinary approach.

It is important to highlight that this was a plasticity of structures and reason that implied psycho-physiological schemes. In turn, these structures cannot be explained by simply appealing to hereditary programming. As he put it:

> these [mental] structures cannot result from a simple hereditary transmission, because if they were attached to genes in the same way as the shape of the skull, the lobe of the brain or some particular instinct, they would be neither necessary, nor general nor endowed with their astonishing constructive plasticity[73].

Piaget then read and used works by the embryologist Wilhelm Roux, and it seems he took the updated notion of plasticity from there[74].

In this context, some core multifaceted issues were approached. Caring about the biological nature of knowledge meant tracing the limits and scope of innate behaviours, for which Piaget held, in the broad sense, that there were no innate cognitive structures, while there exist innate perceptive structures. There he used his works from the 1940s that conciliated lower physiological and higher psychological functions and scrutinized the various evolutionary hypothesis that accounted for human encephalization. A core problem was the hurdle of mathematics, as Piaget recalled: "It is unthinkable that the human brain's capacity for constructing logico-mathematical structures that are so admirably adapted to physical reality should be explained by a mere selection"[75] even more so since, statistically speaking, it is an improbable event. He asked whether the *necessity* of mathematics and their efficacy in modelling and transforming reality were explainable in terms of neo-Darwinian selection. And what would be science and technology without mathematics? Piaget therefore did not hesitate to amplify the epistemological constraints to tackle the issues head on through interdisciplinarity, bringing studies from many disciplines together. The goal was to build a meta-discipline – genetic epistemology applied to psychology and biology – that crossed the field borders, while asking some questions usually ignored:

[73] J. Piaget, *Biologie et connaissance*, Gallimard, Paris 1967, pp. 368-369 [our translation].
[74] Roux is cited in ivi, p. 277.
[75] J. Piaget, *Biologie et connaissance*, cit., p. 316.

Biologists, in their turn, have their own kind of common sense, which takes no account of epistemology or thought processes and likes to treat the human brain as the mere product of selection, just like horses' hooves and fishes's fins; with them in mind, I had to remember that the harmony between mathematics and physical reality is not all that easy to conceive, so that perhaps we have to recast our models of interaction between environment and the organization itself[76].

If the main hypothesis of the book stressed the biological roots of cognition, Piaget showed that the biological level, although frequently reducible to innate and acquired characteristics, was also determined by a tertium quid, that is, the construction of structures due to the subject's activity. The belief of biologists according to whom knowledge was either acquired or innate came up against mere epistemological problems, among others the correspondence between mathematics and reality, and object permanence[77]. Yet to voice his constructivist ideas at a time – the sixties – when almost only Piaget and the Geneva school cultivated it, there was a need of shifting the disciplinary boundaries. *Biology and Knowledge* looks therefore like a hybrid outcome of issues raised within distinct disciplinary fields, pointing towards a crossover agenda that many experts would consider irrelevant. Scientists are trained to focus on specific issues while ignoring others, especially the epistemological. On the contrary, for Piaget, epistemological issues were exactly those that should be echoed in several fields, despite experts' setting them aside, and this is why the object had to be considered as multifaceted. Against the reductionisms on all sides, passing over the disciplinary borders in the framework of the Centre for Genetic Epistemology, the object was regarded from all his potential different viewpoints, a way to build it thanks to the constructivist perspective.

4. *Conclusion*

From a historical perspective, *Biology and Knowledge* can only be understood as a work of heterodox biological theory more in line with Waddington and cybernetics than with the Modern Synthesis or Population Genetics. Although McCulloch, Bertalanffy and several neurologists and psychophysiologists followed Piaget's work and met him, it seems that they did not build on or engage with his studies.

[76] Ivi, p. 348, or. ed. 1967, p. 398.

[77] Ariane Etienne, *The meaning of object permanence at different zoological levels*, "Human Development", XXVII, 1984, pp. 309-320.

As is often the case, keeping away an author from an actual research field results in an exclusion from historiography even though his ideas and practices are, later, taken up. Today many scholars, ignoring Piaget, share some of his ideas – constructivist in the first instance –, practice or style. For instance, when discussing the issues of evolution and cognition or the innate-acquired characteristic debate, scholars rely on interdisciplinary exchange[78]. Few scholars, such as Ceruti, identified interdisciplinarity in Piaget's as an original way to address the evolutionary-behavioural issues[79]. But some biologists considered that the reductionist conception of a linear causality between genome, brain and behaviour is now outdated[80]. Even more, the biologist Alain Prochiantz, who claimed epigenetic plasticity to be a major component of human species, put it, in perfect symmetry to Piaget's claim: "The question is today addressed to all cognitivists. Will this domain remain on its neo-positivistic sectary positions or will it be able to include the reflection from other scientific and philosophical traditions?"[81].

One of the major reasons for that exclusion was that biologists dogmatically believed in the one gene-one protein dogma with no influence of the environment on the genome. On that point, recent works showed on the contrary the importance of epigenetic mechanisms[82]. But, as we saw, there were two other reasons.

The first of it was Piaget's constructivist and antireductionist stance. Piaget struggled for a constructivist approach, arguing that reality was constructed and that scientists should set aside their naïve realism, for the external world as we know it is the outcome of multiple complex biological, developmental, evolutionary and psychological processes that must be studied as different facets of the same object. Certain scholars clearly identified his antireductionist perspective, as Pierre Naville, or Henri Lehalle who put that "the neurons never think just because their

[78] Marie-Cristine Maurel, Bernard Brun, *L'inné et l'acquis, nouvelles approches épistémologiques*, Presses universitaires de Provence, Aix-en-Provence 2005.

[79] Mauro Ceruti, *Presentazione*, in M. Ceruti (a cura di), *Evoluzione e conoscenza*, Lubrina editore, Bergamo 1992, pp. 9-11.

[80] Pierre Roubertoux, *Existe-t-il des gènes du comportement ?*, Odile Jacob, Paris 2004, pp. 74-75.

[81] Alain Prochiantz, *Formes et mémoires: vers une évolution expérimentale ?*, in Pierre Fedida, Daniel Wildlöcher (sous la dir. de), *Les évolutions, phylogenèse de l'individuation*, PUF, Paris 1994, pp. 84-98, p. 97.

[82] J.T. Burman, *Updating the Baldwin Effect: The biological levels behind Piaget's new theory*, "New Ideas in Psychology", XXXI, 2013, pp. 363-373.

connexions are isomorphic to operations"[83]. At the epistemological level, Piaget's distinction between causality and implication was a safeguard against reductionism. Such a fundamental distinction between physical causality valid in the brain and causal attribution based on implications and logical operations in the mind allowed to ground a psychophysiological parallelism where logic was not disconnected from bodily reality. For Piaget, the logic takes its origin in the coordination of material actions and schemes operating on the physical world since the beginnings of the development. While they group together in whole structures, they supply nervous functioning with its conditions for exercise and maturation.

The second reason was the epistemological exigence of interdisciplinarity. Piaget strongly believed that scientific objects are multifaceted and are the product of multiple causal series, each one being studied by a specialized discipline. Moreover, when it comes to a human science like psychology, one cannot invoke naively neurological causality and must understand the construction of necessary knowledge, that is escaping from causality to match implication. The interest of Piaget's work was to propose a model of the relations between mind and brain that rejected the dogmatic positions relying on the disciplinary segmentation of the object.

Of course, psychologists could affirm – and still do – nativism as a solution to understand development. One of Piaget's masters, Théodore Flournoy, considered nativist theories to be mainly "lazy theories"[84]. Yet, in addition to being reductionist, nativism is but a simplistic solution which – once one asks *cui bono* – presents the major advantage of making the scholars ignore that its own disciplinary segmentation cuts the objects off from its complexity and eliminates its multiple faces. Therefore, putting constructivism into practice, interdisciplinarity was Piaget's major solution to raise the question of the multifaceted object, opposed to a segmented object. And it included neurology. Constructivism and interdisciplinarity in the Piagetian way, were more demanding while considering both, the multifaceted object and the complexity of neural and psychological development and evolution.

[83] Henri Lehalle, *Sagesse et illusions de la modélisation*, "Bulletin de psychologie", LI, 1998, pp. 249-263, p. 258.

[84] M. Ratcliff, *Raccourci analogique et reconstruction microhistorique. Les origines du laboratoire de psychologie expérimentale de Genève en 1892*, "Revue d'histoire des sciences humaines", XXIX, 2016, pp. 249-272.