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CONCEPTIONSABOUTTEACHINGDNAINBASICEDUCATIONAREADINGBASEDONHENRIATLAN

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Conceptions about Teaching DNA in Basic Education: A Reading based on Henri Atlan

Elaine Ferreira Machado [α], Ingrid Aline de Carvalho Ferrasa [σ], Awdry Feisser Miquelin [ρ], Adriane Marie Salm Coelho [ω] & Nestor Cortez Saavedra Filho[¥]

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Keywords: DNA; PNLD; biology teaching and learning; epigenetics.

I. Introduction

Henri Atlan, French physician, biophysicist and philosopher, was born in 1931 in Algeria. Gathering knowledge in the area of biology, physics and computing, he presents in his research the complexity of knowledge between the natural sciences and the human sciences, starting to describe from ontology and epistemology in an anthropological approach to the direct link between these sciences.

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Based on the great discoveries occurred between the decades of 1960 and 1970 in molecular biology, Henri Atlan develops his theory of "complexity from noise" (ATLAN, 1992). Although some aspects have been clarified regarding the structure of DNA, its role in human reproduction, its duplication, the transmission of information to new generations within the cells and that genes are DNA molecules, Atlan has since attributed misconceptions to the design of the gene. For the author, considering DNA as a "genetic program" is just a mistaken metaphor (ATLAN, 2003). In this aspect, it is based on models from physics and chemistry for its concept of self-organization, in order to show that the genetic code is a projection of the linear structures of DNA, for those of proteins, that is, a coding, that is not to be confused with a program (idem, 2003).

In face of this, we can refer to the knowledge systematized in basic education. How do Biology teachers articulate knowledge about DNA at school? And, how do school textbooks systematize such knowledge? Does the conception of DNA by the teachers and the one present in the textbooks characterize it as data or a program? How would it be possible, by mediating knowledge about DNA at school, to present teachers with a more complex and integrative terminology? And could the teaching materials have a more integrative organization regarding the approach to teaching DNA?

Thus, analyzing the teaching conception that basic education teachers articulate at school, as well as the textbooks of the last PNLD used in teaching Biology, from the perspective of Henri Atlan, may open up new fields of problematization. Such problematizations occur in the sense of pointing out the current condition of the appropriation of school knowledge, as well as new terminologies that enable conceptual approaches for and in the teaching of Biology, in a more integrative and complex way of knowledge, according to Morin (2013).

II. Henri Atlan's Epigenetics for Biology Teaching and Learning

The knowledge taught at school and present in the school curriculum and in the textbooks of basic education articulate conceptions which, many times, it is necessary to problematize them. Narrowing the channel between the school field and the knowledge articulated

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in the academy allows the student to learn recent conceptions that may contribute to or modify knowledge based on the school curriculum. In this aspect, the pedagogical practice can present itself as a response to scientific conceptions, connected to current paradigms.

Therefore, the genetic paradigm can be placed at the center of controversies. Genetics, as part of the biology occupies in understanding the mechanisms and laws that account for the transmission of the characteristics of living things through the generations.

The genesis of genetics in modern science stems from the studies of the Austrian Gregor Mendel, around 1860. And, with scientific and technological advances, genetics encompasses studies both in the area of Cell Biology and Molecular Biology, which comprises acid molecules deoxyribonucleic (DNA) and structural part of chromosomes, where genes are found, as responsible for information for protein synthesis.

Regarding the study of the functioning of genes in cell nuclei, in 1940, the English biologist Conrad Hal Waddington (1905-1975), presented the concept of epigenetics in his book Organizers and genes (SANTOS, 2015). Epigenetics is a metaphor used to explain the different processes that a cell undergoes in its gene activity in embryonic development and in each cell division.

It is worth noting that the origin of the term "epigenetics" occurred to Aristotle, from their empirical observations on the embryonic development of animals, to refer to the origin of a living being. Such a conception, called vitalist, was accepted until the 18th century. However, it was from the studies of Descartes and Isaac Newton that they started to adopt a material explanation for the origin of a living being linked to organic molecules. (CANGUILHEM, et al, 2003)

The understanding of how, in fact, the representation of complex order characteristics in living organisms is characterized, according to Oliveira and Muller (2015), as a third historical moment in twentieth-century biology. For these authors, at first, Biology was strongly influenced by creationist ideas, even with the advent of the Theory of Evolution; in a second moment, by Newton's mechanistic ideas and, in a third moment, when other theorists, including Henri Atlan, propose the theory of complexity for a broader approach to biological knowledge.

As Henri Atlan (2013) emphasizes, epigenetic mechanisms act to change the way in which the accessibility of chromatin for transcriptional regulation in the modification of DNA and nucleosomes occurs. Such mechanisms are essential for cell development. In addition, gene regulation is influenced by the environment and modifies over time, as shown by current studies and performed in the field of epigenetics. According to Silva and Duarte (2016, p. 438-439):

> Epigenetic mutations occur quite differently from genetic mutations. They are the product of the silencing or activation of a gene and not the change in the order of nitrogenous bases; they just turn genes on and off. Furthermore, epigenetic mutations are always targeted, responding to environmental changes. Some forms of epigenetic mutation can pass on to offspring, functioning as a genetic mutation; but, unlike the latter, they can be reversible.

Thus, this very current epigenetic concept modifies some bases of molecular biology in its central dogma: DNA - RNA - protein, seen in a linear fashion, since different DNA fragments, in combination with others, can generate different proteins in the organism, considering the exons, the introns and the biological phenomenon called splicing. This new fact for Biology has led to genetic research, opposing the idea of linearity of the DNA molecule and, at the same time, demonstrating a character of complexity, fundamental in the teaching of science in the 21st century (MORIN, 2006).

DNA is a polynucleotide that is found with four different species of nucleotides, different from each other by their nitrogen base. Such bases are: adenine (A), thymine (T), guanine (G) and cytosine (C). It is from the structure of the concept of DNA that Atlan (2006) attributes the “Information Theory” in order to present the implications involved in the study of the gene. So, a DNA molecule is made up of thousands of nucleotides, which are organized like written messages of four symbols. Still, following the same criteria, a protein is a polymer made up of millions of amino acids. There are 20 (twenty) different amino acids. So, a protein organizes itself as messages written in 20 (twenty) symbols. This means that “there is a univocal correspondence between the structure of a DNA molecule, determined by the sequence of its bases, and that of a protein, determined by the sequence of its amino acids” (ATLAN, 2006, p. 122).

Under the focus that the amino acid sequence is encoded in the DNA base sequence, effecting the protein synthesis, Atlan (2006) problematizes two aspects: one refers to the coding of messages in an alphabet of 20 (twenty) symbols, in messages with an alphabet of 4 (four) symbols, and another in relation to the coding methods carried out in nature, if they are really the same in all living organisms. In this respect, he claims that the coding is really the same in all organisms, which evidences, according to him, what we call the genetic code, since it constitutes a coding method common to all organisms. However, the author emphasizes that encoding should not be confused with programming (ATLAN, 2013).

It was in the 1960s that Molecular Biology made great discoveries and started to adopt the metaphors commonly known in the field of “information” and “cybernetics”. Studies on the DNA start to present concepts from the structure of DNA findings; its role in reproduction; those genes are DNA molecules and their duplication and transmission of information both within

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cells and to new generations. Given this organization and the fact that the molecules (DNA and proteins) would be endowed with information, their functioning was compared to a computer. So, the DNA would be the program and, from then on, it would be adopted as a "genetic program". Atlan, at the time, attributed the programming analogy to DNA as a metaphor. According to the author "[...] to a very loose metaphor. In fact, when we look at DNA, we don't find any sign of computer language" (ATLAN, 2013, p. 125).

For Henri Atlan, self-organized systems describe the properties and capacities of living organisms to self-organize, thus providing a basis for situations in which living beings self-organize, based on models from Physics and Chemistry. Atlan (2013) was concerned with showing the organization of matter, with some degree of randomness, that is, a source of errors in transmission, which he called noise.

For Atlan, the fact that they consider DNA as a computer program is based on the following attributes:

> [...] DNA is a quaternary script easily reducible to a binary sequence; every sequential deterministic computer program is reducible to a binary sequence; the genetic determinations produced by the structure of the DNA work like a sequential program written in the DNA of genes (ATLAN, 2013, p. 159).

According to the author, the concept of DNA is summarized as a program, without even placing a random sequence at the center of the controversies. Furthermore, a binary sequence is not just a program in the DNA (ATLAN, 2006).

According to Atlan (2013), making the distinction between DNA as a "program" and DNA as a "data set" is to consider the implications involved in the role of the DNA nucleic sequence itself, that is, in the genetic determinations under the form of an alternative, between a program function and a data function. For him, this alternative allows us to question the role of the set of cells when always associated with DNA in the production of such determinations.

The classical notion of genetic program for DNA had, in its time, the heuristic and operational merit according to Henri Atlan (2003, 2006 and 2013). However, it points to situations that lead to the decline of scientific research when considering DNA from a metaphor, governed by unknown mechanisms, at the expense of explicitly knowing such devices. Therefore, it bases the conception of DNA as data, starting from the elements of the Information Theory area from the conceptions of the American Claude Shannon (1916-2001).

Shannon attributes entropy as a way to quantify the degree of uncertainty of a source of information, that is, it makes it possible to quantify the degree of complexity of a data set. "I used Shannon's information theory to formalize noise effects, that is, different factors of random aggression to organized systems" (ATLAN, 2006, p. 15). Using Shannon's formula, it is possible to explain how the amount of information occurs in living organisms and to quantify the complexity of biological systems. The formula shows itself by a function:

$$H(x) = -\sum_{i} p\ (i)\ log_2 p\ (i) \qquad (1)$$

In the formula, the amount of information in a message is represented by (x); (i) represents the index of symbols (x) used in the message (x_1, x_2, x_3, x_4, ... x_i., ..., x_N); p(i) represents the probability of the symbol x_i.;

As a result of experience by the formula [1] Shannon a message is sent through signs or symbols for the recipient to reconstruct the results that arrive to them. This means that there must be a code that allows extracting the result that is transmitted with the symbols of that message. Furthermore, the probabilities of the symbols of a message are independent, that is, the result of an experience does not influence the previous experience (ATLAN, 2006). Atlan justifies from [1] nuances to support his conception of DNA as data and not as a program.

Although the notion of noise for the Communication Theory is undesirable, for natural systems through the occurrence of noise (natural and social elements, among others), there are alternatives in communication, which leads to new forms of organization and survival. Such aspect makes any natural system complex (ATLAN, 2013).

In considering the analogy of the computer program, when referring to DNA, presupposes that it would be enough to wait for it to be executed, step-by-step, successively, in a respective time interval, until completing a cycle. In the case of an embryo, for example, it would develop as such program starts to be executed. What is necessary, according to Henri Atlan, is to understand "[...] how matter can itself change its form and activities, depending on its own history" (ATLAN, 2003, p. 127). For the author, the metaphor of the genetic program allows for mistakes inasmuch as the meanings are hidden from the adopted information. It is like a habit, in which the problem is neglected, both in information technology and in programming sciences, for ignoring that the source of meanings are human individuals: both those who "[...] send and receive a message, or those who write a program and make it possible to be executed" (Atlan, 2013, p. 158). Therefore, Atlan (2013) concludes that if DNA is in fact a program, this set of cells would play the role of a program in encoding the data. And, if DNA is in fact data, it would have the advantage of raising discussions and problematizations about DNA as a program. For the author, when the dimension analyzed is complex, a conduct in the sense of organization and adaptation shows results with disruptive effects and unplanned environment.

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Henri Atlan develops the concept of DNA as "data" in opposition to DNA as a program, thinking exactly about the epigenetic mechanisms, which lead him to suggest that:

> What is transmitted is not just a static molecular structure, but a state of functional activity, that is, a certain expression of the functional significance of the set of cellular structures. Up to now, these phenomena of epigenetic heritability appear as anomalies or by comparison with the tendency of everything to relate to genetic determinations in the form of a DNA sequence. Therefore, they are relatively little studied, even though the necessary techniques are more complicated and less effective than those for cloning genes and their sequencing (ATLAN, 2013, p. 165).

For the author, it uses aspects with attributes to illusionism, followed by an erroneous conception of causality, in which the cause is excessive of its effect, in which it is attributed to the genome imprint properties mystery of what hitherto called life. And, as yet another illusory and magical trick, the program's metaphor reveals the essence of life, "[...] and this is quickly transformed into a sanctuary and heritage. The genome becomes, then, a fetish, fear generator as much as a fascination generator"(ATLAN, 2013, p. 171). The conception of DNA as a "program" is based on the principle of cause and effect, attributing to DNA the unique power to form a life such as the sequence written in its molecular bases. It disregards in this conception, the multiplicity of relations between the bases of the DNA itself (and, let's say, there may be many bases due to the size of the molecule), as well as the environmental interference on those relationships.

Therefore, the teaching of Biology, with regard to DNA, currently needs to reconfigure the linearity proposed in teaching materials and in the classroom discourse. In addition to that, it is important to bear in mind an understanding of life as something sophisticated, bringing the concept of DNA closer to a system that requires integration and, at the same time, complexity and dynamism in relationships. Atlan states that:

> Stable states of the network would modify the activity of certain genes, so that certain metabolic reactions dependent on this activity would cease, while others would be triggered, producing a modification of the structure of the network. Metabolism would thus be taken by another dynamic, different from that first order, towards a new stable state and so on… (ATLAN, 2013, p. 163).

Perhaps, the network structure, so called by Henri Atlan, would be configured as an alternative to program character, which, in turn, is very present in basic education textbooks. This discussion will be carried out in sequence, with the data analysis presented here.

III. The Pnld Biology

A popular resource in the educational process is the Textbook (LD). It is a work written by competent experts in the field, which has a common format. It includes school knowledge, fixation and complementary activities, experiments, illustrations, photographs, maps, guides for teachers and students, complementary readings, websites, applications, movies, among others. The LD is not a work directly linked to equipment or technological resources. In general, it is characterized as a print, very well accepted by the school community.

In Brazil, in 1929, the National Book Institute (INL) was created, an agency of the Ministry of Education (MEC), whose objective was to organize and systematize actions around textbooks. Almost ten years later, Decree Law No. 1006 of 12.30.1938, instituted a National LD Commission (CNLD) that was responsible to organize the LD for production, testing, and indications, among other things.

Among numerous restructurings in the field of democratization of LD was in 1985 that instituted in the country the National Textbook Program - PNLD. And, in 2004, the National Plan of Textbooks for High Schools (PNLEM) was implemented in order to provide the distribution of textbooks for public high school students throughout the country, by Resolution No. 38 of the Fund National Development of Education (FNDE) (BRASIL, 2019).

The FNDE is the agency responsible, together with the Ministry of Education, for the operationalization of the LD Programs throughout the country (FUNDO NACIONAL DE DESENVOLVIMENTO DA EDUCAÇÃO, 2015). After the implementation of the PNLD in 2004, it was only in 2007 that the Biology LD began to be distributed to all students and teachers in public schools across the country, with the exception of the State of Minas Gerais (idem, 2015). Since then, the collections of textbooks for the area of Biology in High School have been evaluated by teachers and specialists in the area, and then sent to schools. Among a number of works that arrive at schools, teachers choose the one they believe is most relevant, and the books are distributed free of charge to students at the school. Once adopted, the books are used for a triennium.

We observe, based on our practice as teachers, that the textbook is the most used didactic resource for the teaching and learning process in the classroom. Although the present LD is presented as a reflection of the school curriculum, many times, it articulates knowledge that present epistemological barriers in relation to the complexity of the phenomena approached (and SOUZA ROCHA, 2017).

In this sense, the epigenetic approach to DNA can be characterized as the most current within the teaching of Biology in elementary school, considering DNA as a given data in a complex cellular and environmental system. Keller (2000, p. 51) […] equating the genetic material of an egg with the magnetic tape of a computer does not in itself entitle us to regard that material as encoding a 'program'; it might

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just as well be thought of as encoding 'data' to be processed by a cellular 'program'. Or by a program residing in the machinery of transcription and translation complexes. Or by extra-nucleic chromatin structures in the nucleus. Computers have provided a rich source of metaphors for molecular biology, but they cannot by themselves be held responsible for the notion of 'genetic program'.

It is important to emphasize that this research is not limited to pointing out conceptual errors, ideologies, graphic representation or methodological aspects presented in the textbooks of the last PNLD, adopted by teachers in schools in the State of Paraná. The objective is to build new terminologies for the mediation of school knowledge by Biology teachers in the use of textbooks adopted, in order to integrate new knowledge into the school curriculum. To this end, we seek to answer the following problem-situation: what are the conceptions about DNA used by teachers and reinforced in textbooks for and in teaching Biology?

IV. Methodology

The methodological approach of this research was quali-quantitative, interpretive in nature, with the analysis and categorization of questionnaires answered by teachers and the content of textbooks adopted by them with regard to teaching Biology and, more specifically, the DNA molecule.

According to Minayo (1997), a social research, as carried out in education, quantitative and qualitative data complements themselves, a fact that contributes to a more thorough analysis of the research problem as well as to the discussions and closing remarks.

Thus, within the universe of this research, we organized all the material as an instrument for data collection: questionnaires carried out with 10 (ten) Biology teachers of Basic Education in the State of Paraná and 8 (eight) LD from PNLD teachers for the years of 2018-2020 received and used as teaching material by these teachers.

In possession of the answered questionnaires and the books as material for analysis, the codification of these data was carried out, according to the adopted scientific educational concepts, so that we could then choose the following premises for appreciation, that is, the categories of analysis:

a. DNA as program/linearity and reductionism in the DNA teaching process preformationism conception program;
b. DNA as data/network structure and complexity/ epigenetics, both for teachers and for textbooks adopted.

a) Data extraction

The possibility of understanding how the systematization of knowledge articulated in the school occurs, mediated by teachers and presented by the adopted textbooks, leads us to present the context of school knowledge in Biology, as well as to point out more appropriate terminologies for the treatment of DNA with regard to episteme of knowledge that is systematized in a complex way.

Next, we present the instruments that we used to collect the data for this research.

b) Questionnaires

To analyze the conceptions of biology professors about teaching DNA, a questionnaire with 13 (thirteen) questions was constructed. These questions were related to teacher education (Degree in Biology, Specialization, Master's and Doctorate), the time the teacher teaches and the conception of DNA based on the discourse they used in the questionnaire.

The objective was to identify by means of probe questions whether the DNA is understood as a program or as given data and to what extent the LD influence the teachers' discourse in the classroom while preparing their lessons on DNA, protein synthesis and the epigenetics.

The ten (10) teachers participating in this research responded to the questionnaire, which adopted the ethical aspect of confidentiality of all information provided by professionals. The answers collected allowed us to analyze the conceptions of DNA mediated by the professors in the classroom in the discipline of Biology.

c) Textbooks

Collections of Biology LD analyzed are part of the collection distributed by the Government of the State of Paraná, provided by the Federal Government. There are 10 (ten) books that were sent for analysis by teachers in 2017 for the 2018-2020 triennium. Of these books, we carefully analyzed 8 (eight) of them under the focus of the presented methodology, all of which are part of the PNLD. The discrepancy between the number of textbooks sent by the Government for analysis and those carefully analyzed in this research was due to the teachers participating in the research not pointing out the arrival of all of them in their schools for analysis and choice.

After analyzing the responses of Biology teachers and the theoretical framework of textbooks adopted in this triennium, the inferences and critical-reflections are presented in sequence, as well as some notes according to the scientific community in the educational area.

V. Presentation and Discussion of Data

This work aims to look at and analyze the concept of DNA the basic education teachers draw under, as well as the LD used by them under the perspective of Henri Atlan which allows an opening to

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problematize fields in relation to the concept of DNA that is mediated in the classroom.

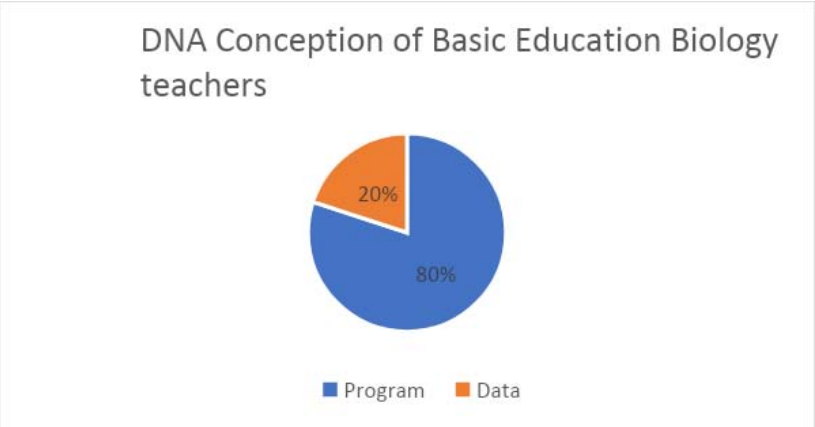
For Henri Atlan (2013, p. 157) "the notion of genetic program is the most fruitful metaphor in Biology today [...], but this is nothing more than a metaphor that allows naming a set of mechanisms that are still not well known". Still, for the author, understanding the ideas of the complexity of DNA and that the genetic is not just in the gene, constitutes one of the challenges of complexity.

In view of this, the data collected from the questionnaires conducted with participating teachers of this research and the LD adopted the same last PNLD was analyzed. Then, a general parameter is presented on how the approach to the DNA theme occurs in the classroom and corroborates the statements of the DNA metaphor proposed by Atlan, in order to contribute with scientific-educational knowledge for the use of more appropriate terminology for the educational context, that which is linked to scientific and technological development.

a) DNA as a program/linearity and reductionism in the DNA teaching process/ preformationism program

According to Atlan, in program design, DNA will always perform the same functions, as expected from a computer program. For him, "[...] the program operates on the data and processes it. The same program will always carry out the same operation, which will always have the same structure [...]" (Atlan, 2013, p. 159-160), that is, the knowledge of epigenetics and the influence of the environment ceases to be valid when DNA is treated like a program.

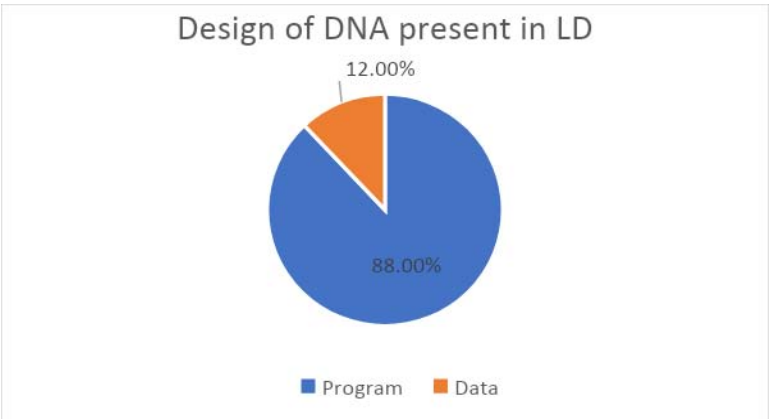
Thus, the analysis of data from the questionnaires and LD adopted by teachers show that the DNA characteristics as a program was the approach mostly used by the participating teachers. Both the responses of teachers, as well as in the analysis of LD have shown that to characterize DNA as program in a concept of linearity and also reductionist, has been the teaching focus for both those who teach as well as those who write the LD for students. These data are quantified next and shown in Graphs 1 and 2:



Source: The author based on research data

Graph 1: DNA conception of Basic Education Biology teachers

It was found in the questionnaires answered by the teachers that 80% of them categorically state that DNA is a program. And when the teachers' response is related to the content present in the textbooks adopted, it is verified that the latter also takes an approach of DNA linearity, as we quantified in the graphs that follow:



Source: The authors based on research data

Graph 2: Design of DNA present in LD

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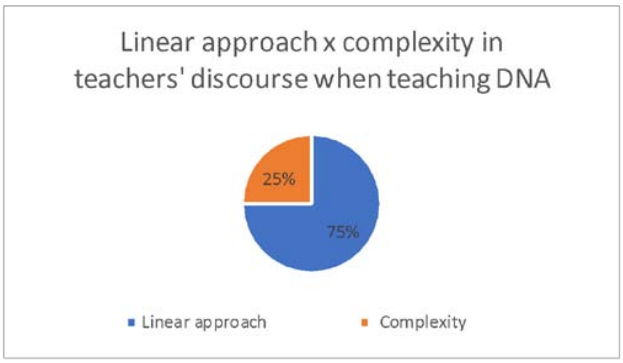
As for the DL, of the 8 (eight) analyzed, approximately 88% address the concept of DNA as a program, referring to it as a "template", "carrier of genetic information" or simplifying its performance with the following metaphor: " changing the number and sequence of the letters, we alter the phrase". Only one work puts DNA in the condition of data. It emphasizes that "DNA contains information regarding the structure and functioning of the organism, yet it is only part of a complex mechanism", providing DNA with a characteristic of data that, when combined in different ways, acts on the complexity of gene performance. As for the DNA approach, the professors state that the LD collection adopted in the last triennium approaches DNA superficially, considering the DNA - RNA - protein linearity, without approaching the cellular mechanisms regulating gene expression, and epigenetics.

Still, we observe quantitatively that the discourse of 75% of teachers participating in this research, the whole is constituted as the sum of the parts, when referring to DNA as a program. In a complex approach, recognition of the DNA concept is not linked to the parts, but to its internal and external interrelationship, that is, between the concept of DNA and the environment in which it is found, as shown in Graph 3:



Source: The authors based on research data

Graph 3: Linear approach x complexity in teachers' discourse when teaching DNA

Still, when questioned about the Human Genome Project (PGH), all the participating teachers answered that the objective was to map, identify and demarcate genes in order to know how each one of them works. It is observed in this question, that the idea of "mapping" and "establishing" within this mapping is to identify exactly what each gene did/does. Once again, we notice the linearity present in the teachers' conception of DNA. This makes us wonder whether really the design of DNA data as part of the conception of the universe of the participating teachers in this research and the how urgent is the mediation of knowledge networked, in contemporary times, to the classroom.

This same linearity was found by Joaquin and El- Hani (2010, p. 94) when they carried out a study on the need to revise the gene concept. For the authors, the PGH also conceptualizes the gene in a reductionist and linear way, "in a classic molecular model, according to one in which a gene is a DNA fragment that encodes a functional product (polypeptide or RNA)". It is also important to mention at this point that very little of the new knowledge about the advances found in Molecular Biology actually reach the classroom, as shown by the analysis of the data results of the questionnaire regarding teachers' conception or by the textbooks adopted in the last PNLD in the State of Paraná.

For Joachim and El- Hani (2010), to review the concept of the gene as a DNA fragment encoding a protein require that research with so-called junk DNA, micro-RNAs, si-RNAs, pseudogenes, Retrogenes, silencing genes, among other knowledge elaborated in the post-PGH, are didactically transposed in the textbooks and presented to the teachers. This can occur in processes of initial and continuing education, which become part of the knowledge mediated by teachers in the classroom, as it provides students with an understanding of the complexity of the gene/DNA, for example, in the formation of the characteristics of eukaryotes:

> The meaning of a gene is not contained in the nucleotide sequence of DNA, but emerges as a process involving the system by which genes are interpreted, including the cell and, in a series of flukes, the supracellular environment. Thus, genes are not given in the DNA, but are made by the cell. This vision is, for researchers, fundamental to the understanding that it is not the DNA that controls the cell, it is not the DNA that 'does things' with the cell, as is often taught, but the cell is the one that 'does things' ' with DNA, which is a repository of useful biological information and not a catalyst for processes or a development program or a cell controller (JOAQUIM and EL-HANI, 2010, p. 110-111).

Thus, DNA gene review of the concept proposed by El-Joachim and Hani supports the proposal advocated here by Henri Atlanta Georgia (2003, 2006 and 2013) to treat DNA as a data set used by the cell as its biological mechanisms and interaction with the environment.

Therefore, both the teachers' discourse and the textbooks adopted for teaching Biology contributed to this analysis and conclusions of how DNA has been

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mediated in the classroom with our students. A mediation that aggregates conceptions of DNA as a program and not as data, demonstrating the linearity of working with the theme in question. Although Biology is conceived within the Newtonian mechanistic model, new studies point to a paradigm shift regarding the concept (Atlan, 2003, 2006 and 2013) and, therefore, a differentiated proposition needs to be proposed in order to advance towards teaching Biology as a complex approach.

Thus, when considering the complex approach to knowledge, it is important to take into account disorder and chance, circularity, unity in multiplicity and contradiction. For Morin (2006), with regard to studies of complexity, it is necessary to adopt a notion of 'system' as one of the operators of knowledge. With this research, the potential in mediating the concept of DNA at school through and in complexity is pointed out. Terminologies based in the 'complex systems', which give the non-linearity of the DNA concept reveals in fact how this molecule behaves in a 'system', for example.

Therefore, it is important to emphasize the need for knowledge mediated in the school curricula be linked to approaches which have been discussed and presented in the academy (wise learning) going through successive transpositions Teaching (Chevallard, 2013) until these are embedded to the school's curriculum and textbooks (learning to teach).

This review of concepts, both in textbooks and in the discourse of teachers is extremely necessary, considering that the reductionist thinking does nothing to contribute to the students' adequate appropriation of the form and function of DNA in cells. For this reason, DNA needs to be understood as a networked and extremely complex data structure, as presented and discussed below.

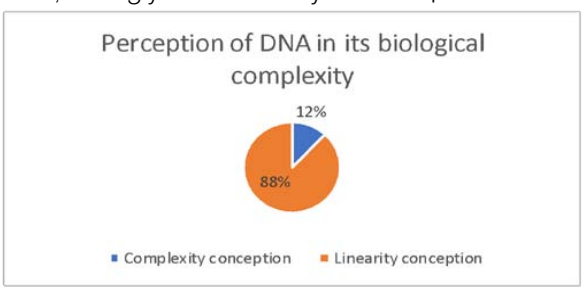
b) DNA as data/network structure and complexity/ epigenetics

We rely on authors as Henri Atlan and Edgar Morin, which contributed with their research in recent decades as they warn us that the complexity relates to an interaction between systems. An approach defended by Atlan (2013) is DNA as data in a systemic and quite complex structure, understanding that, as "data" is observed, DNA has multiple possibilities of combining these data in a dynamic process, strongly influenced by the gene regulation of each cell type and by epigenetic mechanisms.

This epigenetic approach appears very timid in the textbooks analyzed in this research. It is important to emphasize that, a priori, it focused on the teachers' discourse about the design of DNA and how it is reinforced in the textbooks adopted by these professionals in their schools. However, we carefully analyze these adopted textbooks, according to the epistemic foundations presented and discussed, because of the expressive number, a total of 60% of the professors participating in the research, do not know the term and choose not to answer the question, or even, they do not notice the presence of the concept or research with epigenetics in the adopted textbook. From the teachers who answered the questions in the questionnaire: "In the Biology Textbook adopted by your school/college in the last National Textbook Plan (PNLD) how is the theme DNA approached? Does research with epigenetics appear in the chapter that addresses the topic of DNA?", the analysis of the participating teachers answers shows that "DNA is approached in a very theoretical and traditional way, with indications for further complementary readings and the epigenetics is practically non-existent" (teacher 1), or even, "there are few subjects that deal with questions about epigenetic research" (professor 7).

In this aspect, it can be seen from the analysis of the data collected, that the statement of teachers is closely linked to the LD they adopted. From the eight (8) LD analyzed only one (1) presents the epigenetic conception of DNA (as given) and systematizes it as content for High School. Therefore, the present discourse of teachers in the State of Paraná on DNA is strongly based on the textbooks adopted, in which the reductionist/linear approach predominates.

In a DNA-as-data approach, the complexity of cell-DNA interactions are important factors to be considered in teaching and, therefore, recent epigenetic research needs to be present in textbooks, as well as in the knowledge of teachers in the classroom. According Atlanta Georgia (2013), a paradigm shift occurs to the extent of the linearity (DNA-characteristic) becomes considered from the complex (DNA-epigenetic). Unfortunately, it can be seen from the data collected that this paradigm shift is still a long way off, as shown in Graph 4.



Source: The authors based on research data

Graph 4: Conceptions in teaching DNA

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This way, we found that only 20% of teachers participating in this research can visualize the DNA as a data set that operates on functions of different cell situations, but only the relative percentage to 10% of these, present justifications for such an approach as, for example, what we call teacher 8: "I try to demonstrate that even the portion of DNA that is not part of a gene has or can have a future function", that is, an understanding of DNA as a given, just like Henri Atlan (2003, 2006 and 2013), proposes in the study of the same.

The teachers discourse, when considered collectively, it is a given data that obscures the phenomena of interrelations at different levels of activity. What we mean is that it is determinism rooted in positivism, even today, it is responsible for explaining the very phenomenon of life. This occurs in the teachers' discourse (although few still present conceptions of DNA as data), and they end up reinforcing this concept with the program approach, as well as in the adopted textbooks. We observe that teachers do not have a critical and reflective position to problematize and place this situation/condition at the center of controversies in the classroom.

On the other hand, when we consider DNA within a systemic and complex approach, it naturally starts to dialogue with uncertainty and chance. DNA as a network structure is dynamic and at the same time contemplates order, disorder and self-organization, which means pointing to noise (Atlan, 2013). The noise considered from Shannon's Communications Theory is a random element, which includes a set of communicative meanings and provides new ways to arrive at an answer, according to Henri Atlan. This does not mean that we are denying determinism and the laws that govern science as a whole, but we want to point to a complex structure that must be considered in order to propose the construction of new knowledge. And, in particular for this research, in which we point out such terminologies discussed as appropriate for classroom work as with the concept of DNA.

Inserting the concept of epigenetics as a branch of biology that "studies change in gene functions without changing the base sequences (adenine, guanine, cytosine and thymine) of the DNA molecule" (Fantappie, 2013, p. 1) is one of the factors that will contribute to the systemic and complex design of DNA. Another factor to be considered is to include in the school contents of the biology textbooks, the study of the history and philosophy of science in relation to DNA studies, so that teachers understand how reductionist concepts change with new research in the field of Genetics and Molecular Biology, transforming a mechanistic-reductionist paradigm into a thought of complexity.

VI. Final Considerations

The results of this research demonstrate the reductionist and genetic program vision when addressing DNA in the classroom with Basic Education students. Both the teaching material used by the teachers, in this case the textbook, as well as their discourses point to this path.

After so much research in the area of Molecular Biology, Genetics and currently the knowledge of Epigenetics, it is necessary to review the contents of the textbook that refer to DNA, addressing the issue in a more complex and interrelated way, inserting the concept of "data" in approaching this molecule and avoiding DNA-RNA-protein linearity. We observe that such an approach is so common and that it leads to errors of cause-effect, part-whole and it is reproduced in the discourse of teachers in the classroom.

Referring to the DNA as a set of data, the Didactic Transposition with their relationship between knowledge wise, learn to teach and taught knowledge forwards to include in the school knowledge research developed mainly in the last five decades. It is essential that the complex mechanisms of gene expression, which involve numerous studies of DNA, but also of RNA, proteins and the cellular environment that act in the phenotypic determination of genetic characteristics, be present in the school's curricula.

According to Atlan (2013, p. 165) "until now, these phenomena of epigenetic heredity appear as anomalies or exceptions compared to the tendency of everything that relates to genetic determinations in the form of DNA sequences. Therefore, they are relatively little studied, even more as the necessary techniques are more complicated and less effective than those for cloning genes and their sequencing".

The above statement by Henri Atlan clarifies the data found in this study, demonstrating that teaching DNA as a program is simpler and easier to justify, while the introduction of epigenetic concepts treating DNA as a data set implies systemic knowledge from the authors of the textbooks to carry out the didactic transposition adequate to the theme, and it also demands from the biology teachers a continuing education so that the idea of DNA as a complex system is explicit in their classroom discourse.

For Keller (2000) "the deterministic role of genes to produce traits may have been taken for granted by many, but their control, regulation and biological context at the cellular level was seen as interactive" and, therefore, complexity tests are essential for teachers to produce materials in an interactive and integrative DNA-cell perspective while, in the collective construction of knowledge, it enables students to understand the hologram of the cell. Therefore, inserting the complexity of scientific knowledge, understanding Biology and the study of life beyond disciplinary fragmentation, teaching

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about DNA as a set of data with different combinations and performances, as shown by recent discoveries in Molecular Biology, is a challenge for the development of teaching materials that address this perspective, as well as teacher continuous education with the aim of updating them to this new terminology in the paradigm of complexity and, "consequently, it can be conjectured that knowledge in modern genetics and genomics can neutralize beliefs in the excessive attribution of trait formation to genes and, therefore, beliefs in genetic determinism" (Gericke et al., 2017, p. 1251), because the first approach, the analytical one, led to the fragmentation of knowledge and, therefore, we need to reconstruct it to better teach (ROSNAY, 2013).

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