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Genetic epistemology and the (in)visibility of constructivist approaches in neurosciences

Epistemología genética y la (in)visibilidad de los enfoques constructivistas en neurociencias

Epistemologia genética e a (in)visibilidade das abordagens construtivistas nas neurociências

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Abstract

This paper discusses the current debate about the field of cognitive neurosciences, its possible relation with the genetic epistemology of Jean Piaget and the reasons why the constructivist approaches in the neurosciences have been little promoted. In order to demonstrate that the neurosciences don't constitute a singular, unanimous and finalized area as it establishes the common sense, is proposed a theoretical revision of the stages of development of Piaget and the discussion of the psycho-physiological parallelism defended by him. Thus, is presented the neurobiological evidences pointed out by Herman T. Epstein for the occurrence of Phrenoblysis (periods of fast brain growth), interspersed with periods of slow growth and that occurring in correlation with the Piagetian stages. With this, we search to draw possible approximations between the genetic epistemology of Piaget and cognitive neurosciences, demonstrating that human cognitive development is structured in the psychological and biological pillars, and that these are linked to social, cultural, educational and genetic factors as well as to demonstrate that the base of support of the constructivist pole in the neurosciences is quite solid. Also is discussed that the superficial analysis of Piagetian precepts, the adoption of partiality and omission of data, the failure to consider his works as a whole, the attachment to isolated works in certain periods, secondary and tertiary readings of the Piagetian work and the problems of reading and translation of the original texts impede Piaget's view as epistemologist and justify the little dissemination of the constructivist approach in neuroscientific research.

Keywords

Brain, mental development, development psychology, epistemology, neurobiology

Resumo

Este trabalho discute o atual debate sobre o campo das neurociências cognitivas, sua possível relação com a epistemologia genética de Jean Piaget e os motivos pelos quais as abordagens construtivistas nas neurociências têm sido pouco promovidas. Para demonstrar que as neurociências não constituem uma área singular, unânime e finalizada como institui o senso comum, propomos uma revisão teórica dos estágios de desenvolvimento de Piaget e a discussão do paralelismo psico-fisiológico defendido por ele. Assim, apresentamos evidências neurobiológicas apontadas por Herman T. Epstein para a ocorrência de Frenoblenoses (períodos de rápido crescimento cerebral), intercalados com períodos de crescimento lento e que ocorrem em correlação com os estágios piagetianos. Com isto, busca-se traçar aproximações possíveis entre a epistemologia genética de Piaget e as neurociências cognitivas, demonstrando que o desenvolvimento cognitivo humano está estruturado nos pilares psicológico e biológico, e que estes estão ligados a fatores sociais, culturais, educativos e genéticos; além de demonstrar que a base de sustentação do pólo construtivista nas neurociências é bastante sólida. Discutimos, também, que a análise superficial das evidências ou dos modelos piagetianos, a adoção de parcialidade e a omissão de dados, a não consideração dos trabalhos dele como um todo, o apego a obras isoladas em determinados períodos, leituras secundárias e terciárias da obra piagetiana e os problemas de leitura e tradução dos textos originais impedem a visão de Piaget como epistemólogo e justificam a pouca divulgação da abordagem construtivista nas pesquisas neurocientíficas.

Palavras-chave

Cérebro, desenvolvimento mental, psicologia do desenvolvimento, epistemologia, neurobiologia

Resumen

Este artículo discute el actual debate en el área de las neurociencias cognitivas, su posible relación con la epistemología genética de Jean Piaget y los motivos por los cuales los enfoques constructivistas en las neurociencias han sido poco utilizadas. Para demostrar que las neurociencias

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no constituyen un área singular, unánime y finalizada como instituye el sentido común ilustrado, se presenta una revisión teórica de los estadios de desarrollo de Piaget y la discusión del paralelismo psico-fisiológico defendido por él. A continuación, se presentan evidencias neurobiológicas apuntadas por Herman T. Epstein para la ocurrencia de Frenoblenosis (períodos de rápido crecimiento cerebral), intercalados con períodos de crecimiento lento, que estarían relacionados a las etapas piagetianas. De esta forma, se busca trazar aproximaciones posibles entre la epistemología genética de Piaget y las neurociencias cognitivas, demostrando que el desarrollo cognitivo humano está estructurado en los pilares psicológico y biológico, y que éstos están ligados a factores sociales, culturales, educativos y genéticos; además de demostrar que la base de sustentación del polo constructivista en las neurociencias es bastante sólida. Se discute, también, algunos posibles motivos para la negligencia de la obra de Piaget en el área de las neurociencias, donde se apunta: el análisis superficial de las evidencias o de los modelos piagetianos, la no consideración de los trabajos de él como un todo, el apego a obras aisladas en determinados períodos, lecturas secundarias y terciarias de la obra, entre otros. Tales equívocos de lectura impedirían la visión de Piaget como epistemólogo y justifican la poca divulgación del abordaje constructivista en las investigaciones neurocientíficas.

Palabras clave

Cerebro, desarrollo mental, psicología del desarrollo, epistemología, neurobiología.

Introduction

This article aims to discuss the current debate surrounding the field of cognitive neuroscience, its possible relationship with the genetic epistemology of Jean Piaget (1896-1980) and the reasons why constructivist approaches in the neurosciences have been little promoted. Evidence of the polarization of this debate will be presented in the course of the text, which is structured in three sections, mainly regarding the approaches that point to the validity of the Piegetian theory, in order to demonstrate that the neurosciences do not constitute a singular area, unanimous and finalized as established by the enlightened common sense. On the contrary, the debate about constructivism in the neurosciences remains open.

Therefore, the first section addresses the issue of cognitive development for Piaget, which presents the phases of development and the criticisms raised on this topic. Then, in the second section, the discussion on the psycho-physiological parallelism of Piaget is presented, in which the interactions between the biological factors and the physical environment in the constitution of the epigenetic system are discussed. In the end, the last section deals with the cerebral stages of Herman T. Epstein (1920-2007), in which is shown that his studies on brain development are directly related to the Piagetian theory.

Although the neurosciences have only recently acquired their current status - the great advances at the end of the 20th century gave their last decade the title of 'Decade of the Brain'- during the journey the impact

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of beliefs focused towards the absence of environmental influences and for the finalization of the subject centered on its genetic/chromosomal inheritance left deep marks in the widespread knowledge on this subject. It is still possible to find disbelief in the union between cognitive neurosciences and genetic epistemology, as if one automatically cancels the other.

Becker (2003) argues that the great challenge of human learning lies in the overcoming of conceptions based on epistemologies of common sense, be they innate or empirical. Machado (2015) comments on the dichotomy between common sense and scientific knowledge and the fact that common sense tends not to accept the human being as 'markedly organic', while the neurosciences and their scientific knowledge bring an understanding about the human organism, emphasizing the biological context. In this context, we can attack what Corso (2009) presents on brain plasticity, showing it as very recent and highlighting that until then, the neurosciences presented the nervous system as a programmed, non-modifiable structure.

According to Machado (2015), it is necessary to dissociate with common sense that has difficulties in accepting that 'markedly organic' character of humans and also with the academic schools that try to show humanity as only biological. The understanding of the epistemological subject and of the study carried out for this understanding requires the dual character (integrated psychological and physiological approaches) as presented by Piaget and defended in the neuroscientific area, for example, by Herman T. Epstein, Steven R. Quartz, Terrence Sejnowski, William J. Hudspeth, Karl H. Pribram and António Damásio. However, it is important to note the echo highlighted by Corso (2009) that Piaget "considered the maturity of the nervous system a necessary condition, although not sufficient, of cognitive development" (p.229).

Many visions and many approaches exist regarding neurosciences. Many times, the term is not even used in the plural, denoting a unique science, standardized, unanimous. Correa, Agila, Pulamarín and Palacios (2012) present as a common expression to call of 'neuromyths' the misinterpretations about the findings of the neuroscientific field, which shows a certain frequency of these events. Even in applied areas, such as neuroeducation, where a transdisciplinary field is discussed (education, psychology, neurosciences, etc.), a final and standardized vision is presented.

An example of this occurs when Aranha and Sholl-Franco (2012) show the field of neuroeducation responsible for presenting "methods and techniques that optimize, or even make possible, in some cases, a better teacher-student relationship and teaching-learning process" (p.11).

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Just thinking about the possibility that a whole scientific, transdisciplinary and heterogeneous field can have successful recipes ready to be applied, immediately denotes a positioning by the singularization and standardization of this field. Another example to address is the research of Hansen and Monk (2002), in which they developed a work that constituted a review of searches on brain development and learning structures. They constructed proposals for the analysis of learning in science education, which became one of the few references of this subject within the scientific teaching and the didactics of science.

Using Electroencephalogram (EEG) imaging techniques, Cerebral Potential in Related Events (EEG/ERP) and Magnetic Resonance Imaging (MRI) to accompany the mechanisms of brain functioning while the subject was performing the proposed tasks, the work of these authors provided evidence that cerebral maturity can structure the plasticity available for the construction of the mind, and allowed the proposition of the implications of this knowledge for science education. However, when discussing their study, they attract researchers with different views (Alexander Romanovich Luria (1902-1977), Herman T. Epstein (1920-2007), Jean-Pierre Changeux and Stanislas Dehaene) wishing to discuss the maturity of the Pre-frontal cortex, they were able to demonstrate the neuroplasticity being longer in the brain in maturity than shown up to that moment and, also, that the human brain initially has an excess of synaptic connections and performs pruning, maintaining some connections while others are removed. However, not addressing the different views used by the researchers cited in the study once again reinforced the idea that neurosciences have a homogeneous and non-conflictive understanding of their field of study.

The internal conflict of that area is basically polarized between an innatist field and a constructivist one. Eichler and Fagundes (2005), in discussing the famous debate between Piaget and Chomsky, bring this analysis to the focus and demonstrate the points of view and approaches given by both sides of the debate. Using a Piagetian bias in the reading of neurobiology, the authors criticize Chomsky's and Changeux's innate vision, accepted and defended by many, and demonstrate that there would be evidence to suggest, that the discussion on constructivism in the neurosciences is still open.

In this sense, we can cite the constructivist manifesto of Quartz and Sejnowski (1997), who proposed to present the neural basis for cognitive development, which they named neuronal constructivism, as an example of the constructivist side of this debate. Through this manifesto, they dis-

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closed neurobiological evidences that the representational characteristics of the cerebral cortex are constructed in the dynamic interaction between the mechanisms of neural growth and the neuronal activities derived from the environment, whose growth is being shown as a progressive increase of the representational properties of the cortex. Human cognitive evolution should not be seen simply as the increase of specialized structures. Neuronal constructivism shows, on the contrary, that it is the increase in the flexibility of representations that allows environmental factors to mold the structure and functioning of the human brain.

It has been argued that the neuroscientific field is vast, non-homogeneous, polarized in the debate on innatism vs constructivism, and thus it is seen that the enlightened common sense of the subject has not taken these discussions into account. In spite of the currents that affirm the invalidity of the constructivist theory, it is possible to notice among them a quite specific behavior: the supposed invalidity of it comes in the middle of a superficial study of its models, of the adoption of a bias that leads to the omission of data, the non-consideration of Piaget's works as a whole, the attachment to isolated works in certain periods, secondary and tertiary readings of the Piagetian work, problems of reading and translation of the original texts, among other reading problems, as noted, for example, in Eichler and Fagundes (2005). The discussion of Lourenço (2016) about the 'received vision' of Piaget's work clarifies these points well.

An example of a superficial study of the Piagetian work is highlighted by Dongo-Montoya when speaking about the criticisms made by Lev Vygotsky (1896-1934) of Piaget's work. When analyzing questions raised to criticize linguistic egocentrism, Dongo-Montoya (2013) states:

> Next, Piaget affirms that his critics stopped in the observation of the first chapter of its work the Language and the Thought of Infants (1999). In that chapter, Piaget places as an evident an inventory of the spontaneous speech of the infant, trying to distinguish individual monologues and collective monologues from adaptive communications (cooperatives). In the second and third chapters, the conversations and the arguments of the infants are studied, which aim to overcome their own points of view. However, these studies were not taken into consideration by the critics (p.278).

Another good example, now demonstrating the adoption of partiality and omission of data, comes from the position adopted by Maximo Piattelli-Palmarini, editor of the book with the debate between Piaget and Chomsky. For Eichler and Fagundes (2005), the author demonstrates:

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

> [...] tendency to disavow, silence and/or eliminate the perspective that is divergent in relation to the one that he adopts, using, skillfully, the rhetorical arsenal used by Piattelli-Palmarini and can be evidenced in the introductions and in the conclusions that he makes to each chapter of the book (p. 258)

According to Eichler and Fagundes (2005), "the defense of Chomsky's scientific program is made, some years later, by the organizer of the originated book" (p. 256). However, the committed researcher will do exactly the opposite, and in his search for the whole he will deconstruct the stereotypes and discover that many current data and new searches corroborate the Piagetian work, as the current neurobiological investigations show that is, at least, hasty to sustain the credit of constructivist contributions. The debate, therefore, is still open and, at the moment, has created more polarization than productive search.

In this way, this article adds in the sense of keeping this debate alive. For this, we present a review that seems to go against the enlightened common sense and discourse that promotes the neuroscientific field as idealized, homogeneous, infallible, finalist and, finally, singular. Presenting some ideas about constructivist approaches in neurosciences, which have been little disseminated, speculate about the motives of deletions and silences in relation to epistemological controversies in the neurosciences. In short, it is suggested that, if nothing changes, society will continue to believe that there is only one neuroscience, and that it is the possessor of a singular, unanimous and finished wisdom.

Cognitive development for Piaget

Undoubtedly, the stages of cognitive development proposed by Piaget have been the target of much of the criticism involved in the debate discussed here. Opposite points of view and many propositions attempt to analyze the Piagetian context, method and approach (Houdé, 2009, Niaz, 1998, Lourenço, 2016). Houdé (2009) points out Piagetian development phases as occurring in a linear and cumulative way. Carey, Zaitchik and Bascandziev (2015), affirmed that Piaget's work "has two essential theories: constructivism and the theory of phases" (p.36). Following another bias, Lourenço (2016) notes that the stages of development have been "the center of considerable empirical research and theoretical controversy" (p.123) and discusses a "received vision" of Piaget's theory that, together with a weak understanding about development, are responsible for mis-

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

understandings about the subject. Subía and Gordón (2014) affirm that in the origins of psychology there was no presence of cognitive structures and that it was Piaget who established a progression in the stages. Niaz (1998) pointed out several researchers who rejected Piaget's theory for considering the development occurred in too heterogeneous stages, he immediately points out that the critics misinterpreted the meaning of the stages of human intellectual development.

Widely disseminated, the Piagetian theory has been addressed in didactic books and literature focused on the fields of development psychology and pedagogy (education in general). Many of these didactic books (Boyd and Bee, 2011, Bee and Boyd, 2011, Papalia and Feldman, 2013, Gazzaniga and Heatherton, 2005) present extremely short ideas, containing only key points and often reinforcing the idea of that the Piagetian theory revolves around the stages of cognitive development. Boyd and Bee (2011), for example, use a page to present Piaget's theory and the stages of cognitive development are presented only in a picture that occupies almost half of a page.

When dealing with Piaget's stages of cognitive development, Lourenço (2016) highlights a series of fundamental points: 1) Piaget's vision as an epistemologist and not a psychologist, and his interest focused on the emergence of new forms of knowledge and not on individual development; (2) the fact that Piaget has never abandoned the stages of development stands out, and that "it does not imply that the stages are at the center of his theory" (p.124) (3) the reaffirmation of Piaget's belief that development never ends, and that "formal structures can be infinitely elaborated, extended, differentiated, composed and transformed" (p.128); (4) the factors due to which the development changes pointed out by Piaget are due to biological maturity, physical experience and social interaction (where language was included); (4) Critics of the Piagetian theory are pointed out as resulting from readings made from poor translations, from the non-reading of original texts (because they were not translated from the original in French, and therefore from Piaget's lack of understanding as an epistemologist); and finally, (5) pointing out the importance of the stages of development for the studies carried out by the psychology of development and its reiterated affirmation that "if the stages did not exist, we should invent them" (p.132).

In relation to the periodization of cognitive development, Piaget (1956) divided intellectual development into three major periods: the period of sensory-motor intelligence, the period of preparation and organization of specific operations, and the period of formal operations.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

The approach of the characteristics pointed out as the main descriptors of these periods, are propitious to continue with an exploratory and not profound character, with the intention of grounding the discussion that we propose ahead.

On the period of sensory-motor intelligence, briefly, it can be noted that Piaget (1956, 1983) presented the new-born as not being the owner of an awareness of his self, or the limits of its interior and exterior. This period is marked by the undifferentiation of the subject in relation to the world and to others, and by the focus of that subject in itself. About a month after birth, the baby goes on to demonstrate the first habits, called stable conditions and primary circular reactions, which are related to the body itself, such as sucking the finger or hands. Around 4 and a half months the coordination of vision and grip begins and the beginning of secondary circular reactions, which are directed to the manipulated bodies (such as looking, grabbing, etc.). However, the baby still does not look for a missing object because its reference continues to be the body itself because the fixation, being unconscious, remains.

The construction of the Self is only possible insofar as the subject becomes interested in the other and the permanence of the objects is shown first when the infant looks for the figure of that other (the mother, or caregiver, etc.). Around 8 months the coordination of secondary schemes begins, where the baby goes to use known means to reach new objectives and it is when the search for the missing object begins. With about 11 months begins the differentiation of action schemes by tertiary circular reaction and the discovery of new means, such as pulling a blanket to itself or find the missing object in different places when these successive movements are made in a perceptible manner. At last, around 18 months the internalization of the schemes and solutions of some problems begins with the prohibition of action and sudden understanding. According to Piaget (1983), the revolution that is established in the sensory-motor period consists of:

> ... decentralize actions in relation to one's own body, in considering it as an object among others in a space that contains all of them and in associating the actions of objects under the effect of the coordination of a subject that begins to be known as source or even lord of his movements (p. 8).

After this period, a next one is the preparation and organization of the specific operations. Piaget (1956) called this subperiod of 'pre-operative representations'. That period would start around 2 years and extend

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

to about 7-8 years. Around the age of 2, the emergence of the symbolic function and the beginning of the internalization of action schemas in representations, which appear in different forms in language, symbolic play or imagination and imitation. Around the age of 4, representative organizations based on static configurations, or an assimilation to the action itself, are started, characterized by interrogations about objects to manipulate and not preserve sets and quantities. On the observed changes, Piaget (1983) states:

> … the subject quickly becomes capable of elementary inferences, of classifications in spatial configurations, of correspondences, etc. (...) from the early appearance of the "why?" we are seeing a beginning of causal explanations (p.12).

According to Piaget (1983), the great change in relation to the sensory-motor period is due to the capacity of conceptualization, since until then there is no awareness and hardly the material and practical use of the intelligence schemes. However, he also reinforces that this passage of action to thought, or of the sensory-motor scheme to the concept, is the fruit of "a slow and laborious differentiation, which is related to the transformations of assimilation" (p 13). Between 5 and 7-8 years, an intermediate phase between non-conservation and conservation is expected, where the child initiates the links between states and transformations, marked by the beginning of a decentration between concepts or conceptualized actions, differently from the sensory-motor period, when that decentration was given in relation to the movements, initially linked to the body itself (unconsciously). Decentration, seen in this period, allows the establishment of constituent functions (not yet constituted), because they are not quantitative, but qualitative or ordinal. In addition to that, that constituent function is not reversible and, therefore, does not involve the conservations that are characteristic of operations. Therefore, there is still no conservation of sets or quantities of matter.

Then, starting around 7-8 years and extending to about 11-12 years, we proceed to the 'sub'period of the concrete operations'. According to Piaget (1956) is where progressive differentiation, gradual coordination, that lead to the first manifestations of reversibility and conservation are first observed. During the development of this period, as well as in the previous ones, the subjects evolve gradually, slowly and not abruptly, and go on to demonstrate more complex levels of intelligence. The way in which the subject proceeds to solve the problem situations to which it is subjected is characterized by the elaboration of solutions

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

based on information or partial data, characterizing the operative classifications, operative reversibility, operative causality, etc. Explaining these questions, Piaget (1983) notes that:

> ... the "concrete" operations fall directly on the objects: this is equivalent, then, to acting on them, as at the pre-operative levels, but giving those actions (or those that are attributed to them when they are considered as causal operations) an operative structure, that is, modular in a transitive and reversible way (p.23).

Around the age of 9, a second level of 'concrete operations' begins to establish itself, where the general equilibrium of these operations is achieved, mainly in what it is talked about in terms of causality. In addition, new imbalances will lead to the rebalancing that will be established characterizing the next level. However, a series of new questions is raised by the subject and can lead to a false impression of regression when the subject does not master such concepts.

In 'period of formal operations', which starts around 11-12 years, the subject starts operating from hypothesis and not just from objects. According to Piaget (1983), "knowledge surpasses reality itself to be part of what is possible and to directly relate the possible to the necessary" (p. 27). Therefore, the subject needs to perform a deductive operation that goes from the hypotheses to their own conclusions, that is, an operation that is performed on operations or the relationship that is established on relationships. Operating at this level of intelligence, the subject goes on to demonstrate a more complex type of reversibility where investment, reciprocity, predictability, action and reaction are concurrently observed.

According to Eichler (2015), even with the vast work and immense propagation, the Piagetian theory continues to find different interpretations. We have already mentioned Lourenço's reaffirmation (2016) for Piaget's belief in the continuity of cognitive development since formal structures can be infinitely elaborated. Even so, there are more recent works, such as Subía and Gordón (2014), pointing out that with formal operations "it is expected to have a definitive cognitive structure; which is preserved, during the rest of adult life "(p.75).

Another example, about the 'received vision' of Piaget discussed by Lourenço (2016) is seen in the article by Naranjo and Peña (2016) in which they discuss logical-abstract thinking, but they do so without using a direct citation to Piaget. This paper addresses different cognitive theories and briefly discusses Piaget's 'psychogenetic theory', but without, in fact, citing Piaget's only work found in his references.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

Truly understanding the Piagetian vision implies the direct study of his work. There is a great complexity involved in the search, structuring and characterization of the evolution of human cognitive development. One of the ways of understanding the structuring formulated by Piaget to explain the periods of development and that they are constituted as successive processes of equilibrium is (Piaget 1956):

> From the moment when the balance is reached on a point, the structure is integrated into a new formation system, until a new equilibrium is always more stable and with an ever-wider field. It is worth remembering that equilibrium is defined by reversibility. To say that there is a way to balance means that intellectual development is characterized by increasing reversibility. Reversibility is the most apparent characteristic of the act of intelligence, which is capable of deviations and returns (p. 42).

Piaget presents the equilibrium processes while revealing the cognitive development, and for that it makes an approach of the processes and structures necessary for the consolidation of these processes from a multifocal point of view but emphasizing its approach to the psychological and physiological factors involved. This integration of the psychological and physiological systems was known as the psycho-physiological parallelism of Jean Piaget.

The psycho-physiological parallelism of Jean Piaget

During the great period of scientific production of Jean Piaget there was no diagnostic and imaging technology (RMI, EEG, ERP and others) or the current data on the functioning and behavior of the brain to which we have access today. According to Arsalidou and Pascual-Leone (2016), Piaget developed his theory without the benefits of current neuroscience. Even so, the biological knowledge and the studies on adaptation and evolution conducted by him already pointed towards the integration of the psychological and physiological systems. Corso (2009) uses the propositions of Antonio M. Battro to affirm that Piaget studied the brain without neurology and that now is the time to interpret the results he obtained based on current neurology. Battro himself (1996) made important statements to demonstrate Piaget's fundamental concern, as an 'intelligence psychologist', with the general processes of organic equilibrium over the particular processes of the nervous system. According to Battro (1996):

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

> Piaget had a very clear awareness of the limits of his scientific competences in this field - in the famous debate with Chomsky he said: "I know nothing about neurology" (Piatelli-Palmarini, 1979, p.290) - however, he intuited with good reason, that the neurosciences of his time could contribute little to the study of the development of intelligence, as he conceived it (p.2).

Piaget always stressed the influence of biological factors on the development of intelligence and for the acquisition of knowledge. These factors would be connected to what he called the epigenetic system, demonstrating interactions between the genome and the physical environment during the development of those processes that would be manifested by the maturity of the nervous system. The psychophysiological parallelism provided by him accompanied the development of his theory and can be seen in various works, although in some moments the little-known role of neuronal behavior at the time is noteworthy. Battro (1996) reaffirms Piaget's defense of psychophysiological parallelism when he cites the *Treatise of Experimental Psychology*, he states:

> We can remember that Piaget always defended the so-called "psychophysiological parallelism". He was very explicit about it: "if the parallelism between the facts of the conscience and the physiological processes respond to an isomorphism between the truly implicated systems and the material systems of causal order, it is evident then that this parallelism also leads not only to a complementarity more, in the end, to a well-founded hope of the isomorphism between the organicist schemes and the logical-mathematical schemes used by the abstract models" (p. 2).

For Piaget (1973) these 'psycho-biological factors' are not the only attenuating factors. Analyzing observed differences in the development of subjects belonging to different social groups, different cultures, and even subjects of similar realities, he presents several examples where delays or anticipations in development (decalagens) are observed and makes it clear that other factors beyond of biological maturity are involved in these processes. In this context, Piaget (1973) states:

> ... that they are actions executed individually or actions practiced in common with swaps, collaborations, oppositions, etc., would be the same laws of coordination and regulation that would carry the same final structures of operations or cooperations, while cooperations; Thus logic could be considered, while final form of equilibria, as being simultaneously individual and social, individual as general or common to all individuals and also social, as general or common to all societies (p.57).

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

In addressing the relationships that are established between cognitive functions and social factors, Piaget (1973) assumes to be indispensable "to begin by opposing the" general coordinations "of collective actions to the particular cultural transmissions that crystallized differently in each society" (p. 56). Explaining the psychophysiological parallelism, Eichler and Fagundes (2005) assume the behavior as a result of neuronic processes that can be provoked by external stimuli and adhere to the ideas of Bunge and Ardila (1987), postulating that:

> ... human development would be understood as a bio-social process of neural reorganization intertwined with socialization. Thus, only a developmental bio-psychology linked to a social psychology would include the promise of scientific explanations that saw development (p. 259).

Many questions permeate the debate about the psychological and physiological roles of thought structures, the acquisition of knowledge, the functioning of the brain and the mind. Initially, distinguishing the roles of the brain and the mind already brings controversies. Mario Bunge (1988), in the preface to his work *The mind-brain problem: a psychobiological approach*, points out that in the early twentieth century some eminent psychologists and neurophysiologists disseminated the idea that talking about the mind was not scientific, more so a superstition that should be abandoned. Theological concepts about the soul should also be abandoned, as well as ideas of capacity, disposition, state and mental process. Science would only accept to deal with concrete things. For Bunge (1988), there was a need to transform the conception that the mind is a set of brain activities:

> Neurophysiology is necessary, but not enough, because it tends to discard psychological categories, such as the purpose and the thought. And psychology, which, although equally necessary, is not enough -unless it is physiological- once it tends to forget the nervous system (p.16).

In what ways do genetic epistemology and cognitive neurosciences define the role of the brain and the mind? The Neurosciences are focused on the study of the brain, neural networks, cells and their genetic components. Seen that way, some would say that Piaget would have been barely concerned with psychology, with the study of the soul, of the spirit. But, obviously, it was not just that. His attempt to construct a biological explanation for knowledge drew a parallel path for the study of the spirit. In analyzing these points, Corso (2009) states that the:

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

> ... structuring of the nervous system would appear as an intermediary between the physiological and the mental, since the nervous reaction would guarantee the transition between physiological assimilation and the functioning of the organism and the cognitive assimilation or interaction of objects or situations in the schemes of action (p. 228).

The key point of the debate about the mind-brain problem, discussed from Plato to the present day, is summarized in: who is it that perceives, feels, remembers, imagines, wishes and thinks? Is it the mind/soul/spirit or is it the brain? At least two lines of thought are expressed here. One that defends the mind as the owner of all states and mental processes and the other that highlights the brain, because the mind is not independent of it and, therefore, the mind itself is a set of functions or brain activities. Correa, Agila, Pulamarín and Palacios (2012) cite Javier Monserrat to affirm that the mind functions as an interconnected set of "physical, biological-neurological and psychic resources that sustain the human organism alive with the processes of information detection and elaboration of the adaptive responses to the environment" (p. 129). In addition, they also point to "manifest integrity between the body and the brain" (p.130).

By the various demonstrations given by Piaget that the mind functions in an interconnected way to the brain, we can believe that he belongs to the group called by Bunge (1988) of psychophysical dualists. Bunge also analyzes that there are two popular varieties of psychoneural dualism: parallelism and interactionism, both empirically equivalent. For him, the interactionists, such as René Descartes (1596-1650), Karl Raimund Popper (1902-1994), Wilder Penfield (1891-1976) and here Jean Piaget (1896-1980) are added, they conceive the brain (the physical part) and the mind (the mental part) as interacting with each other. The brain would be for them the basis of the mind, although it is controlled by it. According to Piaget (1973):

> ... the psycho-biological factors are far from being the only ones acting. If it were not an intervention but a continuous action of the internal maturity of the organism and the nervous system, the phases would not be only sequential, but also chronological connected to, relatively constant dates, such as the coordination of vision and the subject, around 4-5 months, the appearance of puberty, etc. According to the individuals and family, school or social media in general, there are often considerable progress or delays among children of the same city, which do not contradict the order of succession, which remains constant, but which show that the mechanisms epigenetic factors are added (p.54).

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

Having brought relevant issues to this discussion, mainly addressing several points interrelated with the neurosciences, it is important to analyze the contributions of research in this field to the subject under discussion. Battro (1996) states that "it is difficult to find a single quote from Piaget in the most widespread and influential cognitive neuroscience texts of today" (p.2). Despite this, the author suggests that:

> ... the model of mental operations built by Piaget throughout his life is one of the most apt to study the neurocognitive pathways. Today was the time to do it with rigor and precision. The neurosciences of these last years progressed in such a way that they allow us to advance decidedly in the cognitive field, something that was impracticable in Piaget's time (p.3).

Seeking to establish possible approaches between Piaget's genetic epistemology and cognitive neurosciences, in this article we chose to rescue the works of the American biophysicist Herman T. Epstein, which will be summarized in the next section.

The brain stages of Herman T. Epstein

A significant number of works using non-invasive technologies for the construction of images and the study of brain physiology, mainly while activities are carried out by the subject under study, have brought greater understanding about the functioning of the brain and, more than that, reaffirm the Piagetian theory and demonstrate the construction of the mind.

The evolution of technologies and knowledge about the structures that make up the brain and its functioning will allow ancient beliefs such as precocious brain maturity, that the loss of neurons was irreversible, and that brain anatomy could not be altered with experience, began to be questioned while the notion of plasticity began to be constructed. From there, the growing number of conducted studies build new contours for scientific knowledge about the functioning of the brain and the mind.

Epstein did extensive work on brain development (1974; 1990; 1999), in some of them accompanying the weight gain of that organ and increased circumference of the skull in children and adolescents. He is one of the researchers linked to the neuroscientific field who propose commitments of his work like that of Piaget. In his work entitled *The roles of brain in human cognitive development* (1999), Epstein opens the article emphasizing the relationship between brain development and the Piagetian description of the stages of development. According to him:

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

> Brain development in humans occurs at established stages in correlation with the Piaget stage principle for the development of thought. This provides a description of cognitive development as a partial result, from and dependent on biological events occurring in the brain. Evidence shows that some eventual brain structures depend on a combination of instructive biological events or experimental data (p.1).

Battro (1996) affirms that Piaget always defended the idea of a general process of balances and cognitive imbalances that prolong the regulations and organic deregulations. Corso (2014) highlights the fact that for Piaget behavior is exposed to all imbalances by being dependent on a medium that is unlimited and unstable. Thus, the creation of a permanent compensation system for external disturbances and adjustments that are both retroactive and anticipatory. Piaget (1973) says:

> Individual development is, in fact, a function of multiple activities in its aspects of exercise, experience or action on the environment, etc. It intervenes, without ceasing, between the actions of the particular or increasingly general coordinations. That general coordination of the actions supposes then multiple systems of self-regulation or equilibration, that will depend on the circumstances, as much as the epigenetic potentialities. The intelligence operations themselves can be considered superior forms of these regulations, which shows, at the same time, the importance of the balancing factor and its relative independence, as regards biological pre-information (pp. 54-55).

The intention of Epstein (1974) was to demonstrate that the human brain has periods of great growth in weight, and that these periods are not directly related to the general growth of the body. Using data from previous searches conducted by Coppoletta and Wolbach, Reed and Stuart, Blinkov and Glezer (in Epstein, 1974), he found in that analysis about the increase in brain weight that periods of special organ growth (heart, lungs, liver and kidneys) and the body as a whole, generally did not coincide with the characteristic periods of brain growth. To define those periods of rapid growth, brain and mind, he coined the term *Frenoblenoses*, the Greek *phreno*-brain or mind, *blysis*-emergence, growth of matter and *nosis*-knowledge.

Epstein organized his brain cartography in periods that interspersed rapid and slow growth. During rapid growth there is an increase in brain cells (to some extent) and the spread of neural networks and their associations through connections and the establishment of synapses. In periods of slow growth, these networks are perfected, strengthened, trimmed. The quality with which the networks develop will be mani-

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

fested in the next stage and will serve as a basis for the development of the following skills. These facts reinforce the Piagetian thesis of the construction of knowledge, in which the individual's action on objects and fear and the responses he receives when doing these interactions are the basis of the necessary assimilations for the advancement of his learning. For each period of rapid growth identified by Epstein (1999), corresponds another, slower where he observed that "During periods of rapid brain growth the brain weight increases on average from 5 to 10% while, during interim periods of low brain growth, the increase is maybe 1%" (p. 1). When analyzing the periods described and the ages around which the establishment of these is expected, we see an intimate relationship that reaffirms Piaget's studies, as seen when Epstein (1999) says:

> As the child grows, those movement controls improve with practice and experience then the networks controlling these movements must be being polished and sharpened and, therefore, they work more efficiently. If the child does not gain enough experience and wide variety to activate a whole spectrum of movements, some of these movement networks may be less than optimal (p.3).

In presenting his evidence, Epstein makes clear the need for experience (that is, experience, experimentation, attempt/error, in short, assimilations) and the relationship with objects and the means for the previous structures to be established with quality. His perceptions about human cognitive development reinforce the theory of cognitive development in stages created by Piaget. Still, according to the author (Epstein, 1999):

> ... evolution has proceeded by increasing the number of contacts between areas (and their characteristic functions); this indicates a significant additional arborization. Then the phases (3-10 months and 2-4, 6-8, 10-12, and 14-16 years) are now experimental facts and not just theories. This sudden increase in brain growth has been found occurring from the earliest beginning of the stages of the development of Piaget's thought (Epstein, 1980, 1986, Hudspeth and Pribram, 1990); therefore, they are probably the biological basis of the Piaget stages (p.1).

In order to demonstrate his hypothesis for the occurrence of brachynosis, Epstein (1974) published two studies in which he divided this investigation. First, using biophysical properties (measurements of head circumference and brain weight estimates) at various ages to determine these periods of growth. Next, the examination of behavioral data that show abrupt changes that could be related to brain biophysical changes and that indicate possible ages in which to look for periods of

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

rapid growth. In this way, his discoveries will make possible these classification schemes that are very close to those provided by Piaget.

Epstein's research presented evidence of the existence of periods of rapid growth in brain weight and circumference of the skull and still correlated the physical growth of the brain with the functional growth of the mind. According to Epstein (1974):

> The age spectrum for human frenoblenosis can be correlated with the growth of mental abilities (...) conversing with teachers, we have reason to believe that the periods are related to the growth in learning abilities. Growth between 14-15 years is correlated with the Piagetian stage of formal operations, which is generally assumed to begin after 12 years. The growth of the 11 years is correlated with the rapid growth of the conceptualization on concrete objects in the environment, which is used in schools to build, for example, ideas about fractions and geometric objects. The growth of the 7 years coincides with the start of formal learning normally associated with the acquisition of reading and writing skills for the average child (p.214).

In a study that broadened and corroborated the research on frenoblenosis, Hudspeth and Pribram (1990) used computerized quantification of changes in the frequency spectrum of the EEG (QEEG) to establish statistical relationships between the states of brain regions and maturity. According to them, this analysis provided evidence of five statistically important stages of maturity in the QEEG, providing enough empirical data to demonstrate the periods of rapid and slow growth suggested by Piaget and Epstein. According to them, "it is reasonable to conclude that brain maturity occurs in stages" (Hudspeth and Pribram, 1990, p.883).

Like Piaget, Epstein (1999) presented that babies are born with "some genetically established neural networks" (p.2), these networks being necessary for reflex activities such as breathing, sucking, sensory detection, metabolism, etc. From the birth, through the interactions made by the child (absorption of acts for Epstein, assimilations for Piaget) these networks will be strengthened, weakened, modified, they will have addictions, etc. The first major period of brain growth was identified by Epstein (1999), which occurs between 3 and 10 months. Mainly, this growth works to mature the cerebellum, "facilitating its role in the activation and control of motor actions" (p. 2). Then, a period of low brain growth begins, from 10 months to 2 years, where the child "practically completes complements of actions and controls, thus improving, consolidating and perfecting them to the extent that the networks are optimally arranged for this purpose" (p. 3).

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

For Epstein (1999), the second major phase of brain growth is established between 2 and 4 years, being this focused for the maturity of the senses. He mentions the interconnected development of touch, vision and hearing and comments that "the child can see, hear, taste, touch and smell virtually at the adult level at the end of this phase" (p. 3). Next, there is a period of low brain growth that extends from 4 to 6 years, being characterized by the "gain of experience and expertise in the use of existing networks and the newly modified to perform sensory and motor activities" p. 4), which ends up consolidating these functions. According to Epstein (1999):

> ... individual differences appear due to differences in life experiences from that point onwards. From the point of view of something like the Piagetian phases, new functions are being acquired and sharpened in a chronology somewhat without synchrony and then we see the appearance of what we call compensations: the spreading of stages of development over the ages (vertical compensations) and on top of the parallel domains in each of the same functions can be used (horizontal offsets) (p.4).

Currently, it is important to highlight more once that oldness is not a primary factor. The fact is that the sequence of the phases remains fixed and all individuals go through all of them, and it was identified in different peoples and cultures, delays or overtaking (compensations) in relation to the ages in which they manifested, according to the place where the tests were done. In addition to the biological factors, the social factors of educational and cultural transmission were highlighted by Piaget (1973):

> In order that the biological factors of maturity can be invoked with certainty, it would be necessary to be able to verify the existence, not just of a sequential order of the stages, but even of certain average, chronologically fixed, appearance dates. However, the results of Mohseni show, on the contrary, a systematic backwardness of the peasant children, in relation to the children of the cities, which indicates, of course, that other factors intervene besides those of maturity (p.60).

Speaking about the growth of the neural network and how this makes possible the association of sensorimotor and mental functions that were previously separated, allowing more complex operations around six years, he emphasizes that this acquisition does not depend more on an increase of nerve cells than by means of stimuli, new networks of neuronal communication are established and manifested among previously existing networks, which for him had great biological sense since "the

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

only networks created after this time will be those activities with sensory-motor operations" (p. 5) Epstein (1999), who continues to affirm:

> It is extremely important to note that these new functions are not genetically programmed because, if they were, virtually all children would manifest these concrete thinking functions at the same ages, as they do during the early stages of growth when virtually all children manifest the typical sensory and motor functions. This means that the operation of this augmented network is dependent on modifications by the combination of inputs made by experience and instruction. Their functions must be learned! (p.5).

Following the story of Epstein, he states that above this stage of development the thought seems to be "almost entirely associative" (p.5), and highlights that between the ages of 8 and 10 follows a new period of slow brain growth where the consolidation of new functions occurs. Explaining this question:

> It is very important to note that the synthesis of new brain cells reaches a virtual impasse around the age of 4-5 years (Winick, 1968). Because of the limitations of sensitivity in measurements, it is not possible to state that no synthesis occurs after that. Further, as far as can be determined, there is a cessation of the activity of the enzyme involved in the re-application of DNA (DNA polymerase) is an asymptote in the total DNA by the brain then there is no significant increase in the number of brain cells.
>
> The importance of this finding is that, because the brain increases about 30% in weight after this age, the additional weight must be in weight gain per brain cell. Much of the weight gain is in the increased arborization of neurons, this means that they send axons and dendrites more elongated and more branched to create functional connections between groups of more distant located neurons (Conel, 1939-63, Rabinowicz, 1979). This increase in the complexity of the network becomes possible and inevitable for the more complex mental functioning (p.4).

Around ten years of age a new period of rapid brain growth was identified, with the identification of a significant increase in neuronal arborization where new contacts and associations with pre-existing networks occur. These new contacts allow the association of functions of concrete thought, and from there is the possibility of the manifestation of formal thought. Still, more a phase of rapid growth was identified between the 14-16 years, where the additional arborization allows to connect functions of the concrete thought that still were not connected al-

Sophia 26: 2019.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

lowing the addition of functions of the formal thought that will be added in this period. Considering the general vision of his work, Epstein (1999) concludes that "Piagetian thought schemes have been confirmed and reconfirmed many times" (p. 7).

Conclusions

There is no doubt that human cognitive development is structured in the psychological and biological pillars, and that these pillars are linked to social, cultural, educational and genetic factors. All the interaction of the individual with the environment that surrounds it is mediated by these factors, and it is they who give the basis used in the assimilations made and subsequent accommodations. The differences found in the various replications of the Piagetian tests around the world hardly show the interference of these factors.

In the field of neuroscience, the stages of human development established by Piaget were confirmed by the extensive research of Epstein (1974, 1990, 1999), which established the correlation between brain development and the stages of Piaget for the development of thought, and that later it was corroborated by Hudspeth and Pribram (1990), Hansen and Monk (2002), Quartz and Sejnowski (1997) among others. ing the case, it was shown that it is possible to establish relationships between cognitive neuroscience and genetic epistemology and not only that the base of support of the constructivist pole in the neurosciences is quite solid.

In addition to the stages of development, the demonstrated evidences of the superficial analysis of the Piagetian models, the adoption of partiality and the omission of data, the non-consideration of Piaget's works as a whole, the attachment to isolated works in certain periods, secondary and tertiary readings of the Piagetian work and the problems of reading and translation of the original texts, etc.; they constitute sufficient justifications for the little or almost nonexistent disclosure of the constructivist approach in neuroscientific research.

In this way, it was demonstrated in this article that, contrary to be a homogeneous, infallible, finalized, singular field, neurosciences are constituted in a plural and heterogeneous way, supported by diverse and often contradictory biases, and that the empirical data brought to the discussion allows that the debate between the nativist and constructivist poles remain open.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

Bibliography

ARANHA, Gláucio & SHOLL-FRANCO, Alfred
2012 *Caminhos da Neuroeducação*. Rio de Janeiro: Ciências e Cognição.
ARSALIDOU, Marie & PASCUAL-LEONE, Juan
2016 Constructivist developmental theory is needed in developmental neuroscience. *Science of Learning*, 1, 1-9. https://doi.org/10.1038/npjscilearn.2016.16
BATTRO, António Maria
1996 *Jean Piaget y la neuroeducación*. Disponível em https://goo.gl/qduYir [11-11- 2018].
BECKER, Fernando
2003 *A origem do conhecimento e a aprendizagem escolar*. Porto Alegre: Artmed.
BEE, Helen & BOYD, Denise
2011 *A criança em desenvolvimento*. Porto Alegre: Artmed.
BOYD, Denise & BEE, Helen
2011 *A criança em crescimento*. Porto Alegre: Artmed.
BUNGE, Mario & ARDILA, Rubén
1987 *Philosophy of psychology*. New York: Springer-Verlag.
BUNGE, Mario
1988 *El problema mente-cerebro: Un enfoque psicobiológico*. Madrid: Editorial Tecnos.
CAREY, Susan, ZAITCHIK, Deborah & BASCANDZIEV, Igor
2015 Theories of development: In dialog with Piaget. *Developmental Review*, *38*, 36-54.
CORREA, Fausto Vilatuña, AGILA, Diego Guajala, PULAMARÍN, Juan José & PALACIOS, Walter Ortiz
2012 Sensación y percepción en la construcción del conocimiento. *Sophia: colección de Filosofía de la Educación*, *13*(1), 123-149.
CORSO, Helena Vellinho
2009 Funções Cognitivas-convergências entre neurociências e epistemologia genética. *Educação & Realidade*, *34*(3), 225-246, Set/Dez.
2014 Cérebro e mente: convergências entre os modelos de Piaget e Fuster. *Schème: Revista eletrônica de psicologia e epistemologia genéticas*, *6,* nº especial.
DONGO-MONTOYA, Adrian Oscar
2013 Resposta de Piaget a Vygotsky: convergências e divergências teóricas. *Educação & Realidade*, *38*(1), 271-292. Porto Alegre.
EICHLER, Marcelo Leandro
2015 Acerca das citações à obra de Jean Piaget em revistas indexadas. *Schème: Revista Eletrônica de Psicologia e Epistemologia Genéticas*, *7,* 35-57.
EICHLER, Marcelo Leandro & FAGUNDES, Léa
2005 Atualizando o debate entre Piaget e Chomsky em uma perspectiva neurobiológica. *Psicologia: Reflexão e Crítica*, *18*(2), 255-266.
EPSTEIN, Herman T.
1974a Phrenoblysis: Special Brain and Mind Growth Periods. I. Human Brain and Skull Development. *Developmental Psychobiology*, *7*(3), 207-216.Waltham, Massachusetts.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

1974b Phrenoblysis: Special Brain and Mind Growth Periods. II. Human Mental Development. *Developmental Psychobiology*, Waltham, Massachusetts, *7*(3), 217-224.

1990 Stages in human mental growth. *Journal of Educational Psychology, 82*(4), 876-880.

1999 *The roles of brain in human cognitive development*. Disponível em http://www.brainstages.net/stages [11-11-2016].

GAZZANIGA, Michael S. & HEATHERTON, Todd F.

2005 *Ciência psicológica: mente, cérebro e comportamento*. Porto Alegre: Artmed.

HANSEN, Linda & MONK, Martin

2002 Brain development, structuring of learning and Science education: where are we now? A review of some recent research. *International Journal of Science Education*, *24*(4), 343-356.

HOUDÉ, Olivier

2009 *Dez lições de psicologia e pedagogia: Uma contestação das ideias de Piaget*. São Paulo: Ática.

HUDSPETH, William J., & PRIBRAM, Karl H.

1990 Stages of brain and cognitive maturation. *Journal of Educational Psychology, 82*(4), 881-884. http://dx.doi.org/10.1037/0022-0663.82.4.881

LOURENÇO, Orlando M.

2016 Developmental stages, Piagetian stages in particular: A critical review. *New Ideas in Psychology*, 40, 123-137.

MACHADO, Diandra Dal Sent

2015 Epistemologia genética e neurociências: construção do sujeito cognoscente. 2015. 93 f. Dissertação (Mestrado em Educação) – Faculdade de Educação, Universidade Federal do Rio Grande do Sul, Porto Alegre.

NARANJO, Lilian Mercedes Jaramillo & PEÑA, Luis Alberto Puga

2016 El pensamiento lógico-abstracto como sustento pra potenciar los procesos cognitivos en la educación. *Sophia: colección de Filosofía de la Educación*, *21*(2), 31-55.

NIAZ, Mansoor

1998 The epistemological significance of Piaget's developmental stages: a Lakatosian interpretation. *New Ideas in Psychology*, 16, 47-59.

PAPALIA, Diane E. & FELDMAN, Ruth Duskin

2013 *Desarrollo humano*. Porto Alegre: AMGH.

PIAGET, Jean

1956 Les stades du développment intelectuel de l'enfant et de l'adolescent. In P. Osterrieth, J. Piaget, R. De Saussure, J. M. Tanner, H. Wallon, R. Zazzo, A. Rey, *Le problème des estades en psychologie de l'enfant*; symposium de l'Association de Psychologie Scientifique de Langue Française (pp. 33-42). Paris: Presses Universitaires de France,

1973 *Psicologia e epistemologia: Por uma teoria do conhecimento*. Rio de Janeiro: Forense Universitária.

1983 *A epistemologia genética* / Sabedoria e ilusões da filosofia; Problemas de psicologia genética. São Paulo: Abril Cultural.

QUARTZ, Steven R. & SEJNOWSKI, Terrence J.

1997 The neural basis of cognitive development: a constructivist manifesto. *Behavioral and Brain Sciences*, *20,* 596. Cambridge University Press.

Print ISSN: 1390-3861 / Electronic ISSN: 1390-8626, pp. 113-137.

SUBÍA, Andrés & GORDÓN, Jacqueline
2014 Esbozo crítico sobre las estructuras cognitivas: génesis del pensamiento científico. *Sophia: colección de filosofía de la educación*, *16*(1), 71-82.

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