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Use of a Historical Episode to Teach about Science: Contributions from Fleck[1]

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ABSTRACT

The theme of this study is the History of Science and Fleck´s epistemology (2010), aiming to contribute to science teaching. The objective was to present the historical episode of the social construction of DNA, and its contributions to science teaching through Fleck´s epistemological analysis. Therefore, it proposes a discussion about the elements of the Nature of Science and Technology that appear in the historical episode chosen. When teaching science, every teacher adopts an epistemology of science, even if unconsciously. If this epistemology is not based on the New Philosophy of Science, which is opposed to positivist science, certainly its epistemological vision is based on the empirical-inductivist view. Fleck presented an epistemological model that can be used for historical analysis and his categories of analysis help to understand elements of the social construction of science. This is a qualitative study including document research and historiographical analysis. Fleck´s epistemology was used as the methodology of analysis, through the following analysis categories: thought collective, thought style, harmony of illusions, and emergence of a scientific fact, among others. The main results pointed out that the scientific knowledge has a historical trajectory. For example, in the history of DNA, the idea of heredity appeared first, but the molecule responsible for hereditary transmission was not known. Next, it was believed that proteins were the most complex molecules and, therefore, responsible for genetic inheritance. Finally, a crucial moment in the history of science was the presentation of the molecular structure of DNA as a double helix. Watson (1928-) and Crick (1916-2004) introduced a new style of thought and the emergence of a scientific fact, in which new events started to be discussed and developed in science. In addition to the internal factors related to the scientific knowledge, this historical episode revealed some nuances of the scientific activity such as ethical issues, competition among scientists, gender inequalities, etc., which are essential and must be included in the teaching “of” and “about” science.

KEYWORDS: History of DNA. Features of science. Fleck´s epistemology. Thought Collective. Thought Style.

INTRODUCTION

The History of Science along with Ludwik Fleck's (1896-1961) epistemology in the teaching "of" and "about" science form the theme of this research. The objective of this study is to present the social construction of the molecular structure of DNA and its possible contributions to science teaching, based on the Fleckian epistemological analysis.

Ludwik Fleck was a Polish-Jewish doctor and microbiologist who survived the Holocaust in World War II. As he was a specialist in the typhus vaccine, he secured his life, that of his wife and son during the War by working for the Nazi government (CONDÉ, 2012).

In 1935, Fleck wrote his magnum opus "Genesis and Development of a Scientific Fact", opposing empirical-inductivist science. However, due to anti-Semitic persecutions and for bringing innovative ideas that confronted the ideas of hegemonic science, his book was not known at the time. Almost thirty years later, in 1962, Fleck was cited in the preface to "The Structure of Scientific Revolutions" by Thomas Kuhn, a publication that obtained great success in the scientific and technological scenery of the time. After being mentioned in Kuhn's work, Fleck became known in the academic field and sociologists of science (such as Robert Merton) translated his work into English in 1979. After the 1980s and 1990s, Fleck's epistemology became increasingly important and better known to the general public (CONDÉ, 2012; 2017; SCHÄFER; SCHNELLE, 2010). Its translation into Portuguese only occurred in 2010; however, its use in Science Education research has increased, especially in Brazil (LORENZETTI; MUENCHEN; SLONGO, 2013; 2018).

According to Schäfer and Schnelle (2010), Ludwik Fleck could have been a classic of science theory, as was Karl Popper (1902-1994). However, Fleck's work was unsuccessful since many of those who could have been his interlocutors had already emigrated from the Germanic domains. Condé (2018) also stated that Fleck presented us with a robust epistemological model for writing the History of Science, based on biology and medicine, which makes him different from other philosophers of science, such as Popper and Kuhn, who followed traditional physics.

Fleck (2010) understood that there is a third element belonging to the perception of facts, namely the state of knowledge, which is dependent on the Collective and the Thought Style for a coercive action. In this way, the subject is trained to perceive the facts, his thought is not individual, but belongs to a collective thought and a style of thinking, with no possibility of neutrality in such production. The object is characterized as a Scientific Fact, thus it is not fixed and can undergo changes, that is, new facts can be found if there are new thoughts. Therefore, Fleck (2010) dismisses the idea of fixed as both thoughts and facts are variable. The concepts present in Fleck's work (2010) dismantle the empirical-inductivist ideas, also criticized by Chalmers (1993).

METHODOLOGY

The nature of the research developed is qualitative, with document analysis, and the data was collected from primary sources. According to Severino (2007),

primary sources in the History of Science are those that have a direct correlation with scientists such as manuscripts, correspondence, personal diaries, class notes, books and classic scientific articles, as well as audiovisual sources, such as interviews, photos, and videos. In this research, the Oregon State University webpage was used for containing a collection of primary source materials. This research theme is the DNA social construction history, which occurred in the second half of the 20th century, and whose primary sources are correlated to the scientists Linus Pauling, James Watson and Francis Crick (OSU LIBRARIES, n.d. a).

The methodological steps were developed as follows: 1) selection of primary sources, including videos, audios, texts printed in newspapers of the time, interviews and historical narratives found on the Oregon State University webpage (Chart 1); and 2) historiographical discussion and interpretation, based on Ludwik Fleck's theory of knowledge (Chart 2). Therefore, the historical context and the scientific work collective construction were taken into consideration.

Chart 1 – Primary Sources Surveyed

Source	Description
Classical Scientific Article by Watson and Crick (1953).	*Molecular Structure of Nucleic Acids: a structure for deoxyribosenucleic acid*., OSU Libraries (n.d. b).
Video 1 (Duration 2’40’’) (1973).	*Pauling Discovers the Alpha-Hélix,* OSU Libraries (n.d. c).
Video 2 (Duration 1’20’’) (1973).	*Pauling´s Involvement with* DNA, OSU Libraries (n.d. c).
Video 3 (Duration 0’40’’) (1973).	*Crick´s Early Attitude Toward* DNA, OSU Libraries (n.d. c).
Video 4 (Duration 1’48’’) (1973).	*Watson´s Early Attitude Toward* DNA, OSU Libraries (n.d. c).
Video 5 (Duration 2’12’’) (1973).	*Initial Investigations by Maurice Wilkins,* OSU Libraries (n.d. c).
Video 6 (Duration 1’38’’) (1973).	*Developing an Idea of the* DNA, OSU Libraries (n.d. c).
Video 7 (Duration 1’53’’) (1973).	*Building a model of* DNA, OSU Libraries (n.d. c).
Historical Narratives by OSU Libraries (1950-1953), OSU Libraries (n.d. d).	
Historical Narratives about Rosalind Franklin (1956-1983), OSU Libraries (n.d. e).	
Text from a newspaper (1952).	*Pauling Answer Passport Rejection with Strong Denial He´s Communist,* OSU Libraries (n.d. f).
Text from a newspaper (1952).	*Dr. Pauling Gets Limited Passport,* OSU Libraries (n.d. f).

Source: Osu Libraries (n.d. a).

To analyze the DNA Historical Episode, Fleck's (2010) epistemology analysis categories were used, based on the work “Genesis and Development of a Scientific Fact”. The Fleckian epistemology concepts involved in this analysis refer to the thought collective, thought style, mutation in the style of thought, harmony of

illusions, esoteric circle, intercollective traffic of ideas, protoidea and scientific fact (Table 2).

Chart 2 – Fleck's epistemology analysis categories (2010)

Category	Interpretation
Thought collective	The way of thinking of a collective, representing a group of people that can be institutionalized, such as the scientific community. It concerns the values, norms, rules of the collective and refers to a history of knowledge, with a specific style of thinking.
Thought style	It is the ability to notice, observe a fact, phenomenon, or object. It refers to the *Gestalt* way of perceiving the world. It is directed perception, which is coercive to the subject.
Mutation in the style of thought	When the thought style changes or is altered. The term "mutation" is used by analogy with its use in biology, in comparison to the Theory of Evolution of Species, which occurs slowly and gradually, just like knowledge.
Harmony of Illusions	When an individual (or a collective) is rooted in a theory to the point of not being able to notice something new and/or a change in the thought style. It occurs when a thought system is well elaborated and closed, it becomes difficult to accept new perceptions, or a new thought style.
Esoteric circle	This represents the circle of specialists of certain knowledge area. It represents specialist knowledge.
Intercollective traffic of ideas	This is the circulation of thoughts that occur among collectives of close thoughts, which is able to change the perception and create new facts.
Protoideia	This is a pre-scientific idea, somehow vague and confuse, which might be perfected while circulating among the collectives and thought styles.
Scientific Fact	Facts are directly related to the thought style. It is the inseparable association of the knowledge active and passive parts, in which both parts grow with the number of facts.

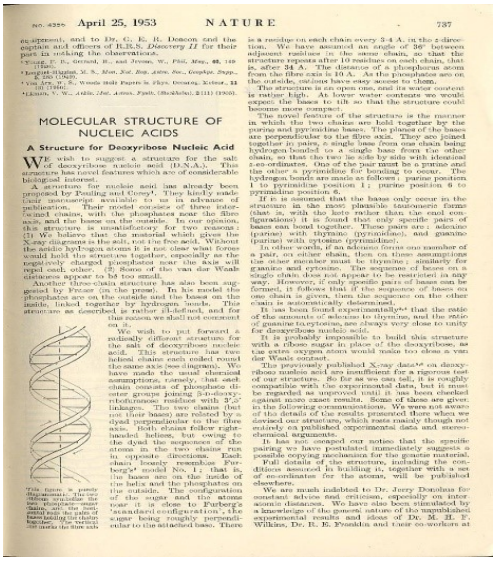
Source: Adapted from Fleck (2010).

SCIENCE HISTORY: ANALYSIS OF THE DNA SOCIAL CONSTRUCTION

In 1953, James Watson and Francis Crick published an article on the molecular structure of DNA in the renowned Nature Magazine (OSU LIBRARIES, n.d. b). An important point to be considered is that the genetic material double helix represented a collective construction of the scientific community, in which scientists from various areas – biology, physics, chemistry – worked to achieve this understanding. For example, the following scientists participated in this search: Watson and Crick (biologist and physicist, respectively), Maurice Wilkins (physicist), Rosalind Franklin (physical chemist), Linus Pauling (chemist), William Lawrence Bragg (mathematician and physicist), among others (SILVA; VIANA; JUSTINA, 2016)

The DNA molecular structure is shown below (Figure 1).

Figure 1 – Publication about the DNA molecular structure in Nature Magazine (1953)



No. 4356 April 25, 1953 NATURE 737

MOLECULAR STRUCTURE OF NUCLEIC ACIDS

A Structure for Deoxyribose Nucleic Acid

We wish to suggest a structure for the salt of deoxyribose nucleic acid (D.N.A.). This structure has novel features which are of considerable biological interest.

A structure for nucleic acid has already been proposed by Pauling and Corey[1]. They kindly made their manuscript available to us in advance of publication. Their model consists of three interwound chains, with the phosphates near the fibre axis, and the bases on the outside. In our opinion, this structure is unsatisfactory for two reasons: (1) We believe that the material which gives the X-ray diagrams is the salt, not the free acid. Without the acidic hydrogen atoms it is not clear what forces would hold the structure together, especially as the negatively charged phosphates near the axis will repel each other. (2) Some of the van der Waals distances appear to be too small.

Another three-chain structure has also been suggested by Fraser (in the press). In his model the phosphates are on the outside and the bases on the inside, linked together by hydrogen bonds. This structure as described is rather ill-defined, and for this reason we shall not comment on it.

We wish to put forward a radically different structure for the salt of deoxyribose nucleic acid. This structure has two helical chains each coiled round the same axis (see diagram). We have made the usual chemical assumptions, namely, that each chain consists of phosphate diester groups joining β-D-deoxyribofuranose residues with 3',5' linkages. The two chains (but not their bases) are related by a dyad perpendicular to the fibre axis. Both chains follow right-handed helices, but owing to the dyad the sequences of the atoms in the two chains run in opposite directions. Each chain loosely resembles Furberg's[2] model No. 1; that is, the bases are on the inside of the helix and the phosphates on the outside. The configuration of the sugar and the atoms near it is close to Furberg's 'standard configuration', the sugar being roughly perpendicular to the attached base. There is a residue on each chain every 3·4 A. in the z-direction. We have assumed an angle of 36° between adjacent residues in the same chain, so that the structure repeats after 10 residues on each chain, that is, after 34 A. The distance of a phosphorus atom from the fibre axis is 10 A. As the phosphates are on the outside, cations have easy access to them.

The structure is an open one, and its water content is rather high. At lower water contents we would expect the bases to tilt so that the structure could become more compact.

The novel feature of the structure is the manner in which the two chains are held together by the purine and pyrimidine bases. The planes of the bases are perpendicular to the fibre axis. They are joined together in pairs, a single base from one chain being hydrogen-bonded to a single base from the other chain, so that the two lie side by side with identical z-co-ordinates. One of the pair must be a purine and the other a pyrimidine for bonding to occur. The hydrogen bonds are made as follows: purine position 1 to pyrimidine position 1; purine position 6 to pyrimidine position 6.

If it is assumed that the bases only occur in the structure in the most plausible tautomeric forms (that is, with the keto rather than the enol configurations) it is found that only specific pairs of bases can bond together. These pairs are: adenine (purine) with thymine (pyrimidine), and guanine (purine) with cytosine (pyrimidine).

In other words, if an adenine forms one member of a pair, on either chain, then on these assumptions the other member must be thymine; similarly for guanine and cytosine. The sequence of bases on a single chain does not appear to be restricted in any way. However, if only specific pairs of bases can be formed, it follows that if the sequence of bases on one chain is given, then the sequence on the other chain is automatically determined.

It has been found experimentally[3,4] that the ratio of the amounts of adenine to thymine, and the ratio of guanine to cytosine, are always very close to unity for deoxyribose nucleic acid.

It is probably impossible to build this structure with a ribose sugar in place of the deoxyribose, as the extra oxygen atom would make too close a van der Waals contact.

The previously published X-ray data[5,6] on deoxyribose nucleic acid are insufficient for a rigorous test of our structure. So far as we can tell, it is roughly compatible with the experimental data, but it must be regarded as unproved until it has been checked against more exact results. Some of these are given in the following communications. We were not aware of the details of the results presented there when we devised our structure, which rests mainly though not entirely on published experimental data and stereochemical arguments.

It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material.

Full details of the structure, including the conditions assumed in building it, together with a set of co-ordinates for the atoms, will be published elsewhere.

We are much indebted to Dr. Jerry Donohue for constant advice and criticism, especially on interatomic distances. We have also been stimulated by a knowledge of the general nature of the unpublished experimental results and ideas of Dr. M. H. F. Wilkins, Dr. R. E. Franklin and their co-workers at

Source: Osu Libraries (n.d. b), Watson and Crick (1953).

Next, the origin of the double helix will be approached by means of the DNA social construction historical episode, which represents a knowledge construction process.

According to Silva, Viana and Justina (2016), in the 19th century, there was already a state of knowledge about genetic inheritance in the scientific scenario. For example, Darwin described the Theory of the Evolution of Species based on the view of inheritance. In the same way, Mendel formulated the first law of genetics considering heredity through factors. In this case, the scientific knowledge about heredity preceded that of “DNA”. From a Fleckian perspective, the knowledge that genetic inheritance was transmitted between generations can be considered a “Protoidea”. However, at that time, nobody knew DNA was the molecule responsible for heredity.

Up to the mid-20th century, the Collective's way of thinking and scientific thought style was that proteins carried genetic characteristics. It was only around 1940 that DNA was considered a structure that could be complex enough to be able to carry inheritable information (SILVA; VIANA; JUSTINA, 2016).

> From Fleck’s historical-epistemological perspective and the reports by biology historians, we can consider that the state of knowledge of that time allowed researchers to consider proteins as the most probable candidates to the role of bearers of the genetic material because the DNA structure was thought to be a simple one. The knowledge available at that time, indicated that proteins were more structurally complex than DNA. It was this state of knowledge, at the time, that imprinted in the scientists’ personality a thought style, that is, certain approach to seek solutions to problems. That state of knowledge might have been responsible for the researchers’ demotivation to try to understand how DNA could be the molecule carrying the genes (SCHEID; FERRARI; DELIZOICOV, 2005, p. 225).

In the collective and thought style of scientist of the early 20th century, there was the belief that only proteins were complex enough to bear the chemical nature

found in the gene. According to historical sources (OSU LIBRARIES, n.d. c), videos 1, 2, 6, and 7, the scientific understanding is justified by the fact that proteins were found in chromosomes, contained 20 or more amino acids, and existed in several observable forms, such as hair, animal horns, and egg yolks, for instance. While nucleic acids were only made of 4 construction blocks, that is, the nitrogen bases, namely: adenine, thymine, cytosine, and guanine.

> Miescher, inserted in a historical-cultural context, mediated by a thought style, contributed to the initial impulse for the understanding of molecular biology. However, one can infer that if the knowledge about the genetic material chemical nature did not advance faster after Miescher's work, it was because the scientific community shared a thought style that led them to believe that the nuclein extracted only from the cell nucleus, was a substance too simple to encompass the highly complex architecture of the genetic material (SCHEID; FERRARI; DELIZOICOV, 2005, p. 224).

In Fleck's epistemology (2010), when the dominant theory or thought style is properly consolidated, it goes through a classical period, constituting the harmony of illusions and, in this phase, only facts that fit perfectly into the dominant theory are observed. For scientists more rooted in the current thought style, it becomes more difficult to break away from it and perceive a new fact. It is believed that biologists at the end of the 19th century did not carry out studies on nuclein (currently known as DNA) because their thinking system was too closed to place expectations on this substance. This new information did not fit the thought style of the time and did not yet represent a phase of complication. In other words, those biologists were in the midst of the harmony of illusions. Furthermore, in the 1940s, Linus Pauling was also at harmony of illusions, since the chemist was focused on research into proteins, rather than on DNA.

As an indicator, in video 1, entitled "Pauling Discovers the Alpha-Helix", Linus Pauling reports on his journey in building scientific knowledge of proteins. That scientist's research problem was "how are polypeptide chains folded in a way compatible with all the knowledge we have about structural chemistry and how can they form hydrogen bonds to keep the parts of the molecule together?" The question clearly shows that Linus Pauling had polypeptide chains as a scientific fact, given his research on structural chemistry. In this way, he carried out the study with a strong focus on proteins and, consequently, arrived at the model of the "alpha-helix" structure before other scientists.

For this reason, Pauling became a reference for Watson and Crick's work from the elaboration of a structure model for chemical substances. Considering the protein structure as presented by Linus Pauling, the alpha-helix represented a helical linear alignment or spiral of atoms of the giant molecules.

Another scientist present in the history of DNA was William Lawrence Bragg (1890-1971), Pauling's competitor in the field of the structure of complex molecules and leader of the Cavendish laboratory, where Watson and Crick worked. Bragg and Pauling had competed for scientific priorities several times since the late 1920s. For instance, they competed against each other in publishing the structures of large inorganic molecules like silicates, and Pauling received the prize. They also fought over the structure of the basic components of proteins, with Pauling beating his opponent in 1951. Bragg was head of Cavendish, in Cambridge, one of the main laboratories in Great Britain. According to the

historical narratives of Osu Libraries (n.d. d), Bragg was unhappy with the fact that Pauling published on the structure of the alpha-helix, that is, the structure of proteins.

In fact, Watson (2014) reported that Linus Pauling's publication on the alpha helix left the Cambridge group in an embarrassing situation. Furthermore, about a year before Pauling's accomplishment, Bragg, together with other scientists (Kendrew and Perutz), published a systematic article on the shape of the polypeptide chain. However, it was an approach that did not solve the relevant problem. According to Watson (2014), Bragg was irritated by the fiasco surrounding his article, and his pride was hurt in a very sensitive area. Over the course of 25 years, there were several meetings with Pauling, and most of the time, Linus presented a solution before Bragg. In Watson's (2014, unpaged) opinion, the Cambridge group needed to face that chemist Linus Pauling was an authority in the subject of structural chemistry at the time. In his words, "[...] we had to face the depressing reality that the world authority in the structural chemistry of inorganic ions was Linus Pauling".

The dispute between Bragg and Pauling would only end when one of them first published the structure of the master molecule of life, that is, the gene. However, the two dedicated their studies to proteins, while the scientific fact to be investigated for this purpose was in DNA. Linus Pauling assumed that he initially did not accept DNA and, in everything that was mentioned about nucleic acid, the chemist changed the nomenclature to nucleoproteins. Furthermore, there was a publication in 1944 by Oswald Avery that highlighted DNA as the potential for transferring genetic characteristics; however, that work was not well accepted by the scientific community.

The Fleckian analysis showed again that Pauling was rooted in the thought style, which believed that proteins were the molecules responsible for heredity, just like Bragg. Both were in the harmony of illusions, including the entire thought collective of scientists who did not understand the potential of DNA as responsible for transmitting genetic inheritance as suggested by Avery's (1944) work. A change in the thought style was needed so that Pauling or Bragg began to dedicate themselves to the study of DNA. It is considered, therefore, that Watson's achievement was thinking of DNA as a molecule complex enough to compose the heredity of the gene. Perhaps, in the absence of such competition between scientists, who sought academic recognition rather than cooperative work, the construction of the molecular structure of DNA might have been consolidated a decade earlier, around 1940. A different scenery could have promoted the circulation of ideas within the esoteric circle, the circle of experts such as Pauling, Maurice Wilkins, Rosalind Franklin, Bragg, Peter Pauling, Watson and Crick, etc. Since the intercollective traffic of ideas, as a communication system results in a change in thinking values, this could have generated small changes or even complete changes in thought style, which could also lead to a fundamental change.

While more experienced researchers focused on building models for protein structures, Watson and Crick were investigating the DNA structure, as they assumed that this scientific fact could lead them to the development of a model. Moreover, as they were part of the "Cavendish" research group, they had the opportunity to access experimental X-ray diffraction studies, that is, Rosalind Franklin's photographs (OSU LIBRARIES, n.d. e).

In the Fleckian epistemology, some of Watson's and Crick's characteristics are observed, which led them to the development of the DNA double helix first. Those characteristics included the fact that they were younger scientists and, therefore, were not rooted in the thought style that considered proteins as transmitters of the genetic material. Also, they were attentive to the scientific community general speculations and dedicated their research to the structure of nucleic acids since they noticed a complexity trend in those compounds.

In "*Crick´s Early Attitude Toward DNA*", video 3, Francis Crick reported that he was also uncertain whether the DNA or the protein was the genetic material since in Cavendish (the esoteric circle Crick belonged to) they were working with the protein structure. Therefore, Crick studied the structure of peptide chains, X-ray diffraction, and remained interested in DNA (OSU LIBRARIES, n.d. c). Watson (2014) reported a quarrel between Crick and Bragg related to protein research. Crick wanted to correct the scientific activities Bragg was developing. However, the latter did not accept the corrections suggested by him and promised that Crick would not continue with him after concluding his doctorate program.

The first attempts to build the DNA molecular structure resulted in a model with three DNA filaments wound into a helix, with phosphate in its nucleus, as proposed by Linus Pauling. From that model, Watson and Crick obtained a copy of "*The Nature of the Chemical Bond*" to look for inorganic ions that met their requirements and considered that Magnesium and Calcium could be a good fit (OSU LIBRARIES, n.d. d).

In his work of 2014, Watson revealed that together with Crick, he carried out a fast reading of the relevant sections of the book *"The Nature of the Chemical Bond"* by Linus Pauling, where they found the correct values for the exact size of the possible inorganic ions. However, such information did not help them to solve the problem of the structure they wanted to assemble.

Furthermore, Watson reported in "*Watson´s Early Attitude Toward DNA*", video 4, that his perception in relation to the DNA structure changed when he understood the complexity that the structure might present when he attended a lecture by Maurice Wilkins. On that occasion, he saw X-ray photographs obtained from crystalline DNA. For this reason, Watson assumed that DNA was the logic molecule to consider. This situation shows that Watson considered a new way of realizing the scientific fact, which means he was open to a new thought style, unlike the other scientists that still believed that proteins played the most important role in influencing genes (OSU LIBRARIES, n.d. c).

According to the historical narratives found in Osu Libraries (n.d. d), Linus Pauling mentioned that the fact that he did not have access to the DNA photographs produced by Rosalind Franklin was a barrier that prevented him from getting to the double helix structure. He believed that the photos would have enabled a better view of that structure. Maurice Wilkins did not send the photographs to the chemist justifying that he needed longer time to appreciate them, but he also informed that he could show them to Linus Pauling if the latter came to his laboratory.

According to Chalmers (1993), the way scientists interpret empirical data depends on the theory guiding such perception and their sight, mainly in scientific thought. Thus, thinking that one would solve the structure first if he or she had the

experimental data refers to Pauling's empirical-inductivist science. The experienced chemist also mentioned the fact that Watson and Crick had had access to Rosalind Franklin's photographs, which according to him was the main reason why those scientists developed the double helix structure. To a certain extent, the experimental data obtained by Rosalind Franklin provided Watson and Crick with the confirmation of what they had been speculating.

According to Watson (2014), Rosalind Franklin's attention was not focused on the structural models, but rather on a standard description of the crystalline X-ray diffraction pattern, which she was still investigating. After attending a lecture by that scientist, Watson concluded that her speech was like a preliminary report that proved nothing fundamental about DNA. This meant to him that the scientist did not have the same interests as him and was not concerned about assembling atomic structures. However, Rosalind Franklin's interest in the DNA molecule was noticeable since she sought further details and characteristics to explain the possible complexity of its structure and, essentially, her technological knowledge production, which was not valued by James Watson in his report.

Watson also referred to Maurice Wilkins's thought regarding Rosalind Franklin's performance at the King's College laboratory. According to Watson (2014), Maurice mentioned that Rosalind produced too many elaborated crystallographic analyses, carried out detailed measurements of the liquid content of her DNA samples, and generated better quality radiographic photographs than those obtained by Wilkins. However, he also stated that she achieved very little real progress since her arrival, and that he doubted she was measuring what she really wanted to. Both male scientists measured Rosalind Franklin's technological knowledge activities in comparison to the scientific activities they developed. This was an unfair comparison since the technological thought is different from the scientific thought. Rosalind Franklin followed action rules, used technological instruments and produced better radiographic images than those produced by Maurice Wilkins. Furthermore, it appears that there was not much dialogue between Watson and Rosalind and, therefore, he could not know much about her academic interests.

When Cupani (2016) addressed the nature of technological knowledge, he stated that technology is a specific way of knowing, which cannot be reduced to a mere application of scientific knowledge. Technology has thinking processes implied in its production, and is a prescriptive knowledge, contrasting with the descriptive knowledge sought by science. Scientific knowledge is "limited by theory", while technological knowledge is "specified by the task". Technological and scientific theories are different and so are the data obtained. While science seeks to establish laws that "govern" natural phenomena, technology creates action rules to originate artificial phenomena or uses devices.

Both types of knowledge, scientific and technological, represent the human ability to think, thus corresponding to intelligence features. Currently, there is technoscience. Technology is no longer a mere instrument, nor can be reduced to know-how. For example, in Cupani (2016), chemical science is classified as a technoscience in a philosophical perspective of chemistry.

The DNA social construction history shows that Watson and Crick developed collective work, since they used previous models to propose a new one. Moreover, they shared all Rosalind Franklin's effort since she refused the DNA triple helix

model by using X-ray diffraction technology. In addition to refusing the triple helix model proposed by Linus Pauling, Rosalind Franklin speculated that the nucleic acid sequences contained an even number, which could be two or four helices. Thus, it is understandable that Watson and Crick did not find the DNA molecular structure by chance, but rather because they were looking for it. Paraphrasing Fleck who observed that "Wasserman did not find his reaction by chance, but rather because he was looking for it [...]" (FLECK, 2010, p. 122).

Therefore, it seems reasonable to assume that scientists do not "discover" facts, but rather study hard to reach expected results, that is, results that are close to the current scientific theory or in a process of formulation. According to Fleck, the word "discovery", commonly found in schoolbooks, would show a better understanding of science if substituted with "invention", which represents a demand for action, creation of facts and scientific and technological occurrences.

Furthermore, it seems relevant to emphasize that despite the existence of a possibility of some scientists having high abilities/being gifted, and on some occasions, have insights, new scientific facts are associated with the collective and thought style, which are coercive to the subject and keep the knowledge history, whose fruit of work is collective and never individualized. This leads to the understanding that "[...] all scientific work is collective work" (FLECK, 2010, p. 84). For instance, in the episode studied, in the construction of the DNA molecular structure, Watson and Crick had previous knowledge, coming from several years of research, including the contribution of several scientists from interdisciplinary areas, namely biology, physics, and chemistry.

> When observing the formal side of the scientific universe, its social structure is obvious: we see collective work organized by labor division, collaboration, preparatory works, technical assistance, exchange of ideas, polemics, etc. Many publications bear the names of several authors that worked together. Apart from those names, in exact sciences works, almost always the name of the institution and its director appear. There is a scientific hierarchy, groups, adepts, and opponents, societies and congresses, periodicals, interchange institutions, etc. The bearer of knowledge is a well-organized collective that overcomes by far the capability of an individual (FLECK, 2010, p. 85).

When studying the origins of the syphilis concept, Fleck (2010) highlighted differences in the conception of such "disease" over five centuries, thus identifying distinct thought styles. The conception of that disease as punishment for sexual desire was among the collective ideas belonging to the religious community in the late 15th century. Later, the "disease" was considered a result of the influence of stars in the perspective of astrologists. After that, the idea that Mercury could be used as a treatment by means of metallotherapy appeared. And finally, the conception of impure blood or syphilitic blood was created and peaked in the development of the Wassermann reaction and the serology in the early 20th century.

Therefore, Fleck's (2010, p. 5) starting point was the idea that the individualist knowledge theory "only leads to a fictional and unsuitable conception of scientific knowledge". In this way, both the sociological structure and the convictions unifying scientists go beyond the individuals' empirical and speculative convictions. In the Fleckian epistemology, an individual alone, no matter how intelligent he/she is, and the technological equipment he/she might have, cannot overcome the ability that the collective has of understanding the entire scientific

view. Fleck exemplified that a doctor alone cannot reach the nosological entity (features) of a disease, only the collective can do that because they have experienced the historical and social trajectory of the fact.

ETHICAL ISSUES IN THE DNA HISTORY

Despite the active participation of Rosalind Franklin in the experimental analysis involving DNA, that scientist never received any recognition in life. In April 1983, James Watson mentioned that Rosalind Franklin did not demonstrate interest in the DNA study since she had never talked to Maurice Wilkins about it. Watson might have mentioned Wilkins for having attended a lecture by that scientist that made him perceive DNA as a molecule complex enough to carry generic inheritance. Such perception would enable the emergence of a scientific fact and, as a consequence, a thought style change.

> Rosalind Franklin was a very intelligent woman, but she really had no reason for believing that DNA was particularly important. She was trained in physical chemistry. I don't think she'd ever spent any length of time with people who thought DNA was important. And she certainly didn't talk to Maurice [Wilkins] or to John Randall, then the professor at Kings (OSU LIBRARIES, n.d. e).

However, Watson did not talk to Rosalind Franklin in person about her technoscientific research to present his conclusions the way he did. Many of his impressions about Rosalind Franklin were in fact opinions expressed by Maurice Wilkins, to whom Watson was more connected. Perhaps, because Wilkins was the head of the laboratory at King´s College, he imagined that Rosalind Franklin "rendered service" to the group and that the results of her research belonged to him since he showed Rosalind's photographs to Watson. As observed in Fleck (2010), in the scientific environment, mainly in exact sciences, collective work is noticed and there is a hierarchy. However, apart from the hierarchy in the scientific world, there was also gender inequality since the scientific work developed by Rosalind Franklin was not valued, and the intellectual property of her activities was transferred to Maurice Wilkins, who shared them with Watson.

In addition, in Watson (2014), some criticism to Rosalind Franklin's appearance was observed, suggesting that she should be more feminine, wear more delicate dresses and change her hair style. On the other hand, no comments regarding her male counterparts' appearance were found in the same proportion. Watson mentioned that Crick was a young man that always smiled and was friendly, but after his argument with Bragg, he became quieter. However, such remarks refer to Crick's personality and the academic situations he faced, rather than his physical appearance. Furthermore, Watson attended a lecture given by Rosalind Franklin about DNA since the young scientist was aware of the need to learn about crystallography and, more, he wanted to know what Rosalind Franklin thought about the issue of molecular structures. However, Rosalind Franklin did not use molecular models in her lecture, which was enough for Watson to conclude that she was not interested in assembling molecular structures since she did not "play with lego", something apparently belonging to the male universe, according to him. This shows clear gender inequality.

According to Silva (2010), Rosalind Franklin was really interested in publishing about the DNA structure, because in July 1953, the scientist published her

experimental data, that is, the X-ray diffraction photos with details in two formats (A and B). However, the helical structure commented in Rosalind Franklin's article was no longer news since Watson and Crick had published the DNA A format in April of the same year. This information was already enough for the construction of the double helix model for DNA.

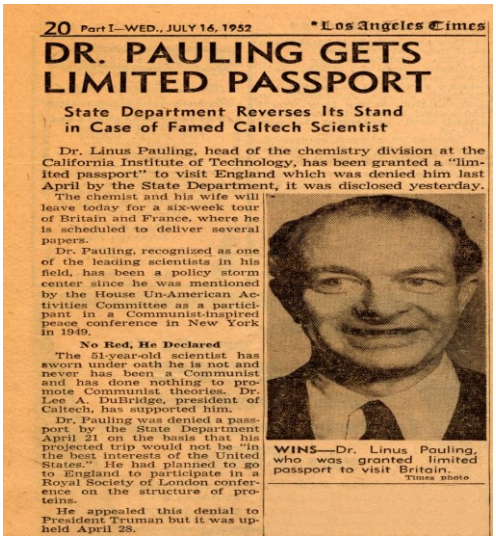
Ava Helen Pauling, Linus Pauling's wife, made a comment about Rosalind Franklin's photographs in September 1977. On that occasion, she questioned Watson's and Crick's ethical character and exposed that both were happy that Linus Pauling could not go to the King's College laboratory, and that both neglected Rosalind Franklin's work, thus denying that scientist recognition for her efforts in the DNA study (OSU LIBRARIES, n.d. e).

> In [*The Double Helix*, Watson] tells about how happy they were, he and Crick, that my husband was not allowed to come because had he come, he would no doubt have seen these excellent photographs that Rosalind Franklin made and had and which, when they saw them, with their other data, they were able to work out the structure of DNA...[If] ever there was a woman who was mistreated, it was Rosalind Franklin, and she didn't get the notice that she should have gotten for her work on DNA (OSU LIBRARIES, n.d. e).

According to Osu Libraries (n.d. f), Linus Pauling had his passport refused the first time he tried to go to England in April 1952, when the government of the United States of America (USA) alleged that his trip to England would not contribute to the country's interests. Pauling even contacted the USA president at the time (Truman), but the refusal was kept. The American State Department considered that the experienced scientist showed some "communist nuances". The chemist had planned to go to England to attend a congress on protein structure. In addition, he would remain a month in England, where he would visit the Faraday society to talk to Sir. Lawrence Bragg and other British scientists. During the trip, Pauling would also visit Maurice Wilkins's laboratory, the King's College, where Rosalind Franklin worked, and observe that scientist's photographs. However, his plans were interrupted with the refusal of his passport. Moreover, Watson found unimaginable that such fact was occurring, that is, Linus Pauling, being considered an atheist and communist by the American government (WATSON, 2014).

Pauling had to declare that he was not a communist or a member of a communist party. Ava and Linus Pauling finally managed to set off to England in August 1953, after the publication of Watson and Crick's article about the DNA double helix in April 1953. Some of this information appeared in the headlines of the Los Angeles Times of California (Figure 2).

Figure 2 – Linus Pauling's restricted passport



20 Part I—WED., JULY 16, 1952 Los Angeles Times

DR. PAULING GETS LIMITED PASSPORT

State Department Reverses Its Stand in Case of Famed Caltech Scientist

Dr. Linus Pauling, head of the chemistry division at the California Institute of Technology, has been granted a "limited passport" to visit England which was denied him last April by the State Department, it was disclosed yesterday.

The chemist and his wife will leave today for a six-week tour of Britain and France, where he is scheduled to deliver several papers.

Dr. Pauling, recognized as one of the leading scientists in his field, has been a policy storm center since he was mentioned by the House Un-American Activities Committee as a participant in a Communist-inspired peace conference in New York in 1949.

No Red, He Declared

The 51-year-old scientist has sworn under oath he is not and never has been a Communist and has done nothing to promote Communist theories. Dr. Lee A. DuBridge, president of Caltech, has supported him.

Dr. Pauling was denied a passport by the State Department April 21 on the basis that his projected trip would not be "in the best interests of the United States." He had planned to go to England to participate in a Royal Society of London conference on the structure of proteins.

He appealed this denial to President Truman but it was upheld April 28.

WINS—Dr. Linus Pauling, who was granted limited passport to visit Britain. Times photo

Source: Osu Libraries (n.d. f).

The American chemist refused to take part in the Manhattan project to produce the atomic bomb, which was highly interesting for the USA, and gave lectures in a conference about world peace. Pauling gave lectures aiming at scientific dissemination, so that the American society could have further information about what occurred in the esoteric circle, the specialist area of that time. For these reasons, the chemist was considered an enemy of the American government, thus having his international traveling limited. In that period, national sovereignty was the most important matter to the USA and, probably, this attitude limited the experienced chemist's scientific production potential. Fleck (2010) observed that political and economic interests might limit the scientific action. This episode also shows that science is not neutral.

SCIENTIFIC AND EPISTEMOLOGICAL DIMENSIONS IN THE HISTORICAL EPISODE

The DNA social construction historical episode was used to illustrate the contributions to teaching about science from Fleck's (2010) epistemological perspective. As a reading of the History of Science, the scientific dimension of the DNA history can be noticed from the epistemological dimension by Fleck (2010) (Chart 3).

Chart 3 – Interpretations of the DNA history according to Fleck's (2010) epistemology

DNA history scientific dimension	**Epistemological dimension DNA history analysis based on Fleck**
Some molecule was responsible for the genetic inheritance, but nobody knew which one.	Protoideia: The heredity notion was a protoideia (or a pre-scientific idea) for DNA 1st moment – Genetic inheritance, heredity factors. 2nd moment – Proteins. 3rd moment – DNA.

Nuclein isolation by Miescher (19th century). Irrelevant study for the scientific community since the importance of DNA (or nuclein as it was called at the time) was not understood.	Thought collective The way of thinking of the thought collective at Miescher's time understood heredity, inheritance, factors, but did not recognize the responsible substance.
Studies on molecular structures (up to the mid-1940s) – Proteins were believed to be responsible for heredity.	Thought collective There were three laboratories interested in research on proteins and/or DNA: 1) King's College from London (Maurice Wilkins and Rosalind Franklin); 2) California Technology Institute- *CALTECH* (Linus Pauling); 3) Cavendish – (Watson, Crick and Bragg).
Scientific thought of the 19th century up to the mid-20th century: proteins are the most complex among the known substances.	Thought Style Genes responsible for heredity present a complex structural form. Nucleic acids are simple substances to support such complexity as the genetic inheritance (as believed by Pauling and Bragg, for example).
Watson and Crick's publication surprised the whole community, especially the most experienced scientists.	Harmony of Illusions Linus Pauling was rooted in the state of knowledge where proteins were responsible for heredity and strong candidates to carry genes. Thus, he focused entirely on them.
DNA presents a helical structure, with a double helix, and is the most complex molecule.	Emergence of a scientific fact and creation of a new though style Watson and Crick build up the DNA molecular structure.

Source: Adapted from Osu Libraries (n.d. a) and Fleck (2010).

There are some elements in the Nature of Science that might go unnoticed in the DNA history. For example, there were changes in the thought style about the complexity of the DNA molecular structure. In addition, there was unification of knowledge, thus indicating that science can be interdisciplinary since when the biology, physics and chemistry areas worked together, they created the DNA social construction and the acceptance of the double helix was immediate since such knowledge circulated throughout the natural sciences, rather than in a specific area only. Another aspect to be considered is that the theory guides the researcher's observation, not the other way around, as thought by the naïve empirical-inductivist scientists criticized by Chalmers (1993). In other words, first the theory is built, and then experiments are carried out and proposals presented to prove it. Therefore, when scientists think the hypotheses for the construction of a theory, they must resort to the existing studies to resolve their research problem. In the DNA history, Watson and Crick believed that DNA was a molecule complex enough to carry genetic inheritance and, thus, worked hard to build its molecular structure. They managed to describe and draw the DNA structure because they were looking for it, it was not a simple "scientific discovery".

In the DNA social construction history, some disputes, competition and inequalities were observed, such as the gender inequality experienced by Rosalind Franklin. Linus Pauling, an experienced and renowned chemist entered an academic dispute to describe the master of life structure. However, the scientific fact he obtained was the protein structure rather than that of the DNA since he lived in the harmony of illusions. Furthermore, political factors hampered his publication of the DNA double helix. William Laurence Bragg, head of the Cavendish research group worked hard to publish better molecular structures than those presented by Linus Pauling but did not achieve recognition of such publications. Watson and Crick belonged to Bragg's group. However, they published the DNA separated from the group, probably due to the argument between Bragg and Crick. Watson and Crick did not give notice of the publication of the DNA double helix since they used experimental data from the King´s College laboratory, run by Maurice Wilkins and Rosalind Franklin. Wilkins received compensation, that is, the Nobel Prize that was later shared, while Rosalind Franklin did not receive any recognition in life (since she died young). Watson (2014) stated that Wilkins knew the DNA complexity and that this could be the molecule carrying the genes. However, Watson did not tell Wilkins that he had been working on DNA but stated to have been researching proteins when asked by Wilkins. That is, Wilkins was naive to believe that Watson was only interested in proteins. Watson (2014) reported that he had researched proteins because that was the interest of the research group that Bragg headed. However, apart from proteins, both (Watson and Crick) also researched DNA.

FINAL CONSIDERATIONS

The historiographic assay presented in this research aimed to show the social construction of the DNA molecular structure and its possible contributions to teaching about science, with elements of the nature of science found in Fleck's (2010) epistemology.

The main characteristics of the Fleckian work focus on the biological matrix, that is, the epistemological model based on biology. In this perspective, scientific knowledge is seen as analogous to evolution processes, which are slow and gradual. The thought style change occurs slowly and gradually too, in a way similar to evolution rather than with abrupt ruptures. From the DNA social construction history, we observed that scientists not always change their opinions, and the more experienced, who are more rooted in a thought style, tend to remain in the closed thought system, thus operating in the harmony of illusions.

With Fleck's epistemology, we understood that in addition to the subject and the object, there is also a third element, namely, the state of knowledge, where influences of the historical trajectory, social and cultural contexts reside. Therefore, apart from the internalist perspective, of how scientific concepts were built, epistemological analyses can also be based on external factors surrounding science, such as social, economic and political instances that influence the scientific fact development in the collective and in the thought style. The DNA history also showed that Linus Pauling was prevented from traveling to England and taking part in a scientific congress in 1952 since he had his passport limited by the United States. Such restriction limited his scientific potential. Thus, the experienced

chemist could not notice the DNA molecule complexity before Watson and Crick's publication in 1953.

The scientists' esoteric circles (biologists, chemists, and physicists) up to the first half of the 20th century, considered the protein structure more complex than that of the DNA. Although DNA had already been extracted in the 19th century, the product of such extraction was called nuclein, and the scientific community was not interested in studying it more deeply. The chemist Linus Pauling, experienced in molecular structures, had great chance to propose the DNA double helix. However, his attempt was a triple helix, based on the protein structure. Rosalind Franklin, who researched X-ray diffraction, discarded the triple helix, thus promoting a new understanding that the DNA could be made by paired bases. Watson and Crick, taking the previously knowledge as a base, built the double helix and realized DNA as a scientific fact, complex enough to constitute the gene.

For this reason, Watson and Crick published the DNA molecular structure before the other scientists and obtained academic merit for the development of their research. However, in addition to the competition among scientists, gender inequality was also observed at the time. Watson and Crick did not tell the King´s College laboratory team about their publication of the DNA double helix. Rosalind Franklin, who worked hard to provide better radiographic photographs did not have her work recognized in life, and endured gender inequality among her peers.

The use of historical episodes in teaching the elements of the nature of science and technology might promote the understanding of the knowledge construction process rather than only presenting science products with applications of knowledge as commonly occurs in the science traditional teaching. Moreover, Fleck's epistemology might optimize the understanding that science results from social, historical, and political contexts, and it holds temporary rather than definite knowledge. It shows that science is a collective activity, where scientists are not alone in their thinking since they are inserted in a collective and thought style. Therefore, it is possible to notice that the scientists' observation is not neutral, but rather loaded with previous theory and knowledge.

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USO DE UM EPISÓDIO HISTÓRICO COMO ESTRATÉGIA PARA O ENSINO SOBRE CIÊNCIA: CONTRIBUIÇÕES A PARTIR DE FLECK

RESUMO

Este trabalho teve como temática a História da Ciência junto à epistemologia de Fleck, visando contribuições para o Ensino sobre Ciência. O objetivo foi apresentar o episódio histórico da construção social do DNA e suas contribuições para o Ensino sobre Ciência, por meio da análise epistemológica de Fleck. Nesse sentido, buscou-se discutir alguns elementos da Natureza da Ciência e da Tecnologia que aparecem no episódio histórico escolhido. Todo(a) professor(a), ao ensinar ciências, adota uma epistemologia da ciência, mesmo que de forma inconsciente. Se esta epistemologia não for baseada na Nova Filosofia da Ciência, que se contrapõe ao positivismo lógico, certamente sua concepção de ciência tem como fundamento a empírica-indutivista. Fleck deixou como legado um modelo epistemológico que pode ser usado para análises históricas e suas categorias de análises auxiliam na compreensão dos processos da construção social da ciência. Como metodologia de pesquisa, utilizou-se a pesquisa histórica, com análises em fontes primárias. Para a metodologia de análise, foi usada a epistemologia de Fleck, por meio das seguintes categorias de análises: coletivo de pensamento, estilo de pensamento, harmonia das ilusões, emergência de um fato científico etc. Como principais resultados, percebe-se que o conhecimento científico possui um percurso histórico e social. Na história do DNA, houve primeiro a ideia sobre hereditariedade, contudo não se conhecia qual molécula era responsável pela transmissão hereditária. Após, acreditou-se dentro do coletivo e estilo de pensamento dos cientistas experientes que as proteínas eram as moléculas mais complexas e, por isso, as responsáveis pela herança genética. Por fim, o momento crucial para a história do DNA foi a representação do modelo da sua estrutura molecular como dupla hélice. James Watson (1928-) e Francis Crick (1916-2004) apresentaram um novo estilo de pensamento, bem como a emergência de um fato científico, no qual novos fatos passaram a ser discutidos e desenvolvidos na ciência. Além dos fatores internos sobre o conhecimento científico, esse episódio histórico revela algumas nuances a respeito da atividade científica, como as questões éticas, as competições entre cientistas, desigualdade de gênero etc., que são essenciais para serem apresentadas no Ensino “de” e “sobre” Ciência.

PALAVRAS-CHAVE: História do DNA. Natureza da Ciência. Epistemologia de Fleck. Coletivo de Pensamento. Estilo de Pensamento.

NOTE

1. A first version of this article was presented in the VII Simpósio Nacional de Ensino de Ciência e Tecnologia (SINECT 2022) [VII National Symposium of Science and Technology Teaching]; however, that article was reviewed and broadened to be submitted to the special edition of the Revista Brasileira de Ensino de Ciência e Tecnologia. VII SINECT Proceedings and Publications (2022): https://sinect.pg.utfpr.edu.br/index.php/anais/.

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