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Original Research

# Evaluating Misconceptions in the Representation of Mendelian Genetic Inheritance in High School Biology Textbooks

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**Abstract**

Genetics learning is prone to misconceptions due to complex concepts, abstract reasoning, and inconsistencies in textbook presentations, which can hinder students' understanding of inheritance patterns such as Mendelian genetics. This study analyzes the potential misconceptions in high school biology textbooks regarding Mendel's Laws and dominance–recessive inheritance using Dikmenli et al.'s categorization, aiming to provide references for teachers in selecting and supplementing instructional materials. This is a descriptive qualitative research using content analysis method. Four textbooks, selected through a survey of biology teachers in Pontianak City, were analyzed by comparing key concepts in the textbooks with scientifically accurate explanations from authoritative references. The findings were systematically examined, categorized, and validated through member-checking to ensure accuracy, highlighting the most common types of misconceptions in the textbooks. The analysis revealed variations in the coverage and accuracy of 13 key concepts related to Mendel's Laws and dominance–recessive inheritance, with Books A–C containing several potential misconceptions while Book D showed none. The most frequent types of misconceptions identified were misidentifications, followed by oversimplifications and overgeneralizations, often involving definitions of gene, genotype, phenotype, and independent assortment. These findings highlight the importance of accurate textbook content and suggest that educators must critically evaluate and clarify textbook explanations to prevent persistent misunderstandings in students' conceptual understanding of genetics.



## Introduction

Learning biology requires students to understand many complex concepts, and differences in how textbooks present these ideas can lead to misconceptions—interpretations that differ from accepted scientific explanations (Astuti, 2017; Ramadhan, 2016). Misconceptions may arise from students' prior knowledge, cognitive limitations, teaching methods, or textbook content, and can hinder their learning (Suparno, 2013; Sarhim & Harahap, 2015). Genetics is especially prone to misconceptions due to its abstract and technical nature, the continued emphasis on classical genetics in textbooks, and students' difficulties in reasoning about inheritance patterns (Candramila & Waskito, 2021; Madukubah et al., 2018; Gusmalini et al., 2020; Hidayat & Kasmiruddin, 2020). Common errors include assuming dominant traits are always more frequent or believing all traits follow simple Mendelian rules (Nusantari, 2013; Fajri et al., 2021; Ningrum et al., 2024; Klug et al., 2011).

Textbooks play a central role in shaping students' understanding (Mahmood, 2011), yet variations in authors' perspectives and presentation styles can introduce conceptual inconsistencies that promote misconceptions (Irani et al., 2020). To prevent this, textbooks should be organized according to students' cognitive development and use clear, precise explanations (Purba et al., 2024; Pathiyah, 2019; Pratiwi & Widyaningrum, 2021). Misconceptions within textbooks can be identified through frameworks such as Dikmenli et al. (2009), which classify errors into misidentification, overgeneralization, oversimplification, obsolete concepts, and undergeneralization.

Identifying these errors is crucial because they impede understanding and make it difficult for students to master more advanced concepts, while categorizing them helps teachers select appropriate instructional interventions (Treagust & Duit, 2008). Previous studies have also reported misconceptions across various biology topics—such as development, metabolism, heredity, evolution, and biotechnology—often caused by ambiguous explanations, misleading illustrations, outdated content, or oversimplification (Agustina et al., 2016; Irani et al., 2020). These findings emphasize the importance of careful textbook evaluation and the teacher's role in providing clarification, updated information, and interactive strategies to prevent the reinforcement of misconceptions (Dikmenli, 2010).

This study specifically analyzes potential misconceptions in Mendel's Laws and dominance-recessive inheritance patterns in high school biology textbooks, using Dikmenli et al.'s (2009) categorization. The way Mendelian inheritance is presented—both in textbooks and classroom instruction—is crucial for shaping accurate understanding. If explanations are overly brief, simplified, or inconsistent, misconceptions may persist, underscoring the need for clear, comprehensive instruction to support students' conceptual mastery of genetics.

## Method

### 2.1 Research Method

This study employed a content analysis method with a descriptive qualitative approach, as outlined by Krippendorff (2004). The analysis aimed to identify potential misconceptions in Grade XII high school biology textbooks related to Mendel's Laws and dominant-recessive inheritance patterns. These misconceptions were categorized using the framework proposed by Dikmenli et al. (2009).

### 2.2 Textbook Selection

The textbooks were selected based on a survey of biology teachers from 27 public and private high schools in Pontianak City. The survey identified four textbooks as the most commonly used: Irnaningtyas (2015), Pratiwi et al. (2018), Nurhayati & Wijayanti (2021), and Safitri (2016). For confidentiality and consistency, these textbooks were coded as Books A, B, C, and D.

### 2.3 Research Instrument

The research instrument consisted of an observation sheet arranged in a table format. The table included columns for key concepts based on Basic Competencies (KD), scientifically accurate concepts from references, content presented in the textbooks (including page and line numbers), and categories of misconceptions according to Dikmenli et al. (2009).

### 2.4 Data Collection

The analysis began by identifying key concepts from the Basic Competencies relevant to Mendelian genetics. Scientifically accurate explanations of these concepts were compiled from four authoritative references: Genetics: Principles and Analysis (Hartl & Jones, 1998), Genetics: A Conceptual Approach (Pierce, 2002), Concepts of Genetics (Klug et al., 2011), and Human Heredity: Principles and Issues (Cummings, 2010). The content of each textbook was examined and recorded, with a focus on how key concepts were presented. Any inconsistencies between the textbook content and the reference explanations were classified into the appropriate categories of misconceptions. The findings were then systematically compiled and described in detail.

### 2.5 Data Analysis

Data analysis followed the standard stages of content analysis, including unitizing, sampling, recording (coding), reducing, inferring, and narrating (Figure 1). Unitizing involved defining the data, which in this case consisted of the four selected textbooks. Sampling involved selecting key concepts from the Grade XII biology syllabus that were relevant to Mendelian genetics. During the recording stage, relevant information from the textbooks was documented. The reducing stage involved filtering out irrelevant content to retain only essential information for easier interpretation. In the inferring stage, conclusions were drawn based on the processed data and guided by the misconception categories established by Dikmenli et al. (2009). The narrating stage involved presenting the findings, highlighting the most frequently identified misconception categories, and supporting them with relevant literature.

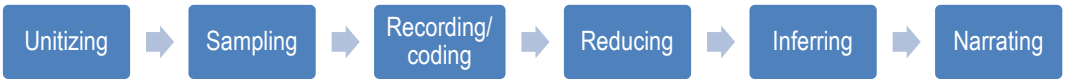


Figure 1. Stages of Content Analysis according to Krippendorff (2004)

2.6. Data Validity

To ensure the validity and reliability of the findings, a member-checking process was conducted. Two academic supervisors reviewed the identified misconceptions to confirm their accuracy and consistency with current scientific understanding.

**Results and Discussion**

3.1. The Availability of Key Concepts

The subtopic of Mendel's Law and Dominance-Recessive Inheritance Patterns comprises 13 key concepts based on the Basic Competencies (KD), including definitions of genes, alleles, genotypes, phenotypes, dominance, recessiveness, segregation, and independent assortment. Additional key concepts cover Mendel's postulates, backcross, test cross, reciprocal cross, and examples of Mendelian inheritance in daily life. The extent to which these concepts are explained varies across the analyzed textbooks (Table 1). Among the 13 key concepts, Books A and B each cover nine concepts, Book C includes eight, and Book D provides the least coverage with only six concepts. Concepts most frequently omitted from textbooks include the definitions of dominant and recessive traits and the contents of Mendel's postulates, while definitions of gene and genotype were most often presented inaccurately. This variation reflects differences in both the depth and comprehensiveness of concept presentation across the textbooks.

**Table 1**. The availability and accuracy of key concepts across the analyzed textbooks

| Key Concepts | Authoritative References | Availability and Accuracy of Key Concepts in Each Book | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| 1. Definition of Gene | Klug et al. (2011) | Inacc. | NA | Inacc. | NA |
| 2. Definition of Allele | Pierce (2002) | Inacc. | Acc. | NA | NA |
| 3. Definition of Genotype | Klug et al. (2011) | Inacc. | Inacc. | NA | NA |
| 4. Definition of Phenotype | Pierce (2002) | Acc. | Inacc. | NA | NA |
| 5. Definition of Dominant | Hartl & Jones (1998) | NA | NA | Inacc. | NA |
| 6. Definition of Recessive | Hartl & Jones (1998) | NA | NA | Inacc. | NA |
| 7. Definition of Segregation | Pierce (2002) | Acc. | Acc. | Acc. | Acc. |
| 8. Definition of Independent Assortment | Cummings (2010) | Inacc. | Acc. | Acc. | Acc. |
| 9. Contents of Mendel's Postulates | Klug et al. (2011) | NA | Acc. | NA | NA |
| 10. Definition of Testcross | Hartl & Jones (1998) | Acc. | Acc. | Acc. | Acc. |
| 11. Definition of Backcross | Hartl & Jones (1998) | Acc. | Acc. | Acc. | Acc. |

| | | | | | |
|---|---|---|---|---|---|
| 12. Definition of Reciprocal Crossing | Pierce (2002) | Acc. | Acc. | NA | Acc. |
| 13. Examples of daily events according to Mendel | Klug et al. (2011); Pierce (2002) | NA | NA | Acc. | Acc. |

Note: NA = Not Available; Acc. = Accurate; Inacc. = Inaccurate

3.1. Misconceptions Found in the Textbooks

Upon closer examination, several key concepts presented in the textbooks were found to contain potential misconceptions (Table 2). Book A showed potential misconceptions related to the definitions of gene, allele, genotype, and independent assortment. Book B contained potential misconceptions regarding the definitions of genotype and phenotype, while Book C exhibited potential misconceptions in the definitions of gene, as well as dominant and recessive traits. In contrast, Book D did not display any potential misconceptions across the key concepts presented. Regarding the types of misconceptions, misidentification was the most frequently observed, appearing in three of the four textbooks. Oversimplification and overgeneralization were less common, each occurring in only one of the textbooks analyzed.

**Table 2**. Misconception findings in the textbooks analyzed

| Key Concepts | Findings of Misconceptions in Textbooks | Misconception Categories and Description |
|---|---|---|
| Definition of gene | Book A (page 162 line 9)<br>*English translation:* Genes are factors that carry traits. | Oversimplification<br>The term "factor" in the sentence "Genes are factors that carry traits" is too vague and may cause misconceptions. A gene is more accurately defined as a "unit of inheritance" or a "DNA sequence encoding a functional product." Replacing "factor" with a precise term avoids oversimplification and conveys the correct scientific meaning. |
| | | Misidentification<br>The phrase "trait carrier" can cause misconceptions, as it wrongly implies that genes directly carry traits. Genes actually contain DNA sequences that influence traits through processes like transcription and translation. A more accurate description would be "units of inheritance" or "DNA sequences that encode polypeptides." |
| | Book C (page 135, lines 22 – 24)<br>*English translation:* This gene itself is a character possessed by the parent that is unique to each organism. | Misidentification<br>The phrase "character owned by the parent that is unique to each organism" can be misleading, as genes are not unique traits. Characters refer to an organism's traits, while genes are basic physical units of inheritance composed of DNA sequences. |
| Definition of allele | Book A (page 162, lines 17 – 20)<br>*English translation:* Alleles are pairs of genes found on homologous | Overgeneralization<br>The examples of trait pairs like long–short or sweet–sour may cause |

| | | |
|---|---|---|
| | chromosomes (from both parents) that show alternative traits to each other, such as long vs. short, sweet vs. sour, smooth vs. wrinkled, and so on. | misconceptions, as allele expression is not always strictly opposite, particularly in genes with multiple alleles. |
| Definition of genotype | Book A (page 162, lines 25 - 27)<br>*English translation:* Genotype is the genetic condition of an individual or population. Genotype is the factor that carries traits from both parents. | Misidentification<br>The term "carrier factor" can be misleading, as it may be mistaken for the genotype. In reality, alleles—not the genotype—carry traits, while the genotype represents the combination of alleles inherited from both parents. |
| | Book B (page 145, lines 5 - 6)<br>*English translation:* The genotype is an invisible trait determined by the gene pairs in an individual. | Misidentification<br>The statement that "gene pairs determine an individual's invisible traits" is misleading. Genotype refers to an individual's specific combination of alleles, not to invisible traits, and determines the potential traits that may be expressed. |
| Definition of phenotype | Book B (page 145, lines 6 - 7)<br>*English translation:* The visible traits or those that can be observed with our senses are called phenotype. | Oversimplification<br>The statement that phenotypes are traits visible to the five senses is misleading. Phenotypes also include biochemical, physiological, and other gene expression traits that are not always externally visible. |
| | | Misidentification<br>The term "five senses" may mislead students to think phenotypes are only externally observable traits. In fact, phenotypes also include biochemical, physiological, and genetic traits that are not directly visible. |
| Definition of dominant | Books C (page 139, lines 2 – 4)<br>*English translation:* In his research using seven pure-bred traits of pea plants (Table 5.1), it was found that the proportion between dominant traits (the most commonly observed traits) and recessive traits (the least observed traits). | Misidentification<br>The statement about "the most frequently encountered trait" is misleading, as allele frequency does not determine dominance. Dominance refers to how an allele affects the phenotype; not how common it is in the population. |
| Definition of Recessive | Book C (page 139, lines 2 – 4)<br>*English translation:* In his research using seven purebred pea plant traits (Table 5.1), it was found that the proportion between dominant traits (the most commonly encountered traits) and recessive traits (the least commonly encountered traits). | Misidentification<br>The phrase "the trait that is least encountered" is misleading, as rare traits are not necessarily recessive. Allele dominance affects phenotype expression, but trait frequency in a population is influenced by other factors like genetic drift and selection. |
| Independent Assortment | Book A (page 167, lines 2 -11) | Misidentification<br>The statement about alleles pairing |

| | | |
|---|---|---|
| | *English translation*: Mendel's Second Law, or the law of independent assortment, is a principle stating that each allele can independently pair with other alleles that are not its counterpart during the formation of gametes. Mendel's Second Law can be explained through dihybrid crosses, which involve crossing two different traits or two different alleles, such as round and wrinkled seeds or yellow and green seeds. This law applies only to genes located far apart on chromosomes, allowing them to assort independently. For genes that are located close to each other, they tend to be linked (unable to assort independently). | freely may be misleading, as "*sealel*" suggests the same allele of a gene. Mendel's Law of Independent Assortment applies to alleles of different genes, which assort independently during gamete formation. |
| | | Misidentification<br>The phrase "two different alleles" may be misleading, as it could imply alleles of the same gene. Independent assortment refers to alleles of different genes assorting independently during gamete formation. |
| | | Misidentification<br>The examples "round–wrinkled" and "yellow–green" may be misleading, as they could be seen as traits of the same gene. In a dihybrid cross, these traits are controlled by alleles from two different genes. |
| | | Misidentification<br>The phrase "only applicable" is misleading, as independent assortment can be affected by factors like genetic linkage. Alleles close together on the same chromosome may be inherited together, limiting independent assortment. |

Based on the study's findings, eight potential misconceptions were identified in Book A, three in Book B, and three in Book C. The most common category of misconception across all three textbooks was misidentification. The definition of genotype in Book A—"a factor that carries traits from both parents"—is misleading because the genotype does not carry traits. What organisms inherit are alleles, the alternative forms of a gene. Genotype refers to the set or combination of alleles an individual possesses for a given trait (Klug et al., 2011; Kockum et al., 2023).

Another potential misconception from Book A, also classified under misidentification, concerns the concept of independent assortment. The statement "each allele can pair freely with other alleles that are not the same allele" is potentially confusing, as it incorrectly implies alleles of the same gene. Independent assortment involves alleles of different genes segregating independently. As Cummings (2010) explains, in a dihybrid cross the alleles of one gene pair segregate independently from those of another, producing all possible allele combinations in gametes.

Another oversimplification in Book A appears in the definition "genes are factors that carry traits." The wording is vague and misleading, suggesting a direct gene-to-trait relationship without explaining mechanisms. A clearer definition describes genes as units of inheritance—DNA sequences that encode functional products such as polypeptides (Zhou, 2020). Genes determine inherited traits by being passed from parents to offspring (Hartl & Jones, 1998) and are identifiable through allelic variants located at specific chromosomal loci (Klug et al., 2011).

A potential misconception in Book B appears in the definition: "Genotype is an invisible trait determined by a pair of genes in an individual." This is misleading because genotype is not an "invisible trait" but the specific allelic composition an individual carries. Genotype refers to the DNA sequence

variants present at particular loci—essentially, the version of the DNA sequence an organism possesses (Wright & Fessele, 2017) and the set of alleles it carries (Pierce, 2002).

Another oversimplification in Book B appears in its definition of phenotype as "traits visible from the outside or observable with the five senses." This is too narrow, as phenotypes also include biochemical, physiological, and behavioral traits that are not externally observable. A phenotype refers to the expression of a characteristic—ranging from physical appearance to internal biochemical and physiological traits (Pierce, 2002; Nachtomy et al., 2007).

A potential misconception in Book C, categorized as misidentification, appears in the definition: "This gene is a character the parent possesses, unique to each organism." This statement mistakenly equates genes with characters. Genes are not traits but DNA sequences that encode the information for trait expression. Traits (characters) result from the expression of these genes. As noted by Hartl & Jones (1998) and Klug et al. (2011), genes are the fundamental physical units of heredity, located at specific loci on chromosomes and identifiable through their allelic variants.

This study identified several potential misconceptions across the textbooks, except for Book D, which showed none. Misconceptions refer to ideas that deviate from scientifically accepted explanations. Research shows that misconceptions in genetics are common—particularly in inheritance patterns, human heredity, and Mendel's laws (Fajri et al., 2022)—and as many as 60.2% of students hold misconceptions about Mendelian inheritance (Mustika et al., 2014). If not addressed, these misunderstandings may persist and hinder the development of accurate scientific knowledge.

Misconceptions in the textbooks were identified using Dikmenli et al.'s (2009) content-based framework, which includes five categories; three appeared in the analyzed books—misidentifications, oversimplifications, and overgeneralizations. Misidentification was the most common, aligning with findings by Aini & Zulyusri (2021) and Pandu Pribadi et al. (2018). This type of misconception involves incorrectly defining or identifying scientific concepts (Radiah & Zulyusri, 2023), leading to explanations that diverge from accepted scientific understanding (Tenzer et al., 2022).

Oversimplification was found in Book B, likely due to shortened explanations that omit essential details (Suranti et al., 2017). Overgeneralization appeared in Book A, where concepts were presented too broadly, increasing the risk of misunderstanding (Ulfa et al., 2024). Because textbooks play a key role in learning, such misconceptions must be addressed promptly to prevent long-term conceptual errors and to support students' understanding of more advanced biological ideas (Afifah & Isnawati, 2023).

The findings show that potential misconceptions remain common in high school biology textbooks, particularly in topics related to Mendel's laws and inheritance. Misidentifications, oversimplifications, and overgeneralizations can hinder students' understanding if left unaddressed (Fajri et al., 2022; Tenzer et al., 2022). Given the central role of textbooks, accuracy must be prioritized. Authors should ensure alignment with current scientific literature, and teachers should critically assess and clarify textbook content. Regular reviews using frameworks like Dikmenli et al. (2009) are recommended to maintain the quality of biology education.

## Conclusion

This study identified potential misconceptions related to Mendel's Laws and dominance–recessive inheritance in three of the four analyzed textbooks (Books A, B, and C), based on Dikmenli et al.'s (2009) framework. The misconceptions fell into three categories—misidentifications, oversimplifications, and overgeneralizations—with misidentification being the most frequent (11 instances). Book A contained eight misconceptions, Book B four, and Book C three, while Book D showed none.

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