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# Genetic Misconceptions in Biology Textbooks: The Case of Linkage and Crossing Over

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**Abstract:** Misconceptions in school textbooks can hinder students' understanding, especially in abstract and molecular topics such as linkage and crossing over. However, research that specifically examines this issue remains limited. This study aims to identify and analyze misconceptions related to the subtopics of linkage and crossing over in four commonly used biology textbooks for 12th grade. A content analysis method was employed, involving the stages of unitizing, sampling, recording/coding, reducing, inferring, and narrating. Data were analyzed using tabulation to categorize findings and concepts based on reference standards. The analysis focused on 11 key concepts derived from the expected learning outcomes. To ensure data validity, peer debriefing was conducted involving subject matter experts. None of the textbooks fully presented all 11 key concepts, and all four were found to contain potential misconceptions. The most frequent type of misconception identified was oversimplification, accounting for 20 out of 31 instances. Textbook D contained the highest number of misconceptions (12 instances), while Textbook C had the fewest (5 instances). Such findings underline the risk posed by textbook errors to student comprehension, stressing the necessity for teachers to intervene and ensure conceptual clarity. Teachers are also encouraged to enrich instruction by incorporating more accurate scientific sources..

**Keywords:** Biology Textbooks, Content Analysis, Crossing Over, Linkage, Misconception

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## 1. Introduction

The learning process aims to provide students with a comprehensive understanding of the material, one of which is through instructional materials in the form of textbooks. Textbooks are the primary learning resources recognized by the Ministry of Education and Culture as a guide to achieving basic and core competencies (Permendikbud, 2016). However, some textbooks often contain misconceptions that can hinder students' understanding of certain concepts (Aini & Zulyusri, 2021).

Genetics is one of the topics in biology education that has long been considered difficult for many students to understand (Hera, 2017; Osman et al., 2017; Mocan, 2021). In Indonesia, in accordance with the biology syllabus of both the 2013 Curriculum and the Merdeka Curriculum the genetic material is taught in 12th-grade senior high school classes. The concepts in genetics are quite difficult to grasp, especially in genetic material, because they tend to be abstract for students due to the focus on the cellular and molecular levels (Mocan, 2021; Sukmawati & Permadani, 2020)). As a result, students often can only imagine and look at pictures without being able to see the concepts directly. However, the genetic material concepts form the foundation of genetic studies, with another key concept being inheritance patterns. Inheritance patterns explain Mendel's laws and the patterns of trait inheritance. The variety of inheritance patterns and the terminology associated with crossbreeding increases the potential for conceptual errors or misconceptions (Suranti & Henuhili, 2017).

Misconception is defined as an inaccurate understanding of a concept scientifically (Suparno, 2013). The causes of misconceptions can stem from factors such as the teacher, students, complex language, or errors in textbooks (Susilawati, 2018; Uitto, 2015; Aivelo & Uitto, 2021). In biology education, particularly in genetic topics like linkage and crossing over, misconceptions are common (Suranti & Henuhili, 2017). Genetics is considered difficult due to its abstract nature, the rapid development of genetic science, and the textbooks' orientation still focusing on classical genetics (Nusantari, 2011). Research results indicate various types of misconceptions in textbooks, such as oversimplification, overgeneralization, and obsolete concepts (Aini & Zulyusri, 2021). For example, misconceptions in textbooks regarding Morgan's research on fruit flies demonstrate errors in explaining genetic mechanisms, leading students to understand the concept only partially (Nusantari, 2011).

A survey of biology textbooks used by biology teachers in various public and private high schools in Pontianak shows that some textbooks still have the potential to contain misconceptions. This can hinder the learning process and the success of students in understanding scientific concepts (Mulia & Zulyusri, 2021). Previous studies have primarily focused on general biology content or broad themes, while specific subtopics that are conceptually abstract and cognitively demanding, such as linkage and crossing over, remain underexplored (Aziz & Akram, 2022; Fakhriyah et al., 2025; Nanda et al., 2025). This research gap is critical because genetic concepts—particularly those involving microscopic and molecular-level-processes—are prone to misunderstanding and are often misrepresented in instructional


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materials. To fill the gap, an in-depth analysis of misconceptions in textbooks is necessary to produce better teaching materials and reduce conceptual errors (Afriliska & Zulyusri, 2021). This study is expected to improve the quality of textbooks as primary learning resources and help both teachers and students better understand biological concepts.

Therefore, this study aims to identify misconceptions in the subtopics of linkage and crossing over in four widely used biology textbooks for grade XII in high schools in Pontianak. This issue is important because the abstract nature of genetics often makes it difficult to visualize microscopic processes, which can potentially lead to misconceptions that affect student understanding. Using a descriptive qualitative method and content analysis, this research focuses on identifying and categorizing misconceptions in several textbooks, covering misidentifications, oversimplifications, overgeneralizations, obsolete concepts and terms, as well as undergeneralizations. The results of this study are expected to serve as a reference for teachers in selecting higher-quality textbooks, help improve student conceptual understanding, and provide an important guide for more effective genetics instruction.

## 2. Method

This study uses a descriptive qualitative approach with content analysis methods. The content context being analyzed is the presence or absence of content that may contain misconceptions in four biology textbooks for 12th-grade high school students on the subtopics of Linkage and Crossing-Over. The selection of textbooks to be analyzed was obtained through a survey with semi-structured interviews with biology teachers from 27 high schools in Pontianak and its surrounding areas. The results of these interviews identified the four most commonly used textbooks, which are:

1. Irnaningtyas (2015), used in 7 out of 27 schools, hereafter referred to as Book A
2. Pratiwi et al. (2018), used in 5 out of 27 schools, hereafter referred to as Book B
3. Nurhayati & Wijayanti (2021), used in 6 out of 27 schools, hereafter referred to as Book C
4. Safitri (2016), used in 6 out of 27 schools, hereafter referred to as Book D

The stages of content analysis refer to Krippendorff (2004), which consist of unitizing, sampling, recording, reducing, inferring, and narrating (Figure 1).

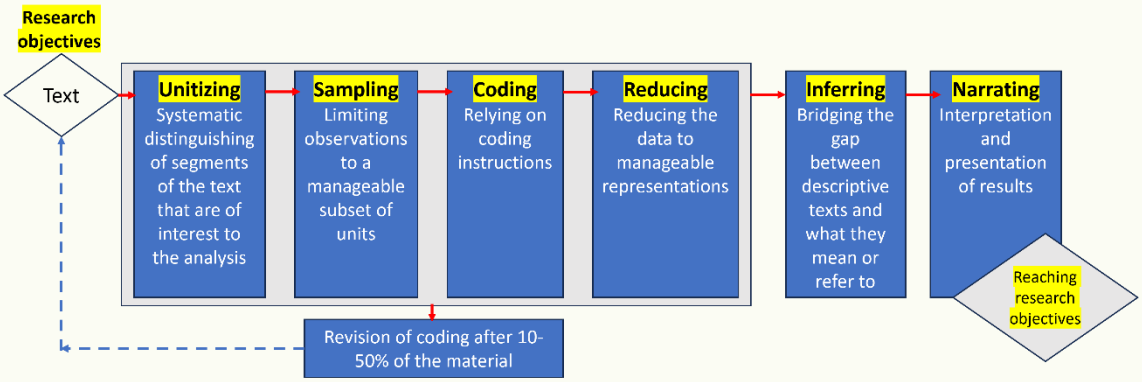


Figure 1. The steps of content analysis according to Krippendorff (2004)


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The steps of content analysis carried out in the study are as follows:

**Unitizing**. In this stage, systematic distinguishing of segments of the text that are of interest to the analysis is employed and the observation units within the reading sources being analyzed are determined. The observation units in this study are the key concepts in the Subtopic of Linkage and Crossing Over according to Competency Standard (KD) 3.6 for the 12th-grade Biology subject as outlined by the Kementerian Pendidikan dan Kebudayaan (2018). In KD 3.6, key concepts are defined based on the objects of study in linkage and crossing over, which include fundamental aspects such as definitions that provide an initial overview of the components forming the object of study, as well as processes or mechanisms explaining how elements in the object interact or work. The key concepts determined for this material are: 1) linkage definition, 2) linkage mechanism, 3) linkage mechanism on autosomes, 4) linkage product on autosomes, 5) linkage mechanism on sex chromosomes, 6) linkage product on sex chromosomes, 7) crossing over definition, 8) crossing over mechanism, 9) single crossing over mechanism, 10) double crossing over mechanism, and 11) crossing over products (recombinant and normal gametes). To determine whether misconceptions exist in the textbooks, each key concept is also cross-referenced with selected comparison sources, such as Pierce (2002), Hartl & Jones (1998), Klug et al. (2011), and Reece et al. (2011).

1. **Sampling**. In this stage, observation to a manageable subset of units is limited to data samples in the form of texts and images from the textbooks. Data samples are being analyzed and collected to obtain the observation units that have been determined. These observation units are the key concepts established in the unitizing stage. In this study, sampling not only involves texts or images containing concepts but also the alignment of the concepts, which includes not only written content but also the essential explanation of the concepts, whether in the form of specific details like sentences or in the overall content of paragraphs.
2. **Recording or coding**. In this stage, data collected, including the correct concepts according to the reference materials and the key concepts presented in the textbooks, are recorded. Next, coding is performed by determining the alignment of the two key concepts and categorizing the content identified as containing incorrect concepts into five categories of misconceptions according to Hershey (2004) and Dikmenli et al. (2009). The five categories of misconceptions are: (1) misidentification, or errors in identifying a concept, (2) overgeneralization, or making excessive generalizations about a concept, (3) oversimplification, or overly simplifying a concept, especially regarding a process or mechanism that is overly simplified, (4) obsolete concepts and terms, or concepts and terms in the textbook that are outdated or no longer used in the current development of biology, and (5) undergeneralization, or concepts that are too specific.
3. **Reducing**. In this stage, the collected data is reviewed. Data that is irrelevant or not aligned with the research needs is reduced and simplified for easier understanding, presentation, and conclusion.


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4. **Inferring**. In this stage, conclusions are drawn based on the data that has been analyzed according to the categorization of misconceptions by Dikmenli et al. (2009). The conclusions drawn must align with the research problem and address the research objectives.
5. **Narrating**. In the final stage, the results of the analysis of misconceptions in the textbooks are described according to the conclusions drawn in the inferring stage. The description is accompanied by supporting theories regarding the accuracy or inaccuracy of the concepts about linkage and crossing-over.

The collected data were analyzed using the tabulation method based on Creswell & Creswell (2018). Each observation unit and finding from the analyzed textbooks, along with the accurate concepts according to the reference comparison, were grouped and organized into tables. This method is used to summarize the data, identify patterns, and streamline the presentation of results. To verify the validity of the data, a peer debriefing technique was conducted following Creswell (2007) to review and critique the process and analysis results. In this study, the colleagues involved were faculty members teaching genetics in the Biology Education Program at the Faculty of Teacher Training and Education, University of Tanjungpura.

## 3. Result and Discussion

The analysis of KD 3.6 in the biology subject as outlined in the Permendikbud No. 37 of 2018 (Kementerian Pendidikan dan Kebudayaan, 2018) established 11 key concepts in the Submaterial of Crossing Over and Linkage. The scope of these key concepts includes the definition and mechanism of linkage and crossing over, as well as the products produced. No textbook presents all 11 key concepts completely (Table 1). The key concepts that are not available in the textbooks are: 1) the definition of linkage (Book C), 2) the mechanism of linkage on autosomal chromosomes (Book C), 3) the products of linkage on autosomal chromosomes (Book D), 4) the mechanism of linkage on sex chromosomes (Book B), 5) the products of linkage on sex chromosomes (Books B and D), 6) the mechanism of single crossing over (Book A), and 7) the mechanism of double crossing over (Book A). The number of key concepts presented in all textbooks is the same, with 9 concepts, although they vary in content.

Table 1. Availability and Accuracy of Explanations for Each Key Concept in Each Textbook (√ = Yes, Correct; X = No, Incorrect)

| Key Concept | Key Concept's Availability (Av) and Accuracy (Ac) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Book A | | Book B | | Book C | | Book D | |
| | Av | Ac | Av | Ac | Av | Ac | Av | Ac |
| 1. Definition of linkage | √ | √ | √ | X | X | - | √ | X |
| 2. Mechanism of linkage | √ | √ | √ | X | √ | √ | √ | X |
| 3. Mechanism of linkage in autosome | √ | X | √ | √ | X | - | √ | X |
| 4. Linkage product in autosome | √ | X | √ | √ | √ | √ | X | - |
| 5. Mechanism of linkage in sex chromosome | √ | X | X | - | √ | X | √ | X |
| 6. Linkage product in sex chromosome | √ | X | X | - | √ | X | X | - |
| 7. Definition of crossing over | √ | X | √ | X | √ | X | √ | X |
| 8. Mechanism of crossing over | √ | X | √ | X | √ | √ | √ | X |
| 9. Mechanism of single crossing over | X | - | √ | X | √ | X | √ | X |
| 10. Mechanism of double crossing over | X | - | √ | X | √ | X | √ | X |
| 11. Product of crossing over (recombinant gamete and normal gamete) | √ | √ | √ | √ | √ | √ | √ | √ |
| Available concepts | 9 | | 9 | | 9 | | 9 | |
| Available and accurate concepts | 3 | | 3 | | 4 | | 1 | |

Six to eight important concepts in each of the biology textbooks do not align with the reference sources (Table 1). The important concept that is accurately presented in all four textbooks is concept 11, which discusses the products of crossing over (recombinant gametes and normal gametes). All four textbooks explain that the crossing over event produces normal and recombinant gametes, with terms that vary somewhat. In Book A, normal gametes are referred to as parental chromosomes, and recombinant gametes are called recombinants (page 198, line 13). In Book B (page 184, line 10) and C (page 178, line 21), normal gametes are called parental-type gametes, while recombinant gametes are called recombination gametes. In Book D (page 148, line 34), normal gametes are referred to as parental-type offspring, and recombinant gametes are called recombinant-type offspring. Despite the varying terminology, the meaning and intention behind the terms used in all four books convey the same concept and therefore do not indicate a potential misconception. This variation is also found in reference sources


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such as Reece et al. (2011)1) and Pierce (2002), who use different terms to explain the concept of recombination due to crossing over. The differences in terminology may be due to the author's writing style or explanatory techniques, but they do not affect the understanding of the core concept. Thus, consistency in the meaning of the concept conveyed is more important than uniformity in terminology.

When comparing the accurate concepts with the available concepts, Book D has the lowest percentage, with only 1 accurate concept out of 9 concepts presented. In terms of the number of explanations that potentially contain misconceptions, Book D also shows the highest number of misconceptions, with 12 out of the total 32 instances of misconceptions found, followed by Book A (6 instances), Book B (6 instances), and Book C (5 instances) (Table 2). Textbooks that are indicated to contain many instances of misconceptions may be caused by various factors, such as the author's lack of competence in the subject matter, the author's attempt to oversimplify the content, which leads to excessive simplification and unclear presentation (Wijiningsih et al., 2016), inconsistency in the use of terms due to multiple authors (Hidayat & Asyhar, 2020), the author's use of less credible references (Suparno, 2005), weak review processes by publishers or peers (Aini & Zulyusri, 2021), and linguistic habits influenced by the local culture of the author (Sriwati, 2023). When confusion and misconceptions occur frequently, it is important to examine the content of the material itself. In-depth analysis of the textbook content shows that such material can present learning barriers that are difficult to understand by both teachers and students (Flodin, 2009). Using credible sources, involving experts in the writing process, and applying strict editorial standards can help reduce the risk of misconceptions.

Table 2. Types of misconceptions indicated in the textbooks for each key concept.

| Key Concept | Type of Misconception | | |
|---|---|---|---|
| | Misidentification | Oversimplification | Undergeneralization |
| 1. Definition of linkage | - | B, D | - |
| 2. Mechanism of linkage | B, D | - | - |
| 3. Mechanism of linkage in autosome | - | A, D | A |
| 4. Linkage product in autosome | A | - | - |
| 5. Mechanism of linkage in sex chromosome | D | A | A |
| 6. Linkage product in sex chromosome | C | A | - |
| 7. Definition of crossing over | A, | A, B, C, D | - |
| 8. Mechanism of crossing over | B, D | A, C, D | - |
| 9. Mechanism of single crossing over | D | B, C, D, D | - |
| 10. Mechanism of double crossing over | D | B, C, D | - |
| 11. Product of crossing over (recombinant gamete and normal gamete) | - | - | - |

The most common type of misconception found is oversimplification, accounting for 20 out of 32 instances of misconceptions. Excessive simplification of scientific concepts is often done to ease readers' understanding but frequently sacrifices scientific accuracy. This may be caused by an imbalance between the need to simplify information and maintaining scientific precision (Dikmenli et al., 2009). For example, the explanation of the definition of crossing over, which only mentions it as "gene exchange," without fully stating that this process occurs between non-sister chromatids of homologous chromosomes during Prophase I of Meiosis I, can confuse readers with other gene exchange concepts like chromosomal translocation. As Klug et al. (2011, p. 213-214) state, "translocation, as the name implies, is the movement of a chromosomal segment to a new location in the genome. Reciprocal translocation, for example, involves the exchange of segments between two nonhomologous chromosomes." The lack of a complete explanation of a concept, especially when defining it, can mislead readers in understanding the concept in its entirety. The issue of textbook authors not emphasizing the most important biological principles has also been raised by Weaver & Brown (1965).

No instances of overgeneralization or obsolete concepts and terms were found in the four biology textbooks. This can be seen as a positive aspect, indicating the quality of the textbooks, particularly for the topics of linkage and crossing over. However, it is also important to ensure that other aspects, such as data accuracy, clarity of presentation, and the book's ability to support students' understanding, are still taken into account. The four textbooks can be categorized as being written in accordance with curriculum requirements and are relatively up-to-date, which is one of the criteria for a good textbook (Rihanah & Irma, 2022). Nevertheless, teachers still have a responsibility to analyze the concepts presented in the textbooks as part of their oversight to ensure the accuracy of the concepts in the textbooks and their alignment with scientific principles that are accessible to students (Apriani & Yunianto, 2016).

Teachers should be especially vigilant with concepts that are incorrect across multiple textbooks and are prone to various types of misconceptions. The presentation of the definition and mechanism of crossing over appears to contain errors in all four textbooks analyzed. Books A, B, and C show potential for misidentification, while oversimplification is found in Books A and D regarding the definition of crossing over. For the mechanism of crossing over, misidentification appears in Books B, C, and D, while oversimplification is found in Books A and D. In response to this, teachers need to increase their awareness of concepts that may contain misconceptions in textbooks. They can complement these with additional


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scientific sources and investigation-based learning approaches to ensure a deeper understanding (Çimer, 2007). Errors such as misidentification and oversimplification highlight the need for revisions in textbooks to make concepts like the definition and mechanism of crossing over more accurate and comprehensive (Pingel, 2010)

Teachers must also anticipate concepts that are likely to experience various types of misconceptions. In this study, the important concept of the linkage mechanism on sex chromosomes has the potential to experience the most diverse types of misconceptions, including misidentification, oversimplification, and undergeneralization. Textbook authors are responsible for presenting the material accurately and in detail, while teachers play a crucial role in detecting and correcting misconceptions through appropriate teaching strategies. Authors should ensure that the material is based on the latest scientific research in genetics and molecular biology to ensure that the concepts presented remain current and accurate (Pingel, 2010). Authors should also separate essential information from supporting information to prevent misunderstandings, for example by using bold text, clear diagrams, and step-by-step explanations to clarify the concepts (Duit & Treagust, 2003). Equally important, teachers must be able to explain the concept of sex chromosome linkage from the basics to more advanced levels in accordance with students' understanding. The explanation can start with simple analogies and progress to complex illustrations to describe the mechanism.

Misconceptions regarding both the definition and mechanism of crossing over also show similarities in the presentation across the four books. For example, the explanation of the definition of crossing over in three of the textbooks contains the type of oversimplification as follows:
Book B, page 184, line 3: *"Peristiwa pindah silang (crossing over), yaitu pertukaran segmen kromatid-kromatid dari pasangan kromosom homolog."* (English: Crossing over is the exchange of chromatid segments from homologous chromosome pairs.)
Book C, page 178, line 11: *"Proses pindah silang dimana terjadi peristiwa pertukaran segmen kromatid-kromatid dari pasangan kromosom homolog."* (English: The process of crossing over is the exchange of chromatid segments from homologous chromosome pairs.)
Book D, page 148, line 8: *"Proses pindah silang dimana terjadi peristiwa pertukaran segmen kromatid-kromatid dari pasangan kromosom homolog."* (English: Crossing over is the event of gene exchange between the genes of one chromatid and those of its homologous chromatid.)
The three books share a similar incomplete definition of crossing over, with simplification of the concept that omits important details about non-sister chromatids. It is necessary to emphasize that the term "chromatid" should be more

accurately described as "non-sister chromatid" because crossing over occurs between chromatids of different homologous chromosomes, not sister chromatids. Furthermore, in Book A, an additional misconception beyond oversimplification is identified, which is misidentification, as seen in the following sentence:
Book A, page 197, line 21: " *Pindah silang adalah bertukarnya gen-gen yang terdapat dalam suatu kromosom dengan gen-gen yang terletak pada kromosom lainnya yang sehomolog maupun yang bukan sehomolog*. (English: Crossing over is the exchange of genes found in one chromosome with genes located on another chromosome, whether homologous or non-homologous.)"
Book A contains a misidentification misconception because crossing over is the exchange of genetic segments between homologous chromosomes during meiosis, not between non-homologous chromosomes. The addition of the phrase "non-homologous chromosomes" leads to misidentification because the term is not accurate for the intended context. As explained by Hartl & Jones (1998, page 801, line 13), "crossing over is a process of exchange between non-sister chromatids of a pair of homologous chromosomes that results in the recombination of linked genes."

The discovery of misconceptions in all four analyzed books demonstrates that conceptual inaccuracies persist even in widely used educational materials. This supports the findings of Sanders & Makotsa (2016), Stern & Kampourakis (2017), and Machová & Ehler (2023), who emphasize that textbooks are among significant sources of student's misconceptions, particularly when dealing with abstract topics like genetics. The recurring misconception types—such as oversimplification, misidentification, and undergeneralization— highlight the complexity of conveying microscopic genetic mechanisms like crossing over and chromosomal linkage in a simplified narrative. These findings align with Afriliska & Zulyusri (2021), who noted that genetics are highly vulnerable to misunderstanding due to their abstract nature and the challenges students face in visualizing processes such as homologous recombination and chromatid exchange. The absence of complete explanations, inconsistencies in terminology, and outdated concepts may not only lead to students internalizing incorrect information but also hinder teachers who rely heavily on textbooks for instruction.

Given the potential of these misconceptions to propagate through the classroom, it becomes essential for teachers to possess adequate pedagogical content knowledge to identify and address inaccuracies during instruction. The involvement of experts during textbook development is a crucial step and should be strongly recommended based on the findings of this study. Publishers and textbook authors should also conduct peer reviews by genetics experts and educators before publication to minimize errors in presenting concepts (Pingel, 2010). Authors


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unfamiliar with the intricacies of molecular genetics may unintentionally oversimplify complex processes, thus increasing the risk of error. Additionally, these findings indicate that the evaluation of textbooks must not be passive. Teachers should be equipped to critically assess the accuracy of the textbooks they use, integrating additional sources such as a peer-reviewed journals, digital simulations, and interactive media, as suggested by Etobro & Banjoko (2017), Stern & Kampourakis (2017), and Machová & Ehler (2023). These resources can support student understanding by making invisible biological processes more tangible.

This study contributes to the literature by focusing specifically on the topics of linkage and crossing over—areas that have not been explored in detail in prior content-based textbook analyses. While several studies have looked broadly at biology textbook content, few have analyzed genetics content at this level of conceptual granularity. Future research should examine the extent to which these textbook-based misconceptions influence students' actual understanding and retention of genetic concepts. In particular, studies could explore how students reconcile textbook information with classroom instruction and how teachers identify and correct textbook-derived misconceptions. It is also crucial to investigate how inquiry-based and constructivist teaching strategies can be used to mitigate these misconceptions effectively. Ultimately, this study reinforces the urgent need for continuous textbook evaluation and development processes grounded in current scientific knowledge and didactic best practices, especially in complex fields such as genetics.

## 4. Conclusion

None of the four textbooks present all eleven key concepts completely. All the textbooks analyzed contain misconceptions, with the most common type being oversimplification (20 out of 31 items). Book D has the highest number of misconceptions (12 items), while Book C has the fewest (5 items), indicating that some books are more accurate than others. Misconceptions in textbooks can become barriers in learning, both for students and teachers. Therefore, teachers play an important role in identifying and correcting conceptual errors in textbooks, as well as enriching learning with more accurate scientific sources.

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