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Original Research

Identification and Categorization of Misconceptions on Mutation in High School Biology Textbooks

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Abstract

This study examined misconceptions found in Grade XII Biology textbooks, specifically in the topic of mutation. A qualitative descriptive approach was employed using content analysis on four Biology textbooks commonly used in senior high schools in Pontianak. Key concepts were identified based on Core Competency 3.8 and compared with credible references from genetic literature. Potential misconceptions were verified by two experts and categorized into five types of errors according to the classification by Dikmenli, Cardak, and Öztas: misidentification, oversimplification, overgeneralization, undergeneralization, and outdated concepts or terminology. Data validity was ensured through triangulation techniques involving teacher interviews, textbook content analysis, and documentation. The results indicate that two out of the four textbooks analyzed contain several misconceptions in presenting mutation material, ranging from definitions and types of gene mutations to chromosomal mutations. These findings highlight the importance of evaluating textbook content as a primary learning resource to prevent conceptual misunderstandings among students. This research is expected to serve as a reference for teachers and students in selecting and utilizing Biology textbooks more critically.

Introduction

Mutation is one of the topics in genetics that remains particularly prone to misconceptions. Misunderstanding fundamental genetic concepts can lead to further conceptual errors in subsequent learning, such as in evolutionary biology (Candramila & Waskito, 2021). Misconceptions related to mutation among students are partly caused by misunderstandings derived from instructional references, including reading materials or textbooks used during the learning process (Mulia & Zulyusri, 2023). According to Maftuha, Najira, & Hidayat (2024), the representation of big ideas in instruction should be a primary consideration in building students' conceptual understanding of a topic. However, many teachers have not yet fully optimized the development and use of teaching materials. Consequently, errors in the organization or presentation of key ideas in textbooks not only affect content accuracy but also increase the risk of miscommunication during instruction. This situation reflects a domino effect, in which inaccurate conceptual representations in textbooks may ultimately contribute to student misconceptions.

Textbooks are systematically structured books based on the content and subject matter of a particular field of study (Rahmawati, 2016). Textbooks serve as one of the essential sources of information for students to support the learning process both inside and outside the classroom. On the other hand, a content analysis of textbooks by Suranti et al. (2017) revealed the presence of misconceptions in each of the textbooks examined, ranging from 14% to 18%. In another study, Candramila and Waskito (2021) found that among 12th-grade science students in Pontianak during the 2018/2019 academic year, the average rate of misconceptions regarding the concept of mutation reached 33%. These misconceptions among students may stem from inaccuracies in textbook content, even though textbooks are expected to serve as accurate sources of information for both teachers and students. Inaccuracies in textbooks can also lead to misconceptions among teachers (Odom, 1993). Therefore, it is important to conduct a thorough analysis of textbook content, particularly those widely used by teachers in a given region.

To identify the most widely used 12th-grade biology textbooks, a preliminary study was conducted in the form of a survey across 27 senior high schools in Pontianak and its surrounding areas in the pre-research. The biology textbook by Irnaningtyas (2015) was found to be one of the most commonly used instructional materials by teachers for classroom instruction. The same survey also identified three other frequently used textbooks, namely those by Pratiwi et al. (2018), Nurhayati and Wijayanti (2021), and Safitri (2016), with the highest usage percentages among the surveyed schools.

An initial review of the 12th-grade Biology textbook authored by Irnaningtyas (2015) revealed a potentially misleading statement found on page 52, line 5, as follows:
"Perubahan materi genetik terjadi pada sel-sel kelamin, kemungkinan besar perubahan sifat akan diturunkan. Namun jika perubahan materi genetik terjadi pada sel-sel somatik (sel tubuh) maka perubahan tersebut tidak akan diturunkan kepada keturunannya". (English Translation: "If changes in genetic material occur in germ cells, the altered traits are likely to be inherited. However, if changes in genetic material occur in somatic cells (body cells), those changes will not be passed on to offspring.")
The statement contains an indication of misconception, as in certain cases somatic mutations can be inherited through both sexual and asexual reproduction. For instance, if a somatic mutation occurs in the bud eye of a citrus plant and subsequently gives rise to germ cells or reproductive cells, the mutation can be passed on. If the bud eye develops into a branch that produces flowers, the mutation may be inherited asexually (Nusantari, 2011).

A study conducted by Dikmenli, Cardak, & Őztas (2009) successfully classified misconceptions into five categories: misidentification (inaccurate explanation of a concept), overgeneralization (excessive generalization), oversimplification (excessive simplification), obsolete concepts and terms (outdated terminology or concepts no longer in use), and undergeneralization (overly narrow interpretation of a concept). This categorization facilitates the identification of specific types of misconceptions, as applied in the studies by Nugroho (2016), Saputri and Widyaningrum (2016), and Fuadi & Susilo (2023). Through this classification system, both teachers and students can critically examine textbook content more thoroughly, which is expected to help reduce the potential for conceptual errors.

Based on the above discussion, it can be concluded that evaluating the content of textbooks—particularly in the topic of mutation within genetics—is essential to minimize the occurrence of misconceptions among students. Textbook content analysis using the misconception categorization approach developed by Dikmenli, Cardak, & Őztas (2009) can serve as an effective tool for systematically identifying conceptual errors. This study aims to identify the types of misconceptions found in the mutation topic within four 12th-grade Biology textbooks most commonly used by teachers in Pontianak and to categorize the identified misconceptions based on the framework of Dikmenli, Cardak, & Őztas (2009). Accordingly, the results of this study are expected to serve as a foundation for improving textbook quality, developing better instructional materials, and enhancing students' conceptual understanding in the field of genetics.

Method

2.1. Design

This study used a descriptive qualitative approach with a document analysis method to identify and classify misconceptions contained in class XII Biology textbooks on mutation material.

2.2. Materials

The four textbooks analysed were selected based on the results of observations of the most use by 27 Biology teachers in Pontianak City high schools (unpublished data). The observation sheets include information on the availability of key concepts, statements of the key concepts in the book, potential misconceptions found, and categories of the misconceptions. The four high school Biology textbooks for grade XII analysed include:

1. Irnaningtyas. (2015). *Biology for SMA/MA Class XII Specialization Group of Mathematics and Natural Sciences*. Jakarta: Erlangga, hereafter coded as Book A.
2. Pratiwi, D. A., Maryati, S., Suharno, & Suseno, B. (2018). *Biology for SMA/MA Class XII Mathematics and Natural Sciences Specialization Group*. Jakarta: Erlangga, hereinafter referred to as Book B.
3. Nurhayati, N. & Wijayanti, R. (2016). *Biology Student Book for SMA/MA Grade 12 Mathematics and Natural Sciences Specialization Group*. Bandung: Widya Yrama, hereinafter referred to as Book C.
4. Safitri, R. (2016). *Biology Student Book for SMA/MA Class XII Specialization in Mathematics and Natural Sciences.* Surakarta: Mediatama, hereinafter referred to as Book D.

2.3. Data Analysis

The data were analysed using the *content analysis* method to ensure the accuracy of the findings. Triangulation is conducted to ensure validity. The data were validated by two experts in the field of genetics, namely lecturers in universities who teach Genetics courses. Both experts came from the Biology Education Study Program, Faculty of Teacher Training and Education, University of Tanjungpura. Each validator assesses the data independently. The results of the review were then compared, and differences in interpretation were discussed until consensus was reached. Content analysis followed the stages outlined by Krippendorff (2004), which included the following steps:

1. *Unitizing*, determining important concepts in mutation material based on Basic Competency (KD) 3.8. The important concepts determined are 1) definition of mutation, 2) types of mutations based on mutated cells, 3) definition of gene mutation, 4) types of gene mutations based on the number of bases, 5) types of gene mutations based on the type of base, 6) definition of chromosome mutation, 7) types of chromosome mutations based on structural changes, 8) types of chromosome mutations based on changes in number, 9) types of mutations based on the source, and 10) the impact of mutations including neutral mutation, null mutation, and lethal mutation.
2. *Sampling*, focusing on the presentation of ten predefined important concepts related to the topic of mutation in the four textbooks analysed.
3. *Coding*, recording sentences or concepts that potentially indicate misconceptions. In this study, potential misconceptions were determined through comparison with other references in the field of genetics that are more trusted for accuracy, including:
   a. Pierce, B. (2002). *Genetics: A Conceptual Approach*. New York: W. H. Freeman.
   b. Hartl, D. L., & Jones, E. W. (1998). *Genetics: Principles and Analysis Fourth Edition*. Canada: Jones and Bartlett Publisher.
   c. Klug, W. S., Cummings, M. R., Spencer, C. A., & Palladino, M. A. (2011). *Concept of Genetics, Tenth Edition*. San Francisco: Pearson Education.
   d. Cummings, M. (2010). *Human Heredity: Principles and Issues, Ninth Edition*. California: Cengage Learning.
4. *Reducing*, reviewing the findings to be analysed as needed. The review was conducted according to the misconception categories of Dikmenli, Cardak, & Őztas (2009) as follows:
   a. *Misidentification,* incorrectly defining terms or concepts
   b. *Oversimplification,* presenting concepts too simply, thereby omitting essential details or conditions necessary for accurate understanding
   c. *Overgeneralization,* the concept presented has a definition that is too broad and is applied beyond its appropriate scope
   d. *Undergeneralization, the* concept is presented in a manner that should be broad in scope but is instead limited in its application

e. *Obsolete concepts and terms, the* use of terms or concepts that are no longer valid or no longer used in current scientific understanding.

5. *Inferring,* drawing conclusions based on the misconception findings that have been analyzed and recapitulated.
6. *Narrating,* describing and discussing the findings that have been analyzed and recapitulated into a conclusion and answer to the problem being studied along with supporting theories and references.

Results and Discussion

The availability of the ten key concepts in each textbook is shown in Table 1. Most of these concepts are covered in all four textbooks. Book C includes all nine important concepts, while Books B and D each cover nine concepts, and Book A presents only eight. The concept of the impact of mutation is discussed exclusively in Book C and is not addressed in the other three textbooks.

Table 1. Coverage of key concepts in each textbook analyzed

Key Concept	Book Code			
	A	B	C	D
Definition of mutation	√	√	√	√
Types of mutations based on the mutated cells	√	√	√	√
Definitions of gene mutations	√	√	√	√
Types of gene mutations by number of bases	√	√	√	√
Types of gene mutations based on structural changes type	X	√	√	√
Definition of chromosome mutation	√	√	√	√
Types of chromosomal mutations based on structural changes	√	√	√	√
Types of chromosome mutations based on the number of changes	√	√	√	√
Types of mutations by source	√	√	√	√
Impact of mutation	X	X	√	X

√ = available; X = unavailable

Potential misconceptions were identified in only two of the four analysed textbooks, namely Books A and B (see Table 2). The most frequent categories of misconceptions included misidentification, such as errors in defining a concept or in naming a part/object, and undergeneralization, where a concept is defined too narrowly. Five key concepts were found to contain misconceptions: (1) the definition of mutation in Book B; (2) the concept of gene mutation based on the number of bases in Book A; (3) gene mutation based on the type of bases in both Books A and B; (4) the definition of chromosome mutation in Book A; and (5) chromosome mutation based on the number in Book B.

Table 2. Misconception findings in the textbooks analysed

Key Concept According to KD 3.8	Textbook Findings	Misconception Category
Definition of mutation	Book B, p. 252 line 2 *Mutasi (Latin, mutatus = perubahan) adalah peristiwa perubahan materi genetic kromosom atau DNA di dalam inti sel.* (English translation: Mutation (Latin, mutatus = change) is an event that changes the genetic material of chromosomes or DNA in the cell nucleus.)	Undergeneralization The phrase "in the cell nucleus" is too limiting in the definition of mutation, as mutations can also occur in prokaryotic organisms that lack a nucleus. Furthermore, mutations may take place in mitochondrial DNA, not only in the nucleus.

Gene mutations based on base count	Book A, p. 231, line 11 *Mutasi bingkai (frameshift mutation) terjadi karena penambahan sekaligus pengurangan satu/beberapa pasangan basa secara bersama-sama.* (English translation: A frameshift mutation occurs due to the addition and subtraction of one or more base pairs together.)	Misidentification A frameshift mutation occurs when the number of bases added or deleted is not a multiple of three. However, the sentence presented in Book A does not specify this important detail.
Gene mutations by base type	Book A, p. 231, line 1 *Mutasi tak bermakna (nonsense mutation) terjadi karena perubahan susunan basa pada kodon (triplet) dari asam amino tetapi tidak mengakibatkan kesalahan pembentukan protein. Misalnya UUU diganti UUC yang juga merupakan kode untuk pembentukan fenilanin* (English translation: *Nonsense* mutations occur due to changes in the base order of the codon (triplet) of an amino acid but do not result in errors in protein formation. For example, UUU is replaced by UUC, which is also the code for the formation of phenylanine.)	Misidentification A nonsense mutation occurs when a codon for an amino acid is changed into a stop codon, leading to premature termination of protein synthesis. The example "UUU replaced by UUC" actually represents a silent mutation, not a nonsense mutation.
	Book B, p. 252, line 31 *Mutasi gen terkadang dapat dikatakan sebagai mutasi tak bernakna (nonsense mutation) jika tidak menyebabkan perubahan apa-apa karena perubahan basa nitrogen pada kodon triplet tidak memengaruhi perubahan pesanan asam amino dalam sintesis polipeptida* (English translation: Gene mutations can sometimes be referred to as *nonsense* mutations if they do not cause any changes because changes in the nitrogenous bases of triplet codons do not affect changes in the order of amino acids in polypeptide synthesis.)	Misidentification The phrase "it doesn't cause any changes" is inaccurate, as nonsense mutations result in significant changes. They cause the polypeptide chain to terminate prematurely, leading to a truncated and typically non-functional protein.
Definition of chromosome mutation	Book A, p. 231, line 17 *Istilah mutasi digunakan untuk perubahan gen, sedangkan perubahan kromosom dikenal sebagai variasi* (English translation: The term mutation is used for gene changes, while chromosomal changes are known as variations.)	Misidentification The word *"variation"* should not be used as a substitute for the definition of chromosomal mutation. Instead, it refers to genetic diversity among individuals in a population, which can result from gene or chromosomal mutations. In this context, *"variation"* is more accurately understood as a consequence of chromosomal mutation, not as its definition.
Chromosome mutation based on number	Book B, p. 260, line 5 *Aneuploid adalah peubahan jumlah kromosom dalam jumlah satu set (genom) kromosom* (English translation: Aneuploid is a change in the number of chromosomes in a set (genome) of chromosomes.)	Misidentification Aneuploidy is an alteration in the chromosome number that is not a multiple of the complete set of chromosomes; it involves the loss or gain of one or more individual chromosomes rather than the entire set.

In Book A, three concepts contain misconceptions: the types of gene mutations based on the number and type of bases, and the definition of chromosomal mutations. Meanwhile, in Book B, potential misconceptions are found in the explanations of the definition of mutation, types of gene mutations, and types of chromosomal mutations. Regarding the definition of mutation, Book B (page 252, line 2) states:

"A mutation is an event that changes the genetic material of the chromosomes or DNA in the cell nucleus."

This statement is not entirely accurate because it limits mutations to only those occurring in the cell nucleus. In fact, DNA is also present outside the nucleus, namely in mitochondria and chloroplasts, which can also undergo mutations. As explained by Klug et al. (2011), mitochondria and chloroplasts possess their own DNA, distinct from nuclear DNA, and can independently replicate, transcribe, and translate their genetic information. Mitochondrial DNA (mtDNA) has unique characteristics, such as maternal inheritance without recombination, a higher mutation rate compared to nuclear DNA, and a greater number of copies per cell than nuclear DNA (Arsana & Juliasih, 2023). Therefore, although the definition in Book B remains relevant in the context of nuclear DNA, it should be expanded to include mutations occurring in extranuclear DNA, such as mtDNA and chloroplast DNA. A more accurate definition is that mutations are permanent changes in genetic material, whether at the DNA or RNA level, that can be inherited. This finding can be categorized as misidentification, as it incorrectly limits the scope of genetic material subject to mutation.

In the concept of gene mutation based on the number of bases, Book A (page 231, line 11) states:

"A frameshift mutation occurs due to the addition and subtraction of one or multiple base pairs together."

This statement contains a misconception because it inaccurately describes the cause of frameshift mutations. According to Klug et al. (2011), frameshift mutations result from the insertion or deletion of one or more nucleotides not in multiples of three, which shifts the reading frame of the triplet codons during translation. Frameshift mutations are not caused by simultaneous additions and deletions but rather by a change in the number of bases that is not divisible by three. If the insertion or deletion involves a multiple of three bases, the reading frame remains intact, and it is not considered a frameshift mutation. The correct explanation should be:

"A frameshift mutation is the insertion or deletion of base pairs at any position in the gene, except in multiples of three, causing a shift in the codon reading frame during translation."

The explanation in Book A can be classified as a misidentification-type misconception, as it reveals an error in understanding and defining the fundamental mechanism of frameshift mutations.

In the concept of gene mutation based on base type, misconceptions were found regarding nonsense mutations in Book A (p. 231, line 1) and Book B (p. 252, line 31). Book A explains that nonsense mutations "do not result in protein formation errors" and provides the example of UUU changing to UUC, which is actually a silent mutation, not a nonsense mutation. Meanwhile, Book B states that a nonsense mutation is "a mutation that does not cause any change because the change in the nitrogenous base does not affect the arrangement of amino acids." This statement contradicts scientific literature, which explains that nonsense mutations change an amino acid codon into a stop codon, causing premature termination of protein synthesis (Klug et al., 2011). A well-known example is the change of the GAA (glutamate) codon to UAA (stop codon). Therefore, both Books A and B contain misconceptions classified as misidentification, involving errors in recognizing and explaining the concept of nonsense mutations. The correct concept is that a nonsense mutation changes a codon that originally codes for an amino acid into a stop codon, causing premature termination of protein synthesis and producing a truncated or non-functional protein.

In the concept of chromosomal mutation definition, Book A (page 231, line 17) states:

"The term mutation is used for gene changes, while chromosome changes are known as variations."

This statement contains a misconception due to the incorrect use of the term *"variation"* in describing the process of chromosomal changes. According to Klug et al. (2011), changes in genetic material involving the structure or number of chromosomes are referred to as *chromosomal mutations* or *chromosomal aberrations*. The term *chromosomal variation*, on the other hand, refers to the outcome of such mutations, typically observed at the phenotypic or genetic level. This is consistent with Pierce

(2002), who explains that mutations can be categorized into those affecting a single gene (*gene mutations*) and those affecting the number or structure of chromosomes (*chromosomal mutations*) (p. 475, line 10). Thus, the correct concept is:

"Chromosomal mutation is a change in the structure or number of chromosomes, while chromosomal variation refers to the result of such changes that may be observed phenotypically or genetically."

The explanation in Book A can be classified as a misidentification-type misconception, as it reflects an error in identifying and using appropriate scientific terminology.

Furthermore, in the concept of chromosomal mutation based on chromosome number, a misconception is found in Book B (p. 260, line 5), which states:

"Aneuploid is a change in the number of chromosomes in a set of chromosomes (genome)."

This definition is inaccurate and reflects a misconception, as it incorrectly describes aneuploidy as a change in the number of entire chromosome sets. In fact, according to Klug et al. (2011), aneuploidy refers to the gain or loss of one or more individual chromosomes, not an entire set. For example, the loss of a single chromosome from a diploid set is called *monosomy*. Based on this explanation, aneuploidy is defined as a numerical chromosomal abnormality in which the number of chromosomes deviates from the normal diploid number, but not in multiples of a complete genome set. Instead, it involves the addition or deletion of individual chromosomes. The misconception found in Book B falls under the misidentification category, as it demonstrates an incorrect understanding of the definition and nature of aneuploidy as a type of chromosomal mutation.

Overall, the analysis indicates that both Book A and Book B contain several misconceptions related to the definitions and classifications of gene and chromosomal mutations. If left uncorrected, such inaccuracies may lead to misunderstandings among students regarding fundamental concepts in genetics, particularly in distinguishing between types of mutations and their underlying mechanisms. Teachers and students can more effectively achieve learning objectives when using high-quality textbooks that meet the four key eligibility criteria: content appropriateness, presentation quality, language accuracy, and visual or graphic design standards (Pratiwi & Widyaningrum, 2021). Improving the clarity and correctness of these explanations is crucial to support meaningful learning and to prevent the persistence of misconceptions in biology education.

Furthermore, the findings of this study require further investigation through empirical research involving students to determine whether the potential misconceptions identified in textbooks actually lead to misconceptions in learners. The presence of inaccurate or incomplete explanations in instructional materials does not automatically lead to student misconceptions, as multiple factors, including prior knowledge, teaching strategies, and classroom interactions, influence misconceptions. According to the conceptual change theory, misconceptions develop and persist because students already possess pre-existing conceptions that interact with new information (Posner et al., 1982). Misconceptions are not caused solely by faulty instructional materials, but also by how students assimilate information. Therefore, subsequent studies are needed to examine the relationship between textbook content and students' conceptual understanding, particularly to verify whether students internalize the identified potential misconceptions during the learning process. Such investigations would provide stronger evidence regarding the direct impact of textbook quality on students' conceptual development in genetics education.

Conclusion

Misconceptions were identified in two of the four textbooks analysed. These misconceptions relate to the definition of mutation, gene mutations based on the number of bases, and chromosomal mutations in terms of structure and number. The misconceptions were found in statements that are inconsistent with established scientific references. The types of misconceptions identified align with categories proposed by Dikmenli, Cardak, & Öztas (2009), particularly misidentification and overgeneralization. The number of misconceptions found differs between Books A and B, as does the total number of key concepts presented in each book. This research highlights the importance of teachers being more critical and selective when choosing textbooks as instructional materials.

Teachers are also encouraged to provide further clarification when textbook content contains inaccurate or incomplete explanations of scientific concepts.

Author contribution

All authors contribute to the design of the research. MAR collected the data; MAR and WC analyzed the data; WC and ABT supervised the entire process; all authors wrote the manuscript.

Conflict of Interest

All authors declare no conflict of interest related to this research and its funding.

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