Revista Guillermo de Ockham

Reflection article Open Access

Rhetoric in Modern Biological Thought: A Case Study of Classical Genetics

Retórica en el pensamiento biológico moderno: un estudio de caso de la genética clásica

Lilian Al-Chueyr Pereira Martins[i]

[i.] *University of São Paulo; Brazil*

Correspondence author: Lilian Al-Chueyr Pereira Martins.
Email: lacpm@ffclrp.usp.br

Received: 19/06/2024

Revised: 01/08/2024

Accepted: 28/08/2024

Cite as follows: Martins, Lilian Al-Chueyr Pereira. (2025). Rhetoric in modern biological thought: A case study of classical genetics. *Revista Guillermo de Ockham, 23*(1), pp.175-187. https://doi.org/10.21500/22563202.7128

Editor in chief: Norman Darío Moreno Carmona, Ph.D., https://orcid.org/0000-0002-8216-2569

Coeditor: Claudio Valencia-Estrada, Esp., https://orcid.org/0000-0002-6549-2638

Declaration of interests: The author has declared that there is no conflict of interest.

Availability of data: All relevant data can be found in the article. For further information, please contact the corresponding author.

Funding: None. This research did not receive any specific grants from funding agencies in the public, commercial, or nonprofit sectors.

Abstract

This paper mainly focuses on the book *The Mechanism of Mendelian Heredity* (1915) by T. H. Morgan (1866–1945), Alfred H. Sturtevant (1891–1970), Herman J. Muller (1890–1967), and Calvin B. Bridges (1889–1938). Considered by some as a landmark in genetics, it convinced specialized and not-specialized at the time that the theory was established despite its crucial problems. It aims to discuss the rhetorical devices the authors used to persuade these people. The methodology[1] comprises the analysis of primary sources, in addition to the text by Morgan *et al.* (1915), and secondary sources dealing with the topic, including some works by the author of this article related to the subject and its representation in science. The study concluded that Morgan *et al.* (1915) used their discourse, some drawings, and diagrams, unaccompanied by photographs, mainly in aspects of the theory where evidence was scarce, giving a false impression that all was clear. It is possible to find historical simplification of the facts to reinforce the authors' arguments, lack of discussion of alternative explanations, diagrams representing ideal objects they did not observe, and theoretical examples that conflicted with the numerical data in their previous papers. In addition, they did not present problems or difficulties related to their theory. All this contributed to some problematic features of the theory not being evident and being accepted.

Keywords: history of genetics, rhetoric, Mendelian chromosome theory, *The Mechanism of Mendelian Heredity*.

Resumen

Este artículo se centra en el libro *The Mechanism of Mendelian Heredity* (1915) de T. H. Morgan (1866-1945), Alfred H. Sturtevant (1891-1970), Herman J. Muller (1890-1967) y Calvin B. Bridges (1889-1938). Considerado por algunos como un hito en genética, convenció a personas especializadas y no especializadas, en su momento, de que la teoría estaba establecida a pesar de sus problemas cruciales. Su objetivo es discutir los recursos retóricos que los autores utilizaron para persuadir a esas personas. La metodología comprende el análisis de fuentes primarias, además del texto de Morgan *et al.* (1915), y fuentes secundarias que tratan el tema, incluyendo algunos trabajos de la autora de este artículo relacionados con la temática y su representación en la ciencia. El estudio concluyó que Morgan *et al.* (1915) utilizaron su discurso, dibujos y diagramas, sin acompañarlos de fotografías, principalmente

1. For more information concerning the methodology adopted in this study, see Martins (2005).

en aspectos de la teoría donde la evidencia era escasa, dando una falsa impresión de que todo estaba claro. Es posible encontrar una simplificación histórica de los hechos para reforzar los argumentos de los autores, falta de discusión de explicaciones alternativas, diagramas que representan objetos ideales que no observaron y ejemplos teóricos que entran en conflicto con los datos numéricos de sus artículos anteriores. Además, no presentaron problemas o dificultades en relación con su teoría. Todo esto contribuyó para que algunas características problemáticas de la teoría no se evidenciaran y se aceptaran.

Palabras clave: historia de la genética, retórica, teoría mendeliana-cromosómica, *The Mechanism of Mendelian Heredity.*

Introduction

> *Rhetoric, the art of persuading, has been contrasted with argument and logic since the time of the Greek philosophers. It developed in the second half of the fifth century BC.*
>
> Jacques Jouanna, *Greek Medicine from Hippocrates to Galen: Selected Papers.*

The rhetorical skill involves getting others to embrace certain beliefs, opinions, or judgments the speaker or writer wishes them to adopt. Both sound arguments and rhetorical techniques are part of the scientific discourse, and different trends in historiographical analysis tend to emphasize them as one aspect of scientific writing.

Rhetorical analysis of any discourse (including scientific works) may disclose several relevant features that contribute to effective communication of beliefs, such as attempts (by the author) to convey the impression that they are credible (good character, honest intentions, competence, devoted to the truth and that their opponent is the converse; attempts to influence the readers by appealing to their emotions (admiration, disdain, hatred, fear), interests, imagination, prejudices (including naive beliefs), etc.; persuasive but false or incomplete arguments (use of peculiar examples, analogy, metaphors, authority, etc.); a convincing structure of the discourse accompanied by an adequate style designed to suppress critical thought and lead the readers to the intended beliefs.

Pictorial representations may also be rhetorical devices in science. As Petra Aczél (2016) stated: "The prevalence of images has apparently won over the skepticism of science towards the non-verbal, and thus we can claim that no thinking, learning, and speaking is conceivable without the pictorial-visual taken into account" (p. 69).

As we mentioned in another work (Martins, 2007, p. 78), several authors have dealt with the role and characteristics of pictorial representations in biology (Gilbert, 1991; Lynch, 1991; Taylor & Blum, 1991) with graphs, diagrams, and printed figures. They have recognized visual representation's relevance in persuasive argumentation in scientific work. However, according to Lynch, diagrams are generally used with photographs, graphic sketches, and verbal and written discourse. They include drawings by hand from photographs (Lynch, 1991, p. 213). Even though visual representations do not present the correct image of what they intend to represent (Ibarra & Mormann, 2005), the inclusion of all the items, as suggested by Lynch, makes the representation closer to what it means.

The present paper discusses a particular case of the use of rhetoric in modern biological thought. It refers mainly to the book *The Mechanism of Mendelian Heredity* by Thomas Hunt Morgan (1866–1945), Alfred Sturtevant (1891–1970), Hermann Joseph Muller (1890–1967), and Calvin B. Bridges (1889–1938), published in 1915, during the period known as classical genetics. The analysis will consider using rhetorical devices in scientific discourse to reinforce the authors' argument and the pictorial (visual) representations that we can also deem rhetorical devices.

It is worthwhile to mention that we are dealing with the first decades of the 20th century, in which the knowledge of genetics was quite different from that of today. In 1900, some botanists such as Correns, De Vries, and Tschermak got in the results of experimental crossings some proportions like the ones Mendel (1866/1966) found in his experiments of peas (*Pisum sativum).* After that, several scientists tried to see if getting the same results in other vegetables or animals is possible. Around 1900, biologists generally accepted that each vegetable or animal had a characteristic number (usually even) of chromosomes in their somatic cells (Wilson, 1900, p. 67). However, there were doubts concerning the permanency of chromosomes throughout the cell divisions and their origin. Since the chromosomes disappeared during what we now call interphase and after that appeared in the same places, people did not know whether they kept their individuality. Walter S. Sutton (1902, p. 39), departing his studies with the grasshopper *Brachystola magna*, thought about the existence of a possibility that the association of paternal and maternal chromosomes' pairs and its subsequent separation during division could represent the physical basis of Mendel's laws of heredity. But even in 1903, he admitted its speculative character (Sutton, 1903, p. 231). In the same year, Sutton started his research, a botanist from Columbia University, the same institution as him, tried to elucidate if there was a cytological basis for the Mendelian law of splitting the hybrid race in cotton. There was no reason to believe that the cytological phenomenon in hybrids was equal to those in organisms of pure lines since their offspring usually varied and could be sterile. Cannon observed both regular and irregular cell divisions in the formation of cotton pollen. The last ones produced abnormal pollen, but the first ones were normal. Cannon (1902, pp. 659–660) concluded that the irregular production of gametes could not explain the regular results obtained by Mendel.

The "Sutton-Boveri chromosome hypothesis" (1902–1903) proposed the existence of a relation between the behavior of chromosomes during cell divisions and Mendel´s laws. However, due to the problems presented above, besides others, most of the scientific community did not accept it at that time or even later, such as William Bateson (1861–1926) and Thomas Hunt Morgan[2] (1866–1945).

Morgan and his collaborators Sturtevant, Muller, and Bridges, working at Columbia University with the fruit fly *Drosophila melanogaster* from 1910 to 1915, tried to relate Mendelian principles to the cytological facts of chromosome structure and behavior. Correlating the results of *Drosophila* experimental crossings to cytological observations, they advocated that it was possible to consider Mendel's factors as specific points or *loci* along the chromosomes (Allen, 1972, p. vi).

According to Garland Allen Morgan and his collaborators presented in *The Mechanism of Mendelian Heredity* "a sound and quantitative experimental basis[3] and led several biologists to grasp the fundamental importance of the new science of genetics"

2. Morgan was a strong opponent of Mendelian and chromosome theories until 1910 (Allen, 1978; Martins, 1998; Morgan, 1909). He taught that chromosome theory did not explain tissue differentiation and development since chromosomes are identical in all tissues (Morgan, 1910). Since closely related species may have different numbers of chromosomes, the chromosome hypothesis did not explain evolution (Morgan, 1910). Chromosomes appear to dissolve in the resting phase, thus losing their individuality (Morgan, 1910). The Mendelian theory that the chromosome hypothesis should explain is unacceptable because some cases do not obey Mendel's laws (Morgan, 1910). Boveri's experiments on the physiological differences between chromosomes are inconclusive (Morgan, 1909). According to him, at that time, embryo development depends on the cytoplasm (Martins, 1997, pp. 121–122; Morgan, 1909).
3. According to the historian of biology Garland E. Allen, between 1910 and 1915, Morgan's group constructed the first chromosome maps, attempting to determine the linear positions of the Mendelian factors. They also worked with multiple alleles, lethal genes, and the non-disjunction of chromosome X (Allen, 1978, p. 172). In 1914, Morgan and his students found about two dozen mutants and detected three linkage groups, that is, that seemed to be inherited together (Allen, 1978, p. 163).

(Allen, 1972, p. vi). Stephen Brush commented that soon after the publication of *The Mechanism*, Morgan's theory began reaching a wider audience of biologists (Brush, 2002, p. 510).

Despite the book not presenting new results, and crucial problems concerning the theory still existing (Bateson, 1916; Doncaster, 1915), several people, not only scientists of that time such as Robert Heath Lock (1879–1915) but also historians of science, such as Ernst Mayr (1982, p. 771), agreed that the Mendelian chromosome theory was made consistent by the genetic data presented in *The Mechanism*, in 1915 (Martins, 2010, p. 329).

Since we know that the Mendelian chromosome theory could be deemed well-founded only in the early 1930s, with the presentation of the cytological evidence of crossing-over by Harriet B. Creighton and Barbara McClintock in *Zea mays* (Creighton & McClintock, 1931; McClintock, 1930) and Curt Stern in *Drosophila* in 1931 (Durbano, 2015, p. 63; 2017, pp. 13–26), this work will try to answer the following questions:

1. Which rhetorical devices were used by the authors of *Mechanism* in defending their views or criticizing opposite opinions?
2. Does the presentation of biological data (the result of observation and experiment) use rhetorical devices?
3. Was rhetoric a strategy for convincing readers when sound arguments were scarce?
4. If one attempts to "clean" biological works of rhetorical devices, will they lose their cogency?

In the next section, we will discuss some rhetorical strategies Morgan and collaborators employed in their book.

Discussion: Rhetorical Devices Used by the Mechanism of Mendelian Heredity's Authors

Indeed, Morgan and his co-workers succeeded in calling the attention of biologists who did not work with heredity and people from other fields. However, the book was concerned with the Mendelian chromosome theory of heredity, in which the authors had worked since 1911, and did not present new facts as we mentioned above.

The Mendelian chromosome theory admitted that the nuclear chromosomes were the bearers of the heredity factors, later called genes, physical entities located along them. Additionally, it was possible to relate the behavior of chromosomes during the cell divisions to the principles Mendel (1866/1966) presented in his work with peas (Martins, 2002, pp. 29–33). However, during the first decade of the 20th century, the theory presented many problems and little favorable evidence. Because of this, several scientists did not accept it, including Morgan himself. Among the issues was the individuality of chromosomes, as the theory admitted. They disappeared during interphase[4] and then reappeared in the same places, which left doubts about whether they maintained their individuality. There were difficulties in observing the different phases of cell divisions under a microscope. Furthermore, the relationship between visible external characteristics to a specific chromosome inexisted. Besides that, the theory explained neither the differentiation of tissues nor the evolution, previous Morgan's criticisms (Martins, 1997, pp. 120–122; Morgan, 1910).

4. The period between two successive cellular divisions.

 https://doi.org/10.21500/22563202.7128

Through the book, it is possible to detect different instances of the use of rhetoric by the authors, such as follows:

Simplification of Historical Facts

Most of the evidence presented in the book came from the author's studies on the fly fruit *Drosophila.* However, Morgan, Sturtevant, Muller, and Bridges referred to a theory concerned with all organisms.

In several parts of the book, we can find a historical simplification of the facts. For instance, at the beginning of Chapter 1 of *The Mechanism*, the authors tried to convey that since 1900, the chromosome hypothesis furnished an adequate explanation for the Mendelian theory. They stated: "But in 1900 when Mendel's long-forgotten discovery was brought to light once more, a mechanism had been discovered that fulfills exactly the Mendelian requirements of pairing and separation" (Morgan *et al.*, 1915, p. 1).

However, this was not the historical reality. Around 1900, knowledge about cell division, chromosome nature, and behavior was scarce. Cytological and embryological studies were inconclusive in explaining heredity related to the chromosomes or cell nucleus.

Although cytology and embryology had developed with the use of new fixatives and dyes, immersion microscopes with a magnification power of 2500 times, and immersion objective lenses without chromatic aberration (Coleman, 1963, p. 130; Moore, 1986, p. 617; Portugal & Cohen, 1977), there were still many observational difficulties. In unfixed and stained cells, it was difficult to observe their contents. Additionally, observing the sequence of events in dead, fixed, and stained cells was challenging. People believed that it was possible to introduce artifacts during fixation and staining. On the other hand, the objects of observation demanded interpretation, which depended on the observer's theoretical assumptions (Baxter & Farley, 1979, p. 139; Martins, 2011, p. 272).

Besides trying to convey the impression that since 1900, the chromosome hypothesis furnished the adequate explanation for Mendelian theory, the authors of the *Mechanism* presented their version of the recent history of genetics: "Sutton was the first to present the idea [chromosome hypothesis] in the form in which we recognize it today" (Morgan *et al.*, 1915, p. 4).

Nevertheless, that was not the case since in 1902–1903, there was no cytological basis for Mendel's "laws" because cytological studies used pure types, hereditary experiments used crossbreeds, and cytological phenomena could differ in those cases.[5] Nobody knew what happened during the process in which chromosomes formed pairs during meiosis (synapsis). There were several doubts about whether chromosomes maintained their individuality during cell division (Martins, 1999, p. 270).

Even later, there were still doubts. Leonard Doncaster, an expert in cytology, commented in this respect: The second objection to the hypothesis that the pairing and separation of chromosomes in gametogenesis gives rise to Mendelian segregation is more serious since it is based on the denial that chromosomes behave as described. Some

5. As we mentioned in the Introduction of this article, Cannon tried to elucidate if there was a cytological basis for the Mendelian law of splitting the hybrid race in cotton. There was no reason to believe that the cytological phenomenon in hybrids was equal to those in organisms of pure lines since their offspring usually varied and could be sterile. Cannon observed both regular and irregular cell divisions in the formation of cotton pollen. The last ones produced abnormal pollen, but the first ones were normal. Cannon concluded that the irregular production of gametes could not explain the regular crossing results obtained by Mendel (Cannon, 1902, pp. 659–660). Since the chromosome hypothesis tried to associate the behavior of chromosomes during cell divisions and Mendel´s principle of segregation detected in the crossing results, the research results obtained by Cannon represented a problem to the hypothesis at that time.

observers refuse to credit chromosomes with individuality of any kind,[6] and without some sort of individuality leading to the constancy in the behavior of the hypothetical units "bearing" Mendelian factors, the whole hypothesis would collapse. Others without admitting the conjugation of chromosomes in synapsis, maintain that it is not a mere coming together in pairs, followed by complete separations, but that two chromosomes which pair fuse so intimately as to make separation of the parts almost or quite impossible[7] (Doncaster, 1915, p. 491).

Absence of Discussion of Alternative Explanations

Besides their explanation, Morgan, Sturtevant, Muller, and Bridges did not discuss other possibilities that existed then and were considered by the scientific community, such as William Bateson and Reginald C. Punnett's (1911) reduplication hypothesis,[8] which did not involve chromosomes. For instance, when explaining characteristics that were inherited independently or always inherited together in the results of the crossings in *Drosophila,* they only mentioned their explanation, which involved chromosomes, linkage, and crossing-over. See, for instance, Chapter 3, where they dedicated 26 pages to discussing linkage, and only on three final pages did they mention the reduplication hypothesis, without discussing it.

When the authors mentioned some factors that were always inherited together, they referred to the phenomenon as linkage without saying that it was previously detected in sweet peas by other authors such as Carl Correns (1864–1933),[9] Bateson, and Punnett and Edith Saunders (1865–1945). They also omitted the previous name they gave to the phenomenon, "coupling":

> Since the discovery 1906 of linkage in sweet peas, many cases have been found in animals and plants. In sweet peas themselves, two groups of linked factors are known, one containing three pairs of factors and the other three or possibly four. (Morgan *et al*., 1915, p. 69)

In addition to this, they criticized alternative proposals such as the presence-absence theory[10] or the reduplication hypothesis (Morgan *et al*., 1915, pp. 74–76, 208–222). Concerning Bateson's analysis of the inheritance of the fowl's comb inheritance (Bateson & Punnett, 1905), they criticized the terminology, suggesting replacing it with the terminology used by them in their studies with *Drosophila* (Morgan *et al*., 1915, pp. 216–220).

A. H Trow (2016), who tested mathematically the reduplication and the linkage hypotheses, wrote:

> The publication of the *Mechanism of Mendelian Heredity* by Morgan, Sturtevant, Muller, and Bridges, marks a definite stage in the development of the hypothesis of *linkage* and crossing-over. The author's faith in this hypothesis has evidently become so strong that they

6. Here, Doncaster referred to the cytological studies developed by F. Meves in the chromosomes of salamanders in 1911.
7. Doncaster refers to two studies of chromosomes by K. Bonnevie during the first decade and the beginning of the second decade of the 20th century.
8. Bateson and Punnett (1911) proposed the reduplication hypothesis in the early 1910s to explain the results of experimental crossings in Lathyrus odoratus in which there were a more considerable number of offspring with maternal or paternal characteristics and a smaller number of offspring in which there was a recombination of the characteristics of the parents. This hypothesis considered the cell divisions involved in the formation of gametes and enabled a numerical prediction
9. Correns (1902) presented a complete account of this subject (Brunelli, 2017, pp. 30–31; Sturtevant, 1965/2001, pp. 35–36).
10. The presence-absence hypothesis began to be considered by several scientists from 1905 onwards. Its rejection occurred around 1920. It initially appeared in work by Bateson and Punnett (1905) in a study on the inheritance of cockscombs that could be pink, pea, walnut, or plain. They considered that such inheritance involved several factors, two of which acted. They explained dominance by the simple presence of a factor and the recessive character by the absence of that factor (Bateson & Punnett, 1905; Swinburne, 1962, p. 132). It is essential to mention that it did not involve the location of factors on chromosomes.

> are not unlikely to infect others with their belief, irrespective of any real demonstration of its validity. It seems therefore desirable that the hypothesis should be subjected to independent criticism. Such criticism is really rendered necessary by the fact that although the authors devote much time and space in their book to elucidation of the simple Mendelian ratios, they give no clear coherent account of their mode of explanation of the more complex and troublesome ratios which students of genetics classify under the headings *coupling, repulsion, reduplication,* and crossing-over. (p. 281)

Presentation of Biological Data

When dealing with cytological *versus* macroscopic levels, instead of discussing whether the chromosomes could exchange factors and how it could happen, Morgan and his co-workers presented several macroscopic crossing-over examples without dealing with the microscopic evidence related to the *Drosophila* chromosomes. Although they had some genetic evidence (macroscopic, through the results of the experimental crossings) that suggested that crossing-over could occur in the female *Drosophila*, they had no available cytological evidence from *Drosophila* (Martins, 2010, p. 344).

Morgan and collaborators presented in Chapter 3 several theoretical examples. Let us compare the data presented in the first table in *The Mechanism* (Morgan *et al*., 1915, p. 50) to those given in a previous paper by Morgan (1914, pp. 196–197), dealing with the same factors. It is possible to notice that the numbers are not equal.

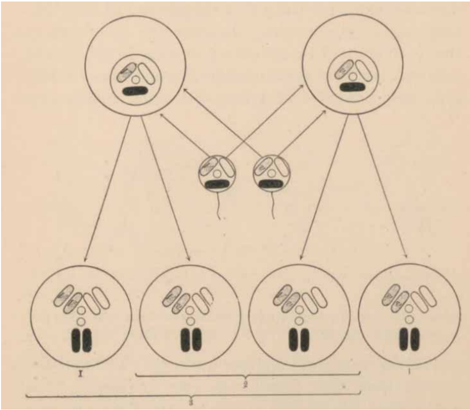
The Use of Pictorial Representations

Contrary to the head of the Department of Zoology, Edmund Beecher Wilson (1856–1939),[11] in his studies on chromosomes in insects, Morgan and his collaborators did not use photographs or photo-diagram pairs in *The Mechanism* (Lynch, 1991; Maienschein, 1991, p. 227) but only isolated diagrams. They presented many drawings and diagrams that showed ideal objects they did not observe, conveying that some problematic features of the theory were not apparent, contributing to the acceptance of the theory inside and outside the specialized scientific community (Martins, 2007, p. 77).

In Figure 1, Morgan *et al.* (1915) represented some results they observed in experimental crossings but did not observe cytologically.

Figure 1

Diagram illustrating the random meeting of two kinds of sperm and two kinds of eggs, showing the proportion 3:1

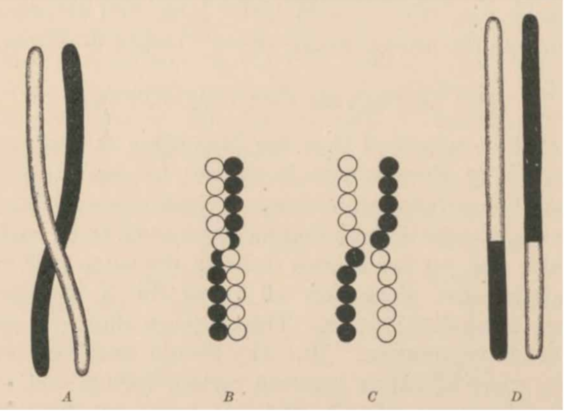


Note. From *The Mechanism of Mendelian Heredity* (p. 12), by Morgan *et al*., 1915, H. Holt and Company.

11. See for instance, Wilson (1909, 1912).

Morgan *et al.* presented linkage and crossing-over as necessary consequences of the theory and not as experimental results that could have other interpretations. To explain the exchanges between chromosomes, the authors used simple, schematic diagrams that did not come from cytological observations (Fig. 2). They did not present the cytological evidence that chromosomes exchanged parts nor estimate when this happens during cell division (meiosis) in 1915. The cytological evidence of crossing-over in *Drosophila* came only in 1931 through the work of Curt Stern (1902–1981), who stated that Morgan's theory was not a theory anymore but a fact (Durbano, 2015, p. 63; Stern, 1931, pp. 586–587).

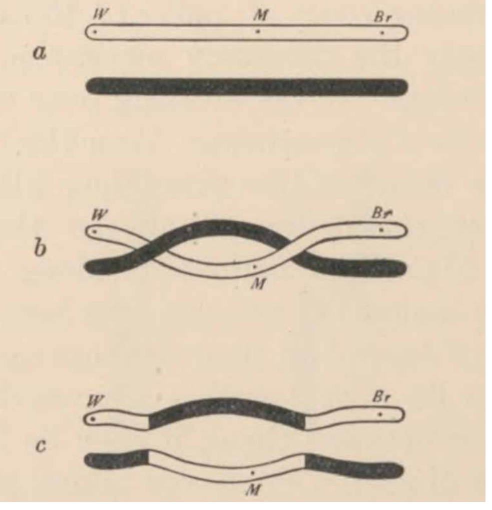
Figure 2
Diagram to represent crossing-over. B and C show the details of crossing over



Note. From *The Mechanism of Mendelian Heredity* (p. 60), by Morgan *et al.*, 1915, H. Holt and Company.

Without the predictions' confirmation, the authors presented different possible models, such as the double crossing-over (Fig. 3), that were also not observed at the microscopic level (Martins, 2007, p. 91).

Figure 3
Diagram to illustrate double crossing-over



Note. From *The Mechanism of Mendelian Heredity* (p. 62), by Morgan *et al.*, 1915, H. Holt and Company.

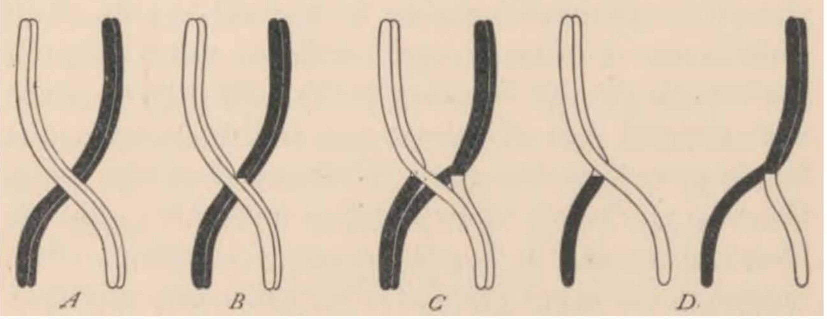
In the diagram below, Morgan and his co-workers reproduced some drawings from Frans Alfons Janssens (1863–1924) related to his cytological studies of some stages of the cell division (meiosis) during the process of formation of the spermatozoon in salamander, *Batracosseps attenuatus* (Janssens, 1909). Looking at them, we saw that the homologous

 https://doi.org/10.21500/22563202.7128

chromosomes twisted several times. Morgan and his co-workers just described them without commenting on them. In the same Chapter, they commented that Janssens' representations were according to their representation in which the chromosomes twisted around each other only once. In this case, the authors of *The Mechanism* were guided by the results of experimental crossings with *Drosophila* since neither Janssens's cytological observations showed that chromosomes exchanged parts nor did their observations in *Drosophila*.

Figure 4

Four stages of crossing over by Janssens



Note. From *The Mechanism of Mendelian Heredity* (p. 133), by Morgan *et al*., 1915, H. Holt and Company.

At that time, Bateson commented in this respect:

> To account for the crossing-over of factors from one chromosome to its mate, Morgan appeals to certain phenomena of twisting and interlacing of chromosomes in synapsis, first made prominent by Jannsens, who observed them in Amphibia. It is suggested that during this process of twisting the chromosomes may anastomose and break again, exchanging parts of their substances. For those unversed in practical cytology, it is difficult to judge how far this hypothesis is in account with observed fact. That twisting takes place in many types, especially Amphibia, is clear; but neither the figures reproduced from Janssens nor the originals from which they are taken—still less the very fragmentary observations of both Stevens and Metz from *Drosophila*—provide more than a slender support for this most critical step in the argument. It is to be hoped that the authors will before long tell us exactly upon what evidence they are here relying. (Bateson, 1916, p. 538)

An anonymous reviewer of the book added:

> Another phenomenon which requires clearing up is the absence of any "crossing-over" in the male for any character whatever, though the number and arrangement of the chromosomes in two sexes are apparently identical. It is of course, not impossible that what now appears to be a weak point might turn out to be a strong one if the cytologist could show that the behaviour of the chromosomes during the maturation division differed in the two sexes. ("The Mechanism of Mendelian Heredity," 1916, p. 118)

The next section will summarize the research results and some conclusions.

Results and Conclusions

Indeed, the theory presented in the *Mechanism* by Morgan and his associates could be deemed reasonably well grounded to some extent. They presented evidence that the chromosome distribution corresponded to Mendelian factors distribution. In some cases, they showed a relation between chromosomes and sex. They also showed that arranging *Drosophila* factors in four linkage groups was possible, and Sturtevant constructed the first chromosome maps ("The Mechanism of Mendelian Heredity," 1916, p. 117). In addition, Bridges related the anomalous condition in a *Drosophila* female to the presence of two chromosomes X and one extra chromosome Y (XXY), showing it through cytological observation (Martins, 2010, p. 356). However, there were still problems and obscure points concerning the theory. It was, particularly in those cases, that the authors used some rhetorical devices throughout the book.

Besides suggesting to the reader that they are presenting something new, they simplified historical facts to reinforce their theory. When they presented their explanation for characteristics that were always inherited together or the cases of the recombination of parental traits in their descendants, they just presented the interpretation of their theory without mentioning other possibilities. For instance, they omitted that the alternative hypothesis to crossing-over, the reduplication by Bateson and Punnet, also offered numerical results and enabled one to make previsions. They presented their understanding of some observable facts (crossing results) without offering cytological evidence, suggesting they had them. They used theoretical examples that conflicted with the numerical data in their previous papers. In short, the Mechanism's authors generally focused on the theory's main points, emphasizing its successes, without mentioning their difficulties (Martins, 2010, p. 360).

Morgan, Sturtevant, Muller, and Bridges presented drawings and diagrams not accompanied by photographs that showed ideal objects they did not observe, conveying that some problematic features of the theory were not apparent, contributing to the acceptance of the theory inside and outside the specialized scientific community.

Besides that, they generally did not present problems related to the theory.

Returning to the questions presented in the Introduction of this article, concerning the first two, we can say that the authors used several rhetorical devices in defending their views, including scientific discourse and pictorial representations. However, this also applied to cases with scarce sound arguments or evidence. In those cases, they appealed to simplifying historical facts, oversimplifying the presentation of biological data and diagrams and drawings showing things that they were not observing but reinforced their theory. They also criticized the terminology employed by the theory, which was accepted then, replacing it with their one. They did not discuss the alternatives to their theory or present problems concerning it. Besides that, they did not mention Morgan's previous criticisms.

Using rhetoric in scientific discourse and visual rhetoric when evidence and argument are sound is a *desideratum*. However, in this case study, rhetoric was often a strategy for convincing readers when sound arguments or evidence were scarce.

We think that "cleaning" biological works of rhetorical devices (including pictorial representations) sometimes leads to losing their cogency since they are necessary and helpful in convincing the reader when the arguments are sound. However, this does not apply to some examples we presented here since they gave the false impression of an established theory when it was not.

References

Aczél, P. (2016). Rediscovering the visual in rhetorical tradition: Persuasion as visionary in suasory discourse. In A. Benedek and A. Veszelszki (Eds.), *In the beginning was the image. The omnipresence of pictures: Time, truth, tradition* (pp. 69–82). Peter Lang AG. https://www.jstor.org/stable/j.ctv2t4cns.9

Allen, G. E. (1972). Introduction. In T. H. Morgan, A. H. Sturtevant, H. J. Muller and C. B. Bridges, *The mechanism of Mendelian heredity* (pp. v–xxv). Johnson Reprint. (Original work published 1915)

Allen, G. E. (1978). *Thomas Hunt Morgan: The man and his science*. Princeton University Press.

Bateson, W. (1916). *The Mechanism of Mendelian Heredity*. By T. H. Morgan, A. H. Sturtevant, H. J. Muller, and C. B. Bridges. Henry Holt and Company, New York. 1915. *Science*, *44*(1137), 536–543. https://doi.org/10.1126/science.44.1137.536

Bateson, W., & Punnett, R. C. (1905). A suggestion as to the nature of the "walnut" comb in fowls. *Proceedings of the Cambridge Philosophical Society*, *13*, 165–168.

Bateson, W., & Punnett, R. C. (1911). On gametic series involving reduplication of certain terms. *Journal of Genetics*, *1*, 293–302. https://doi.org/10.1007/BF02981554

Baxter, A. L., & Farley, J. (1979). Mendel and meiosis. *Journal of the History of Biology*, *12*(1), 137–171. https://www.jstor.org/stable/4330729

Bonnevie, K. (1907). "Heterotypical" mitosis in *Nereis limbata* (Ehlers). *Biological Bulletin*, *13*, 57–83.

Brunelli, A. (2017). *O desenvolvimento do conceito de linkage (1902-1915): uma contribuição histórica para o Ensino de genética* [Master's thesis, Universidade de São Paulo]. Biblioteca Digital USP. https://doi.org/10.11606/D.81.2015.tde-20072015-102850

Brush, S. G. (2002). How theories became knowledge: Morgan's chromosome theory of heredity in America and Britain. *Journal of the History of Biology*, *35*(3), 471–535. https://doi.org/10.1023/A:1021175231599

Cannon, W. A. (1902). A cytological basis for Mendelian laws. *Bulletin of the Torrey Botanical Club*, *29*(12), 657–661.

Coleman, W. (1963). Cell, nucleus, and inheritance: An historical study. *Proceedings of the American Philosophical Society*, *109*, 124–158.

Correns, C. (1902). Über den Modus und den Zeitpunket der Spaltung der Anlagen bei Bastarden der Erbsen-Typus. *Bot. Zeit.*, *60*(2), 65–68.

Creighton, H. B., & McClintock, B. (1931). A correlation of cytological and genetical crossing-over in *Zea mays*. *Proceedings of the National Academy of Sciences of the United States of America*, *17*(8), 492–497. https://doi.org/10.1073/pnas.17.8.49

Doncaster, L. (1915). Chromosomes, heredity, and sex, a review of the present state of the evidence with regard to the material basis of hereditary transmission and sex determination. *Quarterly Journal of Microscopical Science*, *59*, 487–521.

Durbano, J. P. D. M. (2015) As pesquisas de Barbara McClintock sobre o *crossing-over* em *Zea mays*: 1925-1932. *Filosofia e História da Biologia*, *10*(1), 49–65. https://www.abfhib.org/FHB/FHB-10-1/FHB-10-1-04-Joao-Durbano.pdf

Durbano, J. P. D. M. (2017). *O desenvolvimento do conceito de crossing-over 1915-1935: uma introdução histórica para o ensino de genética* [Doctoral thesis, Universidade de São Paulo]. Biblioteca Digital USP. https://doi.org/10.11606/T.59.2017.tde-09112020-101836

Gilbert, S. F. (1991). Epigenetic landscaping: Waddington's use of cell fate bifurcation diagrams. *Biology and Philosophy*, *6*(2), 135–154. https://doi.org/10.1007/BF02426835

Ibarra, A., & Mormann, T. (2005). Interactive representations. *Revista de Estudios sobre Representaciones en Arte, Ciencia y Filosofía*, *1*(1), 1–20.

Janssens, F. A. (1909). Spermatogénèse dans les batraciens, V. La théorie de la chiasmatypie, nouvelle interprétation des cinèses de maturation. *La Cellule*, *25*, 389–406.

Lynch, M. (1991). Science in the age of mechanical reproduction: Moral and epistemic relations between diagrams and photographs. *Biology and Philosophy*, *6*, 205–226. https://doi.org/10.1007/BF02426838

Maienschein, J. (1991). From presentation to representation in E. B. Wilson's The Cell. *Biology and Philosophy*, *6*, 227–254. https://doi.org/10.1007/BF02426839

Martins, L. A-C. P. (1997). *A teoria cromossômica da herança, proposta, fundamentação, crítica e aceitação* [Doctoral thesis, Universidade Estadual de Campinas]. Sophia. https://doi.org/10.47749/T/UNICAMP.1997.781732

Martins, L. A-C. P. (1998). Thomas Hunt Morgan e a teoria cromossômica: de crítico a defensor. *Episteme: Filosofia e História das Ciências em Revista*, *3*(6), 100–126.

Martins, L. A-C. P. (1999). Did Sutton and Boveri propose the so-called Sutton-Boveri chromosome hypothesis? *Genetics and Molecular Biology*, *22*(2), 261–271. https://doi.org/10.1590/S1415-47571999000200022

Martins, L. A-C. P. (2002). Bateson e o programa de pesquisa mendeliano. *Episteme: Filosofia e História da Ciência em Revista*, (14), 27–55.

Martins, L. A-C. P. (2005). História da ciência, objetos, métodos e problemas. *Ciência & Educação*, *11*(2), 305–317. https://doi.org/10.1590/S1516-73132005000200011

Martins, L. A-C. P. (2007). El papel de las representaciones pictóricas en la ciencia: Wilson, Morgan y la teoría cromosómica. *Representaciones: Revista de Estudios sobre Representaciones en Arte, Ciencia y Filosofía*, *3*(2), 77–96.

Martins, L. A-C. P. (2010). The dissemination of the chromosome theory of Mendelian heredity by Morgan and his collaborators around 1916: A case study on the distortion of science by scientists. *Filosofia e História da Biologia*, *5*(2), 327–367.

Martins, L. A-C. P. (2011). O papel do núcleo na herança (1870 -1900), um estudo de caso: A teoria dos idioblastos de O. Hertwig. *Filosofia e História da Biologia, 6*(2), 269 -290. https://www.abfhib.org/FHB/FHB-06-2/FHB-6-2-06-Lilian-Al-Chueyr-Pereira-Martins.pdf

Mayr, E. (1982). *The growth of biological thought: Diversity, evolution, and inheritance*. Harvard University Press.

McClintock, B. (1930). A cytological demonstration of the location of an interchange between two non-homologous chromosomes of Zea mays. *Proceedings of the National Academy of Sciences United States of America, 16*(2), 791 -796. https://doi.org/10.1073/pnas.16.12.791

Mendel, G. (1966). Experiments in plant hybridization. In C. Stern and E. Sherwood (Eds.), *The origins of genetics: A Mendel source book* (pp. 1–48). W. Frieman and Company. (Original work published 1866)

Moore, J. A. (1986). Science as a way of knowing—genetics. *American Zoologist*, *26*(3), 583–747. https://doi.org/10.1093/icb/26.3.583

Morgan, T. H. (1909). What are "factors" in Mendelian explanations? *American Breeders Association Report*, *5*, 365–368.

Morgan, T. H. (1910). Chromosomes and heredity. *The American Naturalist*, *44*(524), 449–496. https://www.jstor.org/stable/2455783

Morgan, T. H. (1914). No crossing over in the male of *Drosophila* of genes in the second and third pairs of chromosomes. *Biological Bulletin*, *26*(4), 195–204.

Morgan, T. H., Sturtevant, A. H., Muller, H. J., & Bridges, C. B. (1915). *The mechanism of Mendelian heredity*. H. Holt and Company.

Portugal, F. H., & Cohen, J. S. (1977). *A century of DNA: A history of the discovery of the structure and function of genetic substance*. The MIT Press.

Stern, C. J. (1931). Zytologisch-genetische Untersuchungenals Beweise fur die Morganschetheorie des Faktorenaustausches. *Biologisches Zentralblatt*, *51*, 547–587.

Sturtevant, A. H. (2011). *A history of genetics*. Cold Spring Harbour Laboratory Press. (Original work published 1965)

Sutton, W. S. (1902). On the morphology of the chromosome group in *Brachystola magna. Biological Bulletin*, *4*, 24–39.

Sutton, W. S. (1903). The chromosomes in heredity. *Biological Bulletin*, *4*, 231–251.

Swinburne, R. G. (1962). The presence-and-absence theory. *Annals of Science*, *18*(3), 131–145. http://doi.org/10.1080/00033796200202762

Taylor, P. J., & Blum, A. S. (1991). Pictorial representation in biology. *Biology and Philosophy*, *6*, 125–134. https://doi.org/10.1007/BF02426834

The Mechanism of Mendelian Heredity. (1916). *Nature*, *97*(2423), 117–118. https://doi.org/10.1038/097117a0

Trow, A. H. (1916). A criticism of the hypothesis of *linkage* and *crossing-over*. *Journal of Genetics*, *5*(4), 281–297.

Wilson, E. B. (1900). *The cell in development and inheritance* (2nd ed.). McMillan.

Wilson, E. B. (1909). Studies on chromosomes V. The “accessory” chromosome of Metapodius. A contribution to the hypothesis of the genetic continuity of chromosomes. *The Journal of Experimental Zoology*, *6*(2), 147–205. https://doi.org/10.1002/jez.1400060202

Wilson, E. B. (1912). Studies on chromosomes VIII. Observations on the maturation phenomena in certain hemipter and other forms, with considerations on synapsis and reduction. *The Journal of Experimental Zoology*, *13*(3), 345–449. https://doi.org/10.1002/jez.1400130302