

Conceptual misconceptions regarding DNA and the genetic code in 8th-grade students' understanding of genetic information

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ABSTRACT

The purpose of this study is to identify misconceptions among eighth-grade students regarding the "DNA and Genetic Code" unit through a word association test. The study group consisted of 186 students, 102 girls and 84 boys, attending a public middle school in Bitlis province during the 2024-2025 academic year. The convenience sampling method, one of the purposeful sampling types, was used in selecting the research group. The study group was selected randomly without any distinction between students and classes. The phenomenological design was used as the research design in the study. The word association test was used as the data collection tool. Inductive content analysis was used in the analysis of the data. The results of the research revealed that students had misconceptions about DNA and genetic code units, perceived the unit concepts abstractly, and that the vast majority of students confused basic concepts (e.g., genotype and phenotype, DNA and chromosome). Furthermore, it was determined that students struggled to construct scientific sentences and mostly constructed sentences at a superficial level of knowledge. This situation indicates that students do not have in-depth knowledge about the genetic code unit. The recommendations section of the study suggests that teachers should ensure that key concepts related to the unit are learned correctly when first introducing DNA and the genetic code unit, that peer education should be provided to students with misconceptions, that more space should be given to concepts related to DNA and the genetic code unit in the preparation of textbooks, and that teaching should be made more concrete through technological applications.

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Introduction

A concept is the first meaning that comes to mind when an object is mentioned (Çepni, 2005). Yürük and Çakır (2000) state that students' misconceptions about concepts hinder new learning and make meaningful and lasting learning difficult. Similarly, Köse et al. (2006) emphasize that meaningful and lasting learning is possible by eliminating pre-existing misconceptions in students.

Coştu et al. (2007) list the factors that cause misconceptions as follows: the inability to concretize abstract topics, the way textbooks explain topics, the way teachers explain topics, students' lack of knowledge about topics, students' prior thoughts and experiences, and students' establishment of incorrect connections between concepts.

Based on these definitions, it is understood that concepts are fundamental structures that form the mental schema in students' learning world and enable them to interpret their learning correctly. When concepts are not learned correctly, students will not be able to structure their existing knowledge correctly and, as a result, will experience difficulties in understanding new information in the future, leading to the formation of incorrect mental schemas. As a result, learning will continue to be flawed and incorrect, making it much more difficult, labor-intensive, and sometimes impossible to provide students with a correct mental schema. In contrast, when concepts are learned correctly and without error, it will be possible to learn information in a more systematic and organized manner. Furthermore, with the elimination of misconceptions, learning becomes more concrete, connected to previous learning, and more meaningful.

In the learning process, just as it is important to teach without creating misconceptions, it is equally important to eliminate existing misconceptions in students and ensure conceptual change. In order to correct misconceptions, it is first necessary to identify the misconceptions that students have and that contradict the scientific explanations of the subject and to prepare an appropriate learning environment. Conceptual misconceptions that arise, especially in lower grades, can lead to various problems in science education in later educational processes (Eyidoğan & Güneysu, 2002). Chambers and Andre (1997) state that students build new concepts they learn on top of their prior knowledge. They emphasize that if previous misconceptions are not corrected, meaningful learning cannot occur, and it becomes more difficult to establish a connection between science and real life.

Chambers and Andre (1997) linked the correction of misconceptions in students to the following four conditions in their study.

1. The concepts presented to students must be understandable and clear in a way that allows them to be constructed.
2. Students must realize that they are unable to solve new problems using their existing concepts.
3. Students should be able to find solutions to problems more easily with the new concepts they have learned.
4. Students should realize that they can solve old problems with the new concepts they encounter.

Science education is organized as a spiral-based learning domain. Therefore, a concept that a student has learned incorrectly or structured differently in their mind can gradually affect the learning of new information in subsequent grade levels and reflect on all their learning in the field of science

(Yılmaz et al., 2018). Furthermore, because science lessons contain abstract concepts, they are among the most challenging subjects for students. However, the knowledge students possess in science lessons, which appear in various forms in different areas of daily life, sometimes does not correspond with scientific knowledge (Palmer, 1999). Yürük and Çakır (2000) stated that students' correct learning of topics and concepts in science education will enable them to use these concepts and knowledge correctly in daily life. Therefore, the correct understanding of science knowledge, which is necessary at every stage of life, by students depends on the effective implementation of concept teaching in science courses. Furthermore, for science concepts to be meaningful and lasting, there must be consistency between students' prior knowledge and the new knowledge they acquire (Yağbasan & Gülçiçek, 2003).

Efe et al. (2005) emphasize that effective science education depends on identifying students' misconceptions; in order to achieve conceptual change, these misconceptions must be corrected and new concepts constructed in a more meaningful way. In this regard, they state that science programs must be planned according to these principles. Similarly, Yağbasan and Gülçiçek (2003) state that while students tend to build new knowledge on top of their existing knowledge, previous knowledge and experiences can sometimes lead to incorrect learning of new concepts. Otherwise, it is understood that misconceptions that are not detected and corrected in time will cause learning difficulties and various problems in the future. Indeed, misconceptions hinder permanent and meaningful learning; however, most of the teaching methods used are insufficient in completely eliminating these misconceptions (Geban & Ertepinar, 2001).

As can be understood from the above explanations, a learning process free of misconceptions enables students to acquire more solid and accurate knowledge. The existence of misconceptions, especially in science courses, prevents the integration of knowledge with real life. This situation makes it difficult to transfer theoretically learned knowledge into practice and even leads to the development of incorrect and erroneous learning.

Numerous studies have been conducted on the topic of inheritance, some of which are presented below as examples.

Focant et al. (2025) examined the extent to which students understand the complexity of genetics. First, teaching programs, school curricula, and textbooks used by French-speaking Belgian teachers were analyzed; it was found that these materials did not reflect the complexity of genetics and reinforced misconceptions. Teachers' practices and students' genetic knowledge were then assessed through surveys. The findings show that genetics teaching is still carried out using a reductionist approach that is outdated and fails to adequately convey contextual nuances.

Rosa et al. (2025) conducted this study to identify and define the types of misconceptions in four 12th-grade biology textbooks that address deviations from Mendel's laws. The four books examined were chosen because they were the most recommended by 27 teachers working in the city of Pontianak. Various misconceptions were identified in three of the textbooks examined (B, C, and D), while only textbook A presented accurate and clear information. The identified misconceptions consisted of examples such as incorrect definitions, oversimplification, outdated terms, and incomplete generalizations. In conclusion, the presentation of clear and accurate information in textbooks is critical in reducing misconceptions and understanding complex biology topics.

Machová and Ehler (2023) conducted a study examining misconceptions in the learning of genetics, a subject that has been taught in the Czech education system's biology curriculum for many years.

To understand the reasons for these misconceptions, research was conducted among middle and high school students in the Czech education system. Students were given a basic test covering the fundamental concepts of genetics. According to the results of this study, students used basic genetic concepts in the wrong context, the majority of students developed misconceptions about inheritance, most students struggled to explain more complex information and omitted important information, they expressed very weak views on how genetics is used in scientific research, and 70% of teachers stated that genetics is one of the most complex topics for students.

In a study by [Köroğlu \(2023\)](#) examining the mental structures of biology teacher candidates regarding the subject of inheritance, it was found that candidates had insufficient knowledge and misconceptions about this subject. In addition, it was determined that students could not fully conceptualize their cognitive structures regarding the subject of inheritance.

[Çakır's \(2023\)](#) study, which examined the longitudinal change in secondary school students' conceptual understanding levels and misconceptions about genetics, indicated that students had numerous misconceptions about genetics. It was concluded that students had particular difficulty establishing a relationship between the concepts of DNA and chromosomes.

In their study on inheritance with 6th, 7th, and 8th-grade students, [Kartal and Saylar \(2022\)](#) examined students' misconceptions about this topic in terms of different variables. According to the research findings, it was determined that students' misconceptions differed according to their grade levels. In particular, the results of the test administered showed a significant difference in favor of 8th-grade students. Furthermore, when evaluated in terms of the gender variable, it was concluded that there was a more pronounced difference in favor of female students.

In [Yıldızay's \(2020\)](#) study, which examined the cognitive structures of 10th-grade students regarding the concept of inheritance by applying the WAT and writing test, it was concluded that students' conceptual structures related to inheritance were rich and that the majority of them were able to construct correct sentences. However, it was noted that in some sentences expressing their feelings and thoughts, students found the topic of heredity difficult due to reasons such as the topic being long and heavy, boring, difficult in mathematical operations, and requiring memorization.

[Büyükkol Köse \(2019\)](#), in his study with high school students, determined that the topic of heredity is one of the most difficult topics for students to understand. The reasons for this situation were identified as the topic being quite detailed, requiring a lot of memorization, the confusion of heredity concepts, the abundance of Latin terms, and the inability to conduct experiments related to the topic of heredity.

In a study by [Turan and Koç \(2018\)](#) examining the conceptual understanding and misconceptions of 8th-grade students regarding genetic concepts, it was concluded that the vast majority of students had difficulty understanding the concepts related to genetics and had various misconceptions.

[Ünlü's \(2015\)](#) study, which examined the misconceptions of primary school students about inheritance, was conducted to determine the learning difficulties and misconceptions of 7th and 8th-grade students regarding the subject of inheritance. The study examined the misconceptions that emerged among students and their causes; it concluded that concept teaching conducted with a constructivist approach would be more beneficial for making inheritance teaching more effective and efficient.

In a study by Karagöz and Çakır (2011) examining biology teacher candidates' understanding of basic genetic concepts, it was concluded that candidates could define the concepts but could not use this information in problem-solving situations.

Mills Shaw et al. (2008) present a systematic analysis of 500 randomly selected essays from 2,443 essays submitted over two years to a high school essay contest held as part of National DNA Day. The analysis reveals students' misconceptions about genetics, the possible sources of these misconceptions, and potential ways to improve genetics education.

Topçu's (2004) study, which examined the difficulties encountered in the learning and teaching of genetics by 8th-grade students, concluded that students had misconceptions stemming from their incomplete understanding of genetic concepts, experienced difficulties in learning genetics, and were unable to solve problems in a comprehensible manner.

As can be understood from the examples given above, the "DNA and Genetic Code" unit is considered one of the most confusing, abstractly perceived, and difficult units for students to learn. The fact that genetics is a constantly evolving and current field, the great importance of learning basic concepts, the perception of the subject as complex by students, and the limited number of WAT studies on misconceptions related to this unit constitute the main reasons for this research. Furthermore, WAT stands out as an important measurement tool, not only identifying students' misconceptions but also revealing the mental connections they establish between concepts, their semantic relationship patterns, and the flawed conceptual relationships underlying these misconceptions. For these reasons, the study offers methodological innovation and contributes to the literature by revealing the mechanisms underlying the formation of misconceptions. Furthermore, examining students' conceptual perceptions by asking them to form sentences for each key concept and analyzing these sentences contributes to a deeper understanding of the learning process. Moreover, the word clouds created for each key concept help to present misconceptions in a clearer and more concrete way, strengthening the contribution of the research to the field.

Purpose of the Research

The purpose of this study is to identify the misconceptions and perceptions of 8th-grade students regarding the concepts in the "DNA and Genetic Code" unit and to highlight the importance of concept learning. Furthermore, it is demonstrated that misconceptions prevent students from fully and correctly understanding the subject, cause them to give irrelevant examples, and lead to the misconstruction of their mental schemas.

Within the scope of this study, the concepts included in the 8th-grade "DNA and Genetic Code" unit that are most confused and perceived abstractly by students were selected with the aim of identifying misconceptions. In this regard, misconceptions related to the key concepts of DNA, Gene, Chromosome, Nucleotide, Genotype, and Phenotype were identified through the WAT.

The key concepts included in the WAT for the research are listed in the following order: "DNA, Gene, Chromosome, Nucleotide, Genotype, Phenotype." To identify misconceptions related to these six key concepts, the researcher sought answers to the following research questions.

- 1) What are the perceptions of 8th-grade students regarding the key concepts of "DNA, Gene, Chromosome, Nucleotide, Genotype, Phenotype"?
- 2) What are the misconceptions of 8th-grade students regarding the key concepts of "DNA, Gene, Chromosome, Nucleotide, Genotype, Phenotype"?

Method

Research Design

In this study, the phenomenology research design was used among qualitative research designs. As [Miller \(2003\)](#) notes, phenomenology is a qualitative research method that focuses on the evaluation of lived experiences. The aim of phenomenological research is to bring together individuals' experiences and experiences related to a concept or phenomenon within a common framework of meaning ([Creswell, 2013](#)). According to [Yildirim and Şimşek \(2011\)](#), data sources in phenomenological studies consist of participants who have experienced the phenomenon under study and can reflect on it. Phenomenology is the explanation of individuals' momentary experiences ([Edmonds & Kennedy, 2017](#)). In line with these definitions, the phenomenological design was chosen in this study to reveal the concepts previously learned by students in the "DNA and Genetic Code" unit with their existing meanings in their minds and to determine their perceptions of these concepts. This approach will contribute to understanding students' perceptions of concepts and their mental schemas.

Study Group

The participants of the research consists of a total of 186 volunteer students, 102 women and 84 men, attending a public school in Güroymak district of Bitlis province. In this study, the selection of students was carried out using the criterion sampling method, one of the purposive sampling methods. In this sampling approach, all individuals or situations that meet the criteria determined prior to the research are included in the study and examined ([Patton, 2014](#)). Accordingly, the criteria of "being enrolled in the 8th-grade" and "having completed the DNA and Genetic Code unit" were used in the study.

Data Collection Tool

The WAT, prepared by the researchers, was used as the data collection tool. The WAT is one of the most common and oldest educational tools used in research on students' cognitive structures ([Bahar et al., 1999](#)). In order to identify misconceptions, a WAT form example, as shown in Figure 1, was prepared for each key concept in the DNA and Genetic Code unit.

Figure 1

Word Association Test (WAT) page example

1) DNA Concept

DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....
DNA:.....

➤ Write an example sentence related to the concept of DNA:
.....

The WAT was administered to students to seek answers to research questions and obtain detailed information. This test was prepared to cover all key concepts and was photocopied onto A4 paper to be distributed to each student. An expert was consulted during the preparation and evaluation of the test to obtain expert opinion.

The researcher created six separate WAT sections for six different key concepts for the students in order to identify misconceptions. The WAT was administered to determine students' perceptions of the concepts, misconceptions, knowledge gaps, knowledge errors, and learning levels. In addition, students were asked to write an example sentence for each concept to examine how the learned concepts were interpreted in their minds.

The data was collected after providing the necessary explanations to the students in the classroom about how the WAT would be applied, the time allowed, and the application process. The WAT is a very easy test to prepare and administer, and it is possible to administer it to a large number of students in just five minutes (Bahar et al., 1999). Short periods of time were used in the KIT studies conducted by Bahar et al. (1999), Bahar and Özatlı (2003), and Erbağcı and Kaf (2020) to reveal students' rapid associations. According to the researchers, the purpose of the test is to determine the concept connections that are instantly activated in the student's mind, not the relationships that come after a long thinking process. Therefore, short periods of time reflect conceptual misconceptions and knowledge organization more validly. In line with these studies, the short time used in WAT applications is consistent with the basic principles of this technique in the literature. In this study, students were given a maximum of one minute for each concept. The researcher monitored the time and provided information to the students at the end of the time allotted for the first concept, then started the time for the second concept. This procedure was repeated for all concepts, and data collection was completed within a total of six minutes. No guidance was provided to the students during the data collection process; they were allowed to transfer their knowledge to the data collection tools in a relaxed environment without any pressure.

Data Analysis

Content analysis was performed on the data. According to Yıldırım and Şimşek (2006), the main purpose of content analysis is to arrive at concepts and relationships that can explain the collected data. Content analysis requires an inductive approach. In inductive analysis, categories and themes are created directly from the data without relying on a predetermined theory or bias. The researcher analyzes the data, identifies patterns, and develops new categories and themes based on the data. Thus, the analysis process becomes an inductive process that allows for the production of new understandings and theories from the material (Dayanan Uğur & Saylık, 2025).

The data analysis was conducted following the sequence below.

In the first stage, the data obtained regarding key concepts and sentences were examined in detail. All answers given by the students were listed in Excel from highest to lowest according to their frequency values. Tables were created by listing all the answers given in descending order of frequency values.

In the second stage, a word cloud was created for each key concept based on its frequency value. In the word cloud, the most frequently repeated concepts were sorted from largest to smallest font size according to their frequency of use. Additionally, words containing conceptual errors were

highlighted in red.

In the third stage, the students' answers to the sentences were fully analyzed in Excel and categorized as "Scientific Sentences," "Partially Scientific or Superficial Sentences," "Non-Scientific Sentences," "Sentences Containing Conceptual Errors," and "Sentences Left Blank." Similar studies in the literature were reviewed when creating the categories (Özışık Yapıcı, 2022; Balbağ, 2018); however, the categories were finalized by the researchers in accordance with the purpose of the study. The sentence frequencies for each category are presented in tables, and two example sentences for each category are added below the tables.

In the fourth stage, conclusions regarding conceptual misconceptions were drawn from all the findings of the study. Based on these conclusions, explanations and observations were made and discussed with examples from the literature. Recommendations were also made in line with the findings.

Validity and Reliability

The necessary ethical approvals for this study were granted by the Muş Alparslan University Scientific Research and Publication Ethics Committee through Decision No. 54 taken at its 4th meeting on 06.02.2024. To ensure the reliability of the research, all responses and findings obtained were reviewed by two different experts in the field of science. Inter-coder agreement was calculated to ensure validity and reliability. To this end, the reliability coefficient was determined based on the formula proposed by Miles and Huberman (1994). The reliability coefficient was calculated using the formula: Reliability coefficient = Agreement / (Agreement + Disagreement) x 100. In the analyses, a ratio above 70% indicates that the study is reliable and consistent (Miles & Huberman, 1994).

This calculation was applied separately to words and sentences related to key concepts. First, consensus was reached on 595 of the total 627 different concepts related to key concepts. Although there was initially disagreement on 32 concepts, consensus was reached after expert opinions, and the necessary corrections were made. In this case;

When the reliability coefficient was calculated as (Consensus=595) / (Consensus=595 + Disagreement=32) x 100, the reliability was determined to be approximately 95%.

When determining the reliability of the sentence categories, it was found that students left a total of 290 sentences blank. Therefore, the calculation was based on the 824 sentences that students responded to for the six key concepts. The review revealed that there were 746 sentences with consensus and 78 sentences with disagreement. In this case;

Reliability coefficient = (Agreement=746) / (Agreement=746 + Disagreement=78) x 100, the reliability was determined to be approximately 90%. The high level of expert evaluation and inter-researcher agreement supports the reliability of the analysis process (Creswell, 2013). Since a reliability coefficient above 70% provides sufficient conditions for the reliability and consistency of the analyses, the study is considered reliable.

Findings

This section presents the findings of the study.

Findings Related to the Key Concept of DNA

All the words written by the students regarding the "DNA" concept are listed in Table 1 below.

Table 1

Students' Responses and Frequencies (f) Related to the DNA Key Concept

Concept	Students' Responses Related to the Concept							
	Concept	f	Concept	f	Concept	f	Concept	f
DNA	Helical structure	88	Guanine	6	Repairable	2	Destiny*	1
	Regulatory molecule	53	Molecule	6	Hair color*	2	Genetic molecule	1
	Nucleotide	48	Life activity	6	Code	2	Genetic disease	1
	Gene	46	Mutation	5	Structural feature	2	Blood type	1
	Genetic code	41	Trait*	5	Adaptation*	1	Concept*	1
	Double-stranded	36	Thymine	5	Transfer*	1	Short stature	1
	Self-replication	30	Appearance*	4	Aziz Sancar	1	Identity determines	1
	Replication	29	Phenotype	4	Base*	1	Copyable	1
	Chromosome	28	Human*	4	Specific order	1	Chromatin filament	1
	Nucleus	22	Inheritance	4	Science	1	Hybrid	1
	Cell	22	Personality traits*	3	Biology	1	Microbes*	1
	Double helix	18	Individual	3	Size*	1	Mitochondria	1
	Fingerprint*	18	Modification	3	Gender	1	Irreparable*	1
	Genetic structure	15	Sugar*	3	Crossbreeding*	1	Protein synthesis	1
	Chain structure	13	Fire escape*	3	Bar*	1	Clock*	1
	Deoxyribonucleic acid	11	Structure*	3	Change*	1	Hair*	1
	Cytoplasm	10	Structural unit*	3	Sequence	1	Hair strand*	1
	DNA test	9	Family resemblance	2	DNA disorder	1	Pure line	1
	Double helix	9	Distinctive	2	Irregularity*	1	Centrosome*	1
	Deoxyribose sugar	8	Bond	2	Parent	1	Single-stranded	1
	Organic base	8	Individual*	2	Different*	1	Tall stature	1
	Cytosine	8	Division	2	Next generation	1	Reproduction	1
	Genetics	7	Diversity	2	Glucose sugar*	1	Artificial selection*	1
	Filamentous structure*	7	Zipper structure*	2	Functional unit*	1	Structural defect*	1
	Adenine	6	Genetic information	2	Mismatch	1	New strand	1
	Phosphate	6	Blood*	2	Animal*	1		
	Genotype	6	Staircase*	2	Internal appearance*	1		
Total frequency					748			
Total concept					106			

Note: Words with misconceptions are marked with an asterisk (*).

Table 2

Categorization of Sentences Written About the DNA Key Concept

DNA Concept	Scientific Sentences	Partially Scientific or Superficial Sentences	Non- Scientific Sentences	Sentences Containing Conceptual Misconceptions	Blank Sentences
Frequency (f)	40	43	32	51	20

Table 2 shows that the sentences written by students about the concept of *DNA* are divided into five categories. Of the sentences written by students, 40 are "*Scientific Sentences*," 43 are "*Partially Scientific or Superficial Sentences*," 32 were classified as "*Non-Scientific Sentences*," 51 were classified as "*Sentences Containing Conceptual Misconceptions*" and 20 were classified as "*Blank Sentences*."

Below are some examples of sentences used by students regarding the concept of *DNA*.

- **Scientific sentences**
 "DNA has a double-stranded, helical structure."
 "DNA gets its name from the 5C deoxyribose sugar."
- **Partially scientific or superficial sentences**
 "Every person's DNA is different"
 "DNA is found inside the cell"
- **Non-scientific sentences**
 "My family and I took a DNA test"
 "DNA is the study of something"
- **Sentences containing conceptual misconceptions**
 "DNA does not exist in organisms without a nucleus"
 "DNA is the structural unit of a chromosome"

Findings Related to the Key Concept of Gene

All words written by students regarding the concept of "*Gene*" are listed in Table 3 below.

Table 3

Students' Responses and Frequencies (f) Related to the Key Concept of Gene

Concept		Students' Responses Related to the Concept						
	Concept	f	Concept	f	Concept	f	Concept	f
Gene	Functional unit	62	Gene	5	From generation to generation	2	Cell membrane*	1
	Nucleotide	34	Cell*	5	Fragment*	2	Filament*	1
	Eye color	24	Skin color	5	Body characteristics*	2	Inheritance	1
	Hair color	23	Tall stature	5	Transmission to offspring	2	Hereditary	1
	DNA	17	Family relationship*	4	Family*	1	Self-replication*	1
	Genetic information	13	Phenotype	4	Six-fingered human*	1	Short hair*	1
	Gene transfer	12	Blood type	4	Mother*	1	Girl*	1
	Structural unit*	11	Short stature	4	Father*	1	Identity characteristics*	1
	Gene therapy	10	Modification	4	Similarity*	1	Personality*	1
	Adenine	9	Base*	3	Information*	1	Personalized*	1
	DNA fragment	9	Recessive	3	Biotechnology	1	Chloroplast*	1
	Chromosome	9	Diversity	3	Body length	1	Ear shape	1
	Thymine	9	Genetic code	3	Nucleus*	1	Key point*	1
	Character*	8	Genotype	3	Behavior*	1	Fingers*	1
	Cytosine	8	Disease*	3	Deoxyribose sugar	1	Protein coat*	1
	Transfer	7	Unit of heredity	3	Sequence	1	Color*	1
	Phosphate	7	Hair style	3	Congenital characteristics*	1	Healthy genes	1
	Guanine	7	Helical structure*	3	Parent gene*	1	Family tree*	1
	Organic base	7	Password	3	Male*	1	Carrier gene	1
	Height*	6	Dominant gene	2	Gene map	1	Treatment*	1
	Genetic diversity	6	Nose shape	2	Genetic breeding	1	In vitro fertilization*	1
	Mutation	6	Crossbreeding	2	Gene cloning	1	Long hair*	1
	Generation	6	Appearance*	2	Genetic structure	1	Body color*	1
	Trait	6	Physical characteristic	2	Privacy*	1	Vital functions*	1
	Sugar*	6	Selective breeding	2	Glucose*	1	Strand*	1
	Allele gene	5	Function*	2	Group*	1	Chain-like*	1
	Gender	5	Eyebrow color	2	Hydrogen bond	1	46 chromosomes*	1
	Difference*	5	Cloning*	2	Cell wall*	1		
Total frequency		484						
Total concept		111						

Note: Words with conceptual errors are marked with an asterisk (*).

As shown in Table 3, the total number of words written by students regarding the concept of *Gene* is 111. The total frequency value of these words is 484. Students most frequently used the concepts

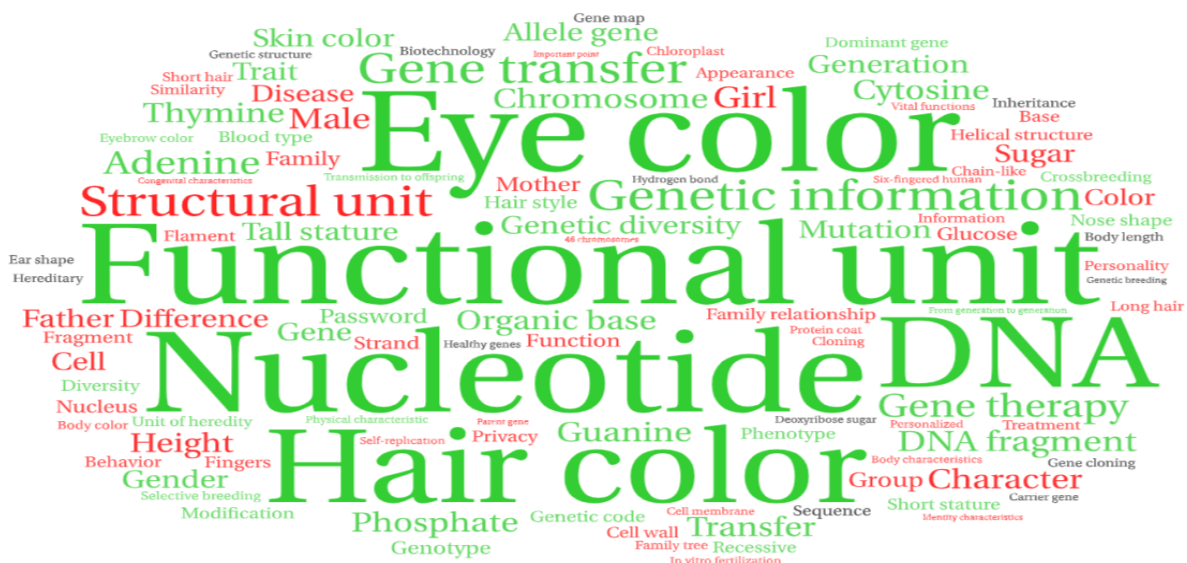
"Functional unit," "Nucleotide," "Eye color," "Hair color," "DNA," "Genetic information," "Gene transfer," and "Gene therapy" to correctly associate these concepts with the *Gene* concept.

Words containing misconceptions related to the concept of *gene* are listed in Table 3. Among these concepts, the words "Structural unit," "Character," "Height," "Sugar," "Difference", and "Cell" are the concepts containing misconceptions with the highest frequency values. Additionally, 22 students were unable to form any ideas related to the concept of *genes*, did not write any words, and left the section on genes completely blank.

Below, in Figure 3, an example of a *Word Cloud* prepared according to the frequency values of the words written by the students regarding the concept of *Gene* is given.

Figure 3

Word Cloud Containing Responses Related to the Key Concept of Gene



In the word cloud in Figure 3, concepts that do not contain misconceptions and are used more than once are shown in green, concepts that do not contain misconceptions but are used only once are shown in black and words containing misconceptions are shown in red. Furthermore, the concepts are sorted by font size according to their frequency of use; concepts with a high frequency value are shown in a larger font, while those with a low frequency value are shown in a smaller font.

The sentences written by the students regarding the concept of *Gene* have been categorized and the frequency values for these categories are given in Table 4 below.

Table 4.

Categorization of Sentences Related to the Key Concept of Gene

Gene Concept	Scientific Sentences	Partially Scientific or Superficial Sentences	Non-Scientific Sentences	Sentences Containing Conceptual Misconceptions	Blank Sentences
Frequency (f)	35	37	30	52	32

Table 4 shows that the sentences written by students about the concept of *Gene* are divided into five

categories. Of the sentences written by students, 35 were classified as "*Scientific Sentences*," 37 as "*Partially Scientific or Superficial Sentences*," 30 as "*Non-Scientific Sentences*," 52 were identified as "*Sentences Containing Conceptual Misconceptions*", and 32 were identified as "*Blank Sentences*."

Below are some examples of sentences used by students regarding the concept of *Gene*

- **Scientific sentences**
 "A gene is the functional unit of DNA."
 "A gene is the unit of hereditary information located on a chromosome."
- **Partially scientific or superficial sentences**
 "A gene is a section within DNA."
 "A gene determines our physical characteristics."
- **Non-scientific sentences**
 "Our teacher gave us a test on gene transfer today."
 "Determining the sex of the deceased."
- **Sentences containing conceptual misconceptions**
 "A gene is the building block of DNA."
 "A gene is not hereditary."

Findings Related to the Key Concept of Chromosomes

All words written by students regarding the concept of "*Chromosome*" are listed in Table 5 below.

Table 5

Students' Responses and Frequencies Related to the Key Concept of Chromosome

Concept	Students' Responses Related to the Concept							
	Concept	f	Concept	f	Concept	f	Concept	f
Chromosome	Protein coat	46	Molly fish	3	Complex structure*	2	Complementary strand*	1
	DNA	44	Organic base	3	Part replacement	2	Protective coat*	1
	46	41	Protein	3	Protein synthesis	2	Chromosome difference	1
	chromosomes							
	X-shaped*	28	Single-celled*	3	Adenine	1	Chromosome structure	1
	Gene	25	Hereditary trait	3	Albinism	1	Scissors*	1
	Nucleotide	2	Division	2	Mother	1	Protein solution*	1
		2						
	Helical structure*	12	Organism type	2	Father	1	Number	1
	Largest structure*	10	Skin color*	2	Five hundred*	1	Cytosine	1
	Filament*	10	Crossing	2	Science	1	Sugar*	1
	Seeds	9	Double helix*	2	Unit*	1	Identical twin*	1
	Cell	8	DNA formation*	2	Merging*	1	Thymine	1
	Double-stranded*	7	Replication	2	Gender	1	Species*	1
	Fern	7	Phenotype	2	Dizygotic twin	1	Reproduction*	1
	Cell division	7	Phosphate	2	Deoxyribose sugar	1	X chromosome	1

Down syndrome	6	Genotype	2	External genetics*	1	XX	1
Mitosis	6	Eye color	2	DNA protector*	1	XY	1
Sperm	6	Animal	2	Correction*	1	Y chromosome	1
Egg	6	Self-fertilizing	2	Deficiency*	1	Fire escape*	1
Person	5	Mathematics*	2	Most complex*	1	Mismatch*	1
Chromatin filament	5	Mutation	2	Maturity*	1	New strands*	1
Meiosis	5	Number*	2	Guanine	1	Regulatory molecule*	1
Difference*	4	Hour*	2	Volume*	1	Strand*	1
Chromosome count	4	Hair color*	2	Homologous chromosome	1	23 chromosomes	1
Plant	3	Number unit*	2	Two new DNA	1		
DNA division*	3	Body*	2	Twin*	1		
Shortening and thickening*	3	Living organism	2	Comprehensive*	1		
Total frequency				441			
Total concept				101			

Note: Words with conceptual errors are marked with an asterisk (*).

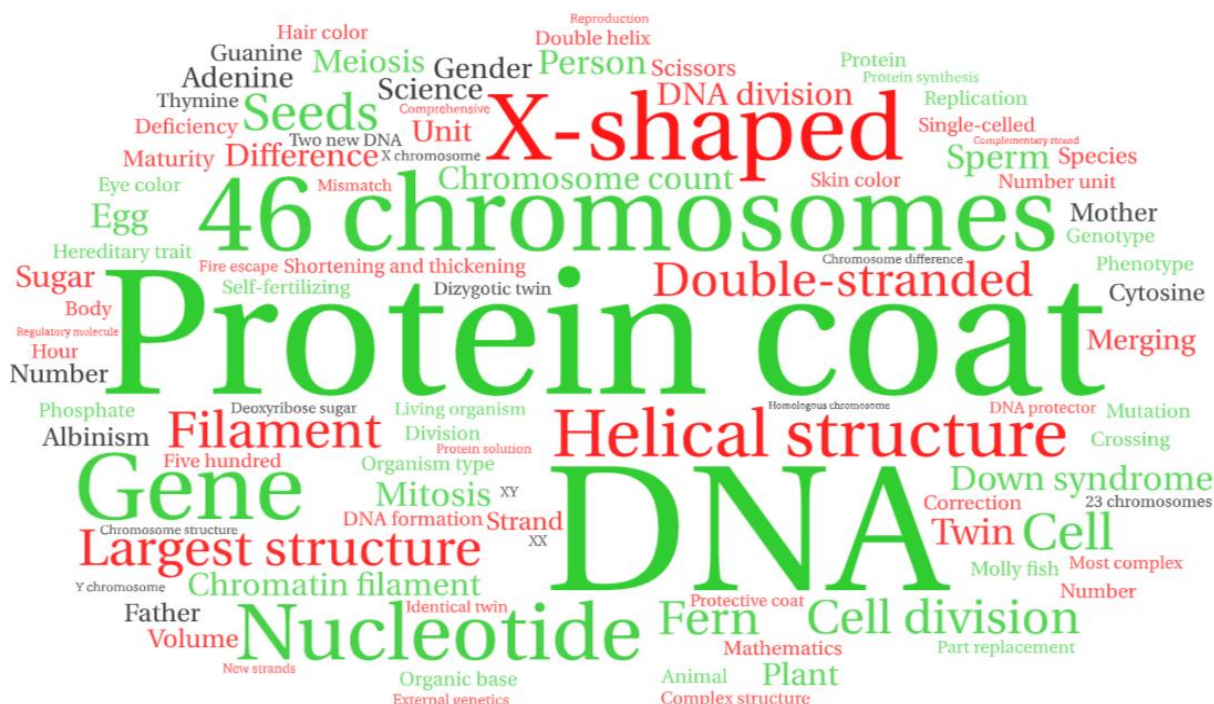
As shown in Table 5, the total number of words written by students regarding the concept of *Chromosome* is 101. The total frequency value of these words is 441. Students most frequently used the concepts "Protein coat," "DNA," "46 chromosomes," "X-shaped," "Gene" and "Nucleotide" in relation to the concept of *Chromosome*, correctly associating these concepts with *Chromosome*.

Words containing misconceptions about the concept of *Chromosome* are listed in Table 5. Among these concepts, the words "X-shaped," "Helical structure," "Largest structure," "Filament" and "Double-stranded" are the concepts containing misconceptions with the highest frequency values. In addition, 24 students were unable to form any ideas about the concept of *Chromosomes*, did not write any words and left the section on *Chromosomes* completely blank.

Below, in Figure 4, an example of a *Word Cloud* prepared according to the frequency values of the words written by the students regarding the concept of *Chromosome* is given.

Figure 4

Word Cloud Containing Responses Related to the Key Concept of Chromosome



In the word cloud in Figure 4, concepts that do not contain misconceptions and are used more than once are shown in green, concepts that do not contain misconceptions but are used only once are shown in black and words containing misconceptions are shown in red. Furthermore, the concepts are sorted by font size according to their frequency of use; concepts with a higher frequency value are shown in a larger font, while those with a lower frequency value are shown in a smaller font.

The sentences written by the students regarding the concept of *Chromosome* are categorized and the frequency values for these categories are given in Table 6 below.

Table 6

Categorization of Sentences Related to the Key Concept of Chromosome

Chromosome Concept	Scientific Sentences	Partially Scientific or Superficial Sentences	Non-Scientific Sentences	Sentences Containing Conceptual Misconceptions	Blank Sentences
Frequency (f)	38	46	33	52	17

Table 6 shows that the sentences written by students about the concept of *Chromosomes* are divided into five categories. Of the sentences written by students, 38 are "Scientific Sentences," 46 are "Partially Scientific or Superficial Sentences," 33 were classified as "Non-Scientific Sentences," 52 were classified as "Sentences Containing Conceptual Misconceptions" and 17 were classified as "Blank Sentences."

Below are some examples of sentences used by students regarding the concept of *Chromosome*.

- **Scientific sentences**
"Healthy humans have 46 chromosomes."

"The number of chromosomes has no relation to the level of development of a living organism."

- **Partially scientific or superficial sentences**

"Humans have 46 chromosomes."

"A chromosome is a genetic structure composed of DNA."

- **Non-scientific sentences**

"There is a child with 44 chromosomes in our village."

"Whether a person is healthy or not"

- **Sentences containing conceptual sentences**

"The structural unit of a chromosome is DNA."

"The outside of the chromosome is surrounded by cytoplasm."

Findings Related to the Key Concept of Nucleotide

All words written by students regarding the concept of *nucleotides* are listed in Table 7 below

Table 7

Students' Responses and Frequencies Regarding the Nucleotide Key Concept

Concept	Students' Responses Related to the Concept							
	Concept	f	Concept	f	Concept	f	Concept	f
Nucleotide	Adenine	115	Nitrogenous organic base	4	Water*	2	Small structure*	1
	Thymine	114	Weak hydrogen bond	4	Dominant*	1	Hybrid*	1
	Guanine	110	Bond*	3	Specific order	1	Molecule	1
	Cytosine	100	DNA	3	To combine	1	Mutation	1
	Phosphate	71	Phenotype*	3	Variety*	1	Point*	1
	Organic base	61	Glucose*	3	Sequence	1	Nucleotide	1
	Sugar*	53	Two bonds	3	Arrangement	1	Nucleotide type	1
	Structural unit	51	Three bonds	3	Zipper*	1	Oxygen*	1
	Deoxyribose sugar	42	Inheritance	3	Guanine sugar*	1	Hair length*	1
	Four types	28	5C deoxyribose sugar	2	Errors*	1	Blonde hair*	1
	Gene	16	Nitrogen*	2	Mismatched nucleotide	1	Helical structure*	1
	Smallest unit*	14	Genotype*	2	Animal	1	Number*	1
	Hydrogen bond	14	Function unit*	2	Hydrogen*	1	Black hair*	1
	Base pairing	10	Eye color*	2	Human	1	Carrier*	1
	Base*	6	Filament*	2	Brown*	1	Wrong match	1
	Chain*	6	Chromosome	2	Character*	1	Structure	1
	Deoxyribose*	5	Property	2	Carbon sugar*	1	Renewal*	1
	Building block	5	Protein*	2	Complementar y binding	1	Regulatory molecule*	1
	5C Sugar	4	Hair color*	2	Personal information*	1		
Total frequency					912			
Total concept					75			

Note: Words with conceptual errors are marked with an asterisk (*).

Table 8

Categorization of Sentences Related to the Key Concept of Nucleotide

Nucleotide Concept	Scientific Sentences	Partially Scientific or Superficial Sentences	Non-Scientific Sentences	Sentences Containing Conceptual Misconceptions	Blank Sentences
Frequency (f)	40	21	23	32	70

Table 8 shows that the sentences written by students about the concept of *Nucleotide* are divided into five categories. Of the sentences written by students, 40 are "*Scientific Sentences*," 21 are "*Partially Scientific or Superficial Sentences*," 23 were classified as "*Non-Scientific Sentences*," 32 were classified as "*Sentences Containing Conceptual Misconceptions*", and 70 were classified as "*Blank Sentences*."

Below are some examples of sentences used by students regarding the concept of *Nucleotide*.

- **Scientific sentences**
"A nucleotide is the smallest structural unit of DNA."
"Nucleotides derive their name from the nitrogenous organic base they contain."
- **Partially scientific or superficial sentences**
"Phosphate is present in nucleotides."
"Mismatched nucleotides are repaired."
- **Non-scientific sentences**
"Found in both the mother and child."
"Our teacher explained the nucleotide sequence."
- **Sentences containing conceptual misconceptions**
"A nucleotide is the functional unit of DNA."
"It is the smallest structural unit found in humans and animals."

Findings Related to the Key Concept of Genotype

All the words written by the students regarding the concept of *Genotype* are listed in Table 9 below.

Table 9

Students' Responses and Frequencies Regarding the Key Concept of Genotype

Concept	Students' Responses Related to the Concept							
	Concept	f	Concept	f	Concept	f	Concept	f
Genotype	Dominant	65	Homozygous recessive	5	Father	1	Amputation of the arm*	1
	Heterozygous	53	Pure recessive	5	Dominant offspring*	1	Ear*	1
	Homozygous	51	Recessive allele	4	Plant*	1	Generation*	1
	Recessive	47	Phenotype	4	Nose*	1	Lowercase	1
	Hybrid	39	Homozygous dominant	4	Capital letter*	1	Hybrid dominant	1
	Recessive gene	38	Difference*	3	Alive*	1	Modification*	1
	Dominant gene	36	Genetics	3	Gender*	1	Color*	1
	Allele gene	34	Eye color*	3	Recessive offspring*	1	Hair*	1
	Pure line	27	Patient*	3	Variety	1	Hair length*	1
	Internal appearance*	26	Heterozygous dominant	3	Change*	1	Not pure	1

Crossbreeding	23	Character*	3	Unchangeable*	1	Blonde hair*	1
Pure	16	Short stature*	3	Offspring*	1	Yellow seed*	1
Hybrid offspring	14	Mendel	3	Replication	1	Number*	1
AA	12	Property	3	Married*	1	Cytoplasm*	1
Aa	12	Healthy*	3	Different varieties	1	Black hair*	1
Gene	12	aA*	2	Phosphate*	1	Sugar*	1
aa	10	Tree *	2	Temporary*	1	Three types*	1
Gene count*	9	Wrinkled*	2	Genetic pair	1	Reproduction*	1
Internal structure*	9	External appearance*	2	Genetic lettering	1	Structure*	1
Mutation	8	Proper*	2	Glucose*	1	Structural unit*	1
Gene structure	7	Permanent	2	Functional unit*	1	Green seed*	1
Inheritance	7	Organic base*	2	Beauty*	1	Harmful genotype*	1
True-breeding	6	Hair strand*	2	Letter	1	Zygote*	1
Body length*	6	Water*	2	Disease gene*	1	Chain reaction*	1
Pure dominant	6	Seed*	2	Hydrogen bond*	1		
Carrier	6	Leaf*	2	Probability*	1		
Dominant allele	5	Consanguineous marriage*	2	Hereditary disease	1		
Pea	5	Area*	1	Eye-brow color*	1		
Genetic sequencing	5	Mother	1	Eye-brow shape*	1		
Total frequency				725			
Total concept				111			

Note: Words with conceptual errors are marked with an asterisk (*).

As shown in Table 8, the total number of words written by students regarding the concept of *Genotype* is 111. The total frequency value of these words is 725. The words most frequently used by students regarding the concept of *Genotype* are: "Dominant," "Heterozygous," "Homozygous," "Recessive," "Hybrid," "Recessive gene," "Dominant gene," "Allele gene," "Pure line," "Internal appearance," "Crossbreeding," "Pure," "Hybrid offspring," "AA," "Aa," "Gene" and "aa." Thereby correctly associated these concepts with the concept of *Genotype*.

Words containing misconceptions related to the concept of *Genotype* are listed in Table 8. Among these concepts, the words "Internal appearance," "Gene count," "Internal structure" and "Body length" are the concepts containing misconceptions with the highest frequency values. Furthermore, 30 students were unable to form any ideas about the concept of *Genotype*, did not write any words and left the section on *Genotype* completely blank.

Below, in Figure 6, an example of a *Word Cloud* prepared according to the frequency values of the words written by the students regarding the concept of *Genotype* is provided.

- "They are the hereditary characteristics possessed by an individual."
- **Non-scientific sentences**
 "The tree's flowers are hybrids."
 "My uncle's eyes were predominantly blue."
 - **Sentences containing conceptual misconceptions**
 "Genotype is the structural unit of DNA."
 "Genotype does not manifest in outward appearance."

Findings Related to the Key Concept of Phenotype

All the words written by the students regarding the concept of *Phenotype* are listed in Table 10 below.

Table 10

Students' Responses and Frequencies Related to the Key Concept of Phenotype

Concept	Students' Responses Related to the Concept							
	Concept	f	Concept	f	Concept	f	Concept	f
Phenotype	External appearance	148	Height	4	Handsome	2	Blood type	1
	Hair color	26	Eye	4	Adaptation*	1	Eyebrow color	1
	Eye color	25	Character*	4	Mouth	1	Red hair	1
	Tall stature	19	Short	4	Albinism	1	Short hair	1
	Recessive*	16	Color	4	Bond*	1	Weight gain	1
	Blue eyes	16	Black hair	4	Dominant phenotype*	1	Identity*	1
	Dominant*	15	Long	4	Head	1	Arm fracture	1
	Blonde hair	12	Shape	4	Fair skin	1	Mathematics*	1
	Skin color	12	Environmental factors	3	Unit*	1	Mendel	1
	Heterozygous*	11	Smooth	3	Plant color	1	Myopia*	1
	Homozygous*	11	Appearance	3	External characteristics*	1	Qualification*	1
	Short stature	11	Brown eyes	3	Skin color	1	Nucleotide*	1
	Crossbreeding*	9	Eyebrow	3	Skin shape*	1	Organic base*	1
	Straight hair	9	Weight	3	Skin structure	1	Hair style	1
	Curly hair	9	Hybrid*	3	Recessive phenotype*	1	Pure dominant*	1
	Recessive gene*	8	Purple color	3	Variety*	1	Healthy*	1
	Gene*	8	Hair length	3	Change*	1	Yellow pea	1
	Pure line*	8	Pure line*	2	Teeth	1	Number*	1
	Dominant gene*	7	Foot	2	Hand	1	Adjective*	1
	Body height	7	Nose structure	2	Married*	1	Acne	1
	Wrinkled	7	Wrinkled seed	2	Temporary*	1	Black skin	1
	Hybrid offspring *	7	Wavy hair	2	Pore	1	Nail shape	1
	Purple flower	7	Arrangement*	2	Sunburn	1	Seed	1
	Physical characteristics	6	Flat seed	2	Volume*	1	Long hair	1
	Modification	6	Difference	2	Patient phenotype*	1	Body	1
	Allele gene*	5	Genotype*	2	Himalayan rabbit	1	Structure*	1

Pea	5	Inheritance	2	Hobby*	1	Green peas	1
Mutation*	5	Trait	2	Internal structure*	1	Chain*	1
Hair	5	Number*	2	Two types*	1		
Green eyes	5	Hour*	2	Not permanent*	1		
White flower	4	Unit of count *	2	Genetic diversity	1		
Total frequency				596			
Total concept				121			

Note: Words with conceptual errors are marked with an asterisk (*).

As shown in Table 10, the total number of words written by students regarding the concept of *Phenotype* is 121. The total frequency value of these words is 596. Students most frequently used the concepts "External appearance," "Hair color," "Eye color," "Tall stature," "Blue eyes," "Blonde hair," "Skin color" and "Short stature" to correctly associate these concepts with *Phenotype*.

Words containing misconceptions related to the concept of *Phenotype* are listed in Table 10. among these concepts, "Recessive," "Dominant," "Heterozygous," "Homozygous," "Crossbreeding," "Recessive gene," "Gene," "Pure line," "Dominant gene," "Hybrid offspring," "Allele gene" and "Mutation" are the concepts with the highest frequency values that contain misconceptions. In addition, 31 students did not write any words, unable to form any ideas related to the concept of *Phenotype* and left the section on *Phenotype* completely blank.

Below, in Figure 7, is an example of a *Word Cloud* prepared according to the frequency values of the words written by the students regarding the concept of *Phenotype*.

Figure 7

Word Cloud Containing Responses Related to the Key Concept of Phenotype



In the word cloud image in Figure 7, concepts that do not contain misconceptions and are used more than once are shown in green, concepts that contain misconceptions or uncertainties are shown in red and words that do not contain misconceptions but are used only once are shown in black. Furthermore, the concepts are sorted by font size according to their frequency of use; concepts with a higher frequency value are displayed in a larger font, while those with a lower frequency value are displayed in a smaller font.

The sentences written by the students regarding the concept of *Phenotype* have been categorized and the frequency values for these categories are given in Table 10 below.

Table 10

Expression of Sentences Related to the Phenotype Key Concept by Category

Phenotype Concept	Scientific Sentences	Partially Scientific or Superficial Sentences	Non-Scientific Sentences	Sentences Containing Conceptual Misconceptions	Blank Sentences
Frequency (f)	34	32	15	38	67

Table 10 shows that the sentences written by students regarding the concept of *phenotype* are divided into five categories. Of the sentences written by students, 34 are "*Scientific Sentences*," 32 are "*Partially Scientific or Superficial Sentences*," 15 were classified as "*Non-Scientific Sentences*," 38 were classified as "*Sentences Containing Conceptual Misconceptions*" and 67 were classified as "*Blank Sentences*."

Below are some examples of sentences used by students regarding the concept of *Phenotype*.

- **Scientific sentences**

"Phenotype refers to the characteristics that determine an organism's external appearance."

"A person having blue eyes is a phenotype."

- **Partially scientific or superficial sentences**

"It manifests in physical appearance due to the effect of the genotype."

"The phenotype is dependent on genetic structure."

- **Non-scientific sentences**

"It determines whether a person is beautiful or not."

"The phenotype was very good."

- **Sentences containing conceptual misconceptions**

"Phenotype only shows its effect when genes are purely recessive."

"The dominant gene is effective in the phenotype."

Results and Discussion

This study aimed to identify misconceptions among 8th-grade students regarding concepts in the "DNA and Genetic Code" unit. The findings of the study were examined, and detailed results were presented. In addition, the results obtained were discussed with support from the literature.

According to the results obtained from the examination of the key concept of *DNA*, the majority of students correctly associated DNA with the concepts of "Helical structure," "Regulatory molecule," "Nucleotide," "Gene," "Genetic code," "Double stranded" and "Self-replication." This finding indicates that they have formed a correct mental structure regarding the function and structure of the *DNA* concept. Furthermore, this result shows that the concepts that are essential for understanding *DNA* have been learned correctly. In addition, it is seen that students most frequently associate DNA with the concept of "Fingerprint," falling into the misconception of linking the concept of "DNA fingerprint" with the concept of "Fingerprint." Furthermore, it is understood from the sentences written by the students regarding the concept of DNA that they confuse the concept of "DNA fingerprint" with the "Fingerprint" found on the surface of the finger. The fact that students associate DNA more with the term "Structural unit," which is related to the concept of *Nucleotides* and the term "Functional unit," which is a distinct feature of the concept of *Genes*, shows that they

confuse the basic information about these concepts. Furthermore, the fact that students use non-scientific and meaningless concepts unrelated to the concept of *DNA*, such as "Sugar," "Fire escape," "Zipper structure," "Staircase," "Size," "Irregularity," "Internal appearance," "Destiny" and "Clock"—which are unscientific and meaningless concepts unrelated to *DNA*—shows that they have misconceptions and misunderstandings about *DNA*.

When examining the sentences constructed around the key concept of *DNA*, approximately one-fifth of the students constructed *Scientific Sentences*, indicating that the number of students with accurate knowledge of the *DNA* concept is not insignificant. However, the fact that approximately one-fifth of the students constructed *Partially Scientific or Superficial Sentences* reveals that there are also a considerable number of students who have not learned the concept of *DNA* in depth and who have conceptual confusion. The fact that a significant portion of students constructed *Non-Scientific Sentences* shows that these students did not learn the concept of *DNA* at a scientific level and perceived the everyday use of concepts as scientific usage. The fact that approximately a quarter of the students constructed *Sentences Containing Conceptual Misconceptions* shows that there are many students who have misconceptions about the concept of *DNA* and misunderstand it. This situation is considered a negative result. Furthermore, the fact that a small proportion of students did not construct any sentences about the concept of *DNA* and left the section blank suggests that these students have no knowledge about the concept of *DNA*. However, the small number of students who left the sentences blank is considered a positive finding.

According to the results obtained from the examination of the key concept of *Gene*, the majority of students associate the concept of *Gene* with the "Functional unit," indicating that they know *Gene* as the functional unit of *DNA* and have correctly learned the basic association related to the concept of *Gene*. However, the fact that some students use the concepts of "Structural unit" associated with the concept of *Nucleotides* and "Helical structure" associated with *DNA* for the concept of *Gene* indicates that there are some gaps in knowledge and misconceptions at a basic level between concepts. In addition, the fact that students write non-scientific and meaningless concepts such as "Male," "Privacy," "Glucose," "Group," "Filament," "Short hair," "Girl," "Important point," "Long hair" and "Chain-like," which are non-scientific and meaningless concepts, indicates that they have misconceptions and misunderstandings about the concept of *gene*.

When the sentences constructed for the key concept of *Genes* were examined, it was found that approximately one-fifth of the students constructed *Scientific Sentences*, indicating that the number of students with accurate knowledge about the concept of *Genes* is not negligible. However, the fact that nearly one-fifth of them constructed *Partially Scientific or Superficial Sentences* reveals that there are also a considerable number of students who have not learned the concept of *genes* in depth and who have conceptual confusion. The fact that a significant portion of students constructed *Non-Scientific Sentences* shows that these students have not learned the concept of *Genes* at a scientific level and perceive the everyday use of concepts as scientific usage. Approximately a quarter of the students constructing *Sentences Containing Conceptual Misconceptions* about the concept of *genes* indicates that there are many students who have misconceptions about the concept of *Genes* and misunderstand it. Furthermore, less than one-fifth of the students did not construct any sentences about the concept of *Genes*, leaving the section blank, suggesting that these students have no knowledge about the concept of *Genes*. In addition, the high number of students who left the sentences blank is considered a negative finding.

According to the results obtained from the examination of the key concept of *Chromosomes*, it is seen

that the vast majority of students associate the concept of *Chromosomes* most with the concepts of "Protein coat," "DNA", and "46 chromosomes," which is the number of chromosomes in a healthy human. This finding reveals that students correctly know the basic structures that make up chromosomes and have correctly learned the basic concepts related to the structure of the *Chromosome* concept. On the other hand, the fact that students associate the concept of *Chromosome* with concepts such as "X-shaped" and "DNA protector" and associate it with the characteristics of the *DNA* concept, such as "Helical structure," "Double helix", and "Regulatory molecule", shows that students have misconceptions about the concept of *Chromosome*. Furthermore, students' association of the concept of *Chromosome* with unrelated and potentially misleading concepts such as "Filament," "Mathematics," "Number," "Hour," "Number unit," "Five hundred," "Correction," "Deficiency," "Volume," "Scissors" and "Fire escape" demonstrate that they have misconceptions and misunderstandings about the concept of *Chromosomes*.

When examining the sentences constructed for the key concept of *Chromosome*, approximately one-fifth of the students constructed *Scientific Sentences*, indicating that these students have accurate knowledge about the concept of *Chromosome*. However, the fact that a larger majority of students constructed *Partially Scientific or Superficial Sentences* reveals that these students have not learned the concept of *Chromosomes* in depth, and that this situation may lead to conceptual confusion. The fact that less than one-fifth of the students constructed *Non-Scientific Sentences* shows that these students have not learned the concept of *Chromosomes* at a scientific level and perceive the everyday use of concepts as scientific usage. The fact that the vast majority of students formed *Sentences Containing Conceptual Misconceptions* shows that these students have misconceptions about the concept of *Chromosomes* and have not grasped the concept of *Chromosomes* at a scientific level. Furthermore, the fact that a very small proportion of students did not construct any sentences about the concept of *Chromosomes* and left the section blank suggests that these students have no knowledge about the concept of *Chromosomes*.

According to the results obtained from the examination of the key concept of *Nucleotides*, the majority of students correctly associated the concept of *Nucleotides* with the structures belonging to nucleotides, namely "Adenine," "Thymine," "Guanine," "Cytosine," "Phosphate", and "Organic base." This shows that students have accurate knowledge about the concept of *Nucleotides*. However, it is also seen that some students have incomplete knowledge about the concept of *Nucleotides*, associating it only with the concepts of "Sugar," "Base," "Deoxyribose," "Nitrogen," "Guanine sugar" and "Carbon sugar." Furthermore, it was concluded that they fell into conceptual confusion by incorrectly associating the concept of "Functional unit" with the concept of *Gene* and the concepts of "Helical structure" and "Regulatory molecule" with the concept of *DNA*, with the concept of *Nucleotide*. Furthermore, it was observed that students associated the non-scientific concepts of "Glucose," "Water," "Variety," "Zipper," "Brown," "Personal information," "Small structure," "Point," "Oxygen," "Hair length," "Number," "Carrier" and "Renewal"—concepts that are non-scientific and meaningless—demonstrate that they have misconceptions and errors in understanding the concept of *Nucleotides*.

When examining the sentences constructed using the key concept of *Nucleotides*, the fact that one-fifth of the students constructed *Scientific Sentences* indicates that a significant majority of students possess accurate knowledge about the concept of *Nucleotides*. However, the fact that a small portion of students constructed *Partially Scientific or Superficial Sentences* reveals that these students did not learn the concept of *nucleotides* in depth and that this situation could lead to conceptual confusion.

Furthermore, the small number of such students is considered a positive result. The fact that a small proportion of students constructed *Non-Scientific Sentences* indicates that these students have not learned the concept of *Nucleotide* at a scientific level and perceive the everyday usage of the terms as scientific usage. The small number of such students is also considered a positive result. The fact that approximately one-fifth of the students formed *Sentences Containing Conceptual Misconceptions* shows that a significant proportion of the participants have misconceptions about the concept of *Nucleotides* and have not grasped the concept of *Nucleotides* at a scientific level. Furthermore, the fact that a large proportion of students did not construct any sentences about the concept of *Nucleotides* and left the relevant section blank suggests that these students do not have knowledge about the concept of *Nucleotides*. However, the fact that the number of sentences left blank regarding the concept of *Nucleotides* is much higher than for the other concepts examined also suggests that the students did not attach as much importance to the concepts at the end as they did to the first three concepts and therefore did not answer them.

According to the results obtained from the examination of the key concept of *Genotype*, a large proportion of students associated the concept of *Genotype* with "Dominant," "Heterozygous," "Homozygous," "Recessive," "Hybrid," "Recessive gene," "Dominant gene," "Allele gene," "Pure line," "Crossbreeding," "Pure," and "Hybrid offspring." This indicates that they have correctly learned the basic concepts related to the concept of *Genotype*. However, the fact that some students associated the concept of *Genotype* with "Internal appearance," "Gene count," "Internal structure," "External appearance," "Dominant offspring," "Recessive offspring," "Functional unit," "Hydrogen bond," "Structural unit", and "Harmful genotype." Furthermore, students wrote down non-scientific and meaningless concepts unrelated to the concept of *Genotype*, such as "Tree," "Hair strand," "Water," "Seed," "Leaf," "Area," "Change," "Unchangeable," "Married," "Temporary," "Glucose," "Beauty," "Generation," "Color," "Hair," "Hair length," "Number," "Three types" and "Chain reaction" that are not scientific and meaningless concepts, indicating their misperceptions and misconceptions about the concept of *Genotype*. Students have fallen into conceptual errors by using characteristics commonly associated with the concept of *Phenotype*, such as "Body length," "Eye color," "Short stature," "Wrinkled," "External appearance," "Eyebrow color," "Eyebrow shape," "Modification," "Blonde hair," "Yellow seed," "Black hair" and "Green seed." Furthermore, when compared to the key concepts examined above, the higher number of misconceptions related to the concept of *Genotype* compared to other key concepts suggests that students perceive the concept of *Genotype* as more abstract and difficult to understand than other key concepts.

When examining the sentences constructed using the key concept of *Genotype*, the fact that only a very small proportion of students constructed *Scientific Sentences* indicates that these students possess accurate knowledge of the *Genotype* concept. However, the fact that these students are in the minority is considered a negative result, indicating that the level of learning about this concept is very low. Furthermore, the fact that a small number of students constructed *Partially Scientific or Superficial Sentences* reveals that these students did not learn the concept of *Genotype* in depth, and that this could lead to conceptual confusion. The fact that a small number of students formed *Non-Scientific Sentences* shows that these students did not learn the concept of *Genotype* at a scientific level and perceived the everyday use of concepts as scientific usage. The small number of students in this group is considered a positive result. The fact that nearly one-third of the students constructed *Sentences Containing Conceptual Misconceptions* indicates that these students have misconceptions about the concept of *Genotype* and have not grasped the concept of *Genotype* at a scientific level. The high number of students with misconceptions about the concept of *Genotype* is considered a negative

result. Furthermore, the fact that nearly half of the students did not construct any sentences about the concept of *Genotype* and left the relevant section blank suggests that these students do not have knowledge about the concept of *Genotype*. However, the fact that the number of sentences left blank regarding the concept of *Genotype* is much higher compared to other key concepts suggests that this concept is perceived as more abstract by students and that there is a greater lack of knowledge and misconception at the conceptual level.

According to the results obtained from the examination of the key concept of *Phenotype*, it was concluded that the majority of students associated the concept of *Phenotype* with the concepts of "External appearance," "Hair color," "Eye color," "Tall stature," "Blue eyes," "Blonde hair," "Skin color" and "Short stature" and thus had accurate knowledge about the concept of *Phenotype*. However, regarding the concept of *Genotype*, they experienced conceptual confusion between the concepts of "Recessive," "Dominant," "Heterozygous," "Homozygous," "Recessive gene," "Pure line," "Dominant gene," "Hybrid offspring," "Allele gene" and "Genotype" concepts, experiencing conceptual confusion between the concepts of *Phenotype* and *Genotype* and thus falling into conceptual error. Furthermore, it is understood that students fall into conceptual errors by associating the concept of *Phenotype* with concepts unrelated to it, such as "Arrangement," "Number," "Hour," "Unit of count," "Dominant phenotype," "Unit," "External characteristics," "Skin shape," "Recessive phenotype," "Variety," "Change," "Married," "Temporary," "Volume," "Patient phenotype," "Hobby," "Internal structure," "Two types," "Not permanent," "Identity," "Mathematics," "Myopia," "Qualification," "Number," "Adjective," "Structure" and "Chain" demonstrate that they possess incorrect information about the concept of phenotype and experience conceptual misunderstanding.

When examining the sentences constructed around the key concept of *Phenotype*, approximately one-fifth of the students constructed *Scientific Sentences*, indicating that these students possessed accurate knowledge of the concept of *Phenotype*. However, the fact that another fifth of the students constructed *Partially Scientific or Superficial Sentences* reveals that these students did not learn the concept of *Phenotype* in depth and that this situation could lead to conceptual confusion. The fact that a very small proportion of students constructed *Non-Scientific Sentences* shows that the concept of *Phenotype* was learned better than other key concepts. The fact that approximately one-fifth of the students constructed *Sentences Containing Conceptual Misconceptions* indicates that these students have misconceptions about the concept of *Phenotype* and have not grasped the concept of *Phenotype* at a scientific level. However, the fact that students have fewer misconceptions about the concept of *Phenotype* compared to other key concepts suggests that the concept of *Phenotype* is better learned and perceived as more concrete by students. Furthermore, the fact that one-third of the students did not construct any sentences about the concept of *Phenotype* and left the relevant section blank suggests that these students do not have knowledge about the concept of *Phenotype*.

According to the results obtained from the WAT, which examined the research questions, the majority of students confuse the basic concepts within the unit, struggle to establish the correct relationships between these concepts, and fall into various misconceptions. Similarly, in the research conducted by [Turan and Koç \(2018\)](#) examining the conceptual understanding and misconceptions of 8th-grade students regarding the concept of genetics, it was found that the vast majority of students had misconceptions about genetics, had difficulty establishing relationships between concepts, and struggled to understand basic concepts. Furthermore, the same study showed that students' inability to establish correct connections between basic genetic concepts or to establish incorrect relationships indicated misconceptions about these concepts and that the structures and

functions of the concepts were not fully understood.

The study found that students' use of meaningless and ambiguous sentences or leaving sentence parts blank regarding key concepts indicates that the relevant key concepts have not been fully learned. These findings largely coincide with research findings in the literature that reveal misconceptions in the "DNA and Genetic Code" unit. Indeed, in [Büyükkol Köse's \(2019\)](#) study with high school teachers and students, inheritance was determined to be one of the topics that students found most difficult to understand. Similarly, [Johnstone and Mahmoud's \(1980\)](#) survey study also revealed that genetics was one of the biology topics that students found most difficult to understand and that teachers found most difficult to convey.

Furthermore, the results of the study show that a significant portion of conceptual misunderstandings stem from students' abstract perception of the "DNA and Genetic Code" unit. Since abstract topics are more difficult to learn than concrete topics, this situation leads to an increase in conceptual misunderstandings. Similarly, the study by [Bahar et al. \(1999\)](#) states that most of the concepts that constitute scientific knowledge in biology are abstract and that the complex structure of the relationships between these concepts makes it difficult for students to learn biology topics, which is consistent with the results of this study. Similarly, [Demir and Sezek's \(2009\)](#) study emphasized that the "DNA and Genetic Code" unit is quite abstract for students and that they experience difficulty in correctly relating this topic. The researchers stated that if abstract concepts in genetics were made concrete with graphic materials, students would be able to understand the subject more easily. Furthermore, it was stated that the lesson hours determined by the Ministry of National Education (MEB) were insufficient due to the abstract and difficult-to-understand nature of these concepts; increasing this time and making the subject concrete with the support of graphic materials were among the measures that would facilitate learning. Similarly, a study conducted by [Etobro and Banjoko \(2017\)](#) with biology teacher candidates studying at the Faculty of Education, Department of Science and Technology Education, Lagos State University, examined misconceptions about genetics. This study found that 75.1% of participants had misconceptions about genetic concepts. It was concluded that these misconceptions stemmed from factors such as the difficulty of textbooks, teaching methods, the English language skills of teaching staff, cultural beliefs and practices, laboratory conditions and the abstract nature of genetics. In a similar study, [Gusmalini and Wulandari \(2020\)](#) conducted research with 12th-grade science students, examining students' misconceptions about genetic concepts and the reasons for these misconceptions. The study found that the fundamental cause of misconceptions stems from the structure of genetic concepts. Furthermore, it was concluded that the concepts in which students most frequently held misconceptions were DNA, genes, and chromosomes.

The overall result of this research shows that eliminating misconceptions during the learning process is critically important; otherwise, new learning will be flawed, students' mental schemas will be organized incorrectly, and correcting this situation will become difficult.

Recommendations

Based on the findings of the study, the following recommendations are made regarding misconceptions about inheritance:

- When preparing the national education curriculum, priority can be given to activities aimed at learning genetic concepts in the creation of course content.

- When preparing textbooks, more emphasis and priority can be given to activities aimed at learning genetic concepts.
- Teachers should adopt an approach that ensures the correct and permanent learning of concepts related to heredity at the initial stage of learning.
- At the end of the "DNA and Genetic Code" unit, assessments can be made to determine whether the concepts covered in the unit have been learned correctly.
- At the end of the unit, students with misconceptions about inheritance can be supported in overcoming these misconceptions through peer education.
- Abstract genetic concepts can be made more concrete and enjoyable through simulations on the EBA platform and internet-based applications, thereby increasing their retention.
- To make the concepts of inheritance more concrete, Augmented Reality activities related to the concepts can be added to textbooks.
- Virtual Reality studies can be conducted to enable a deeper experience and observation of concepts related to heredity and to ensure lasting learning.

Declarations

Ethics statement: The necessary ethical approvals for this study were granted by the Muş Alparslan University Scientific Research and Publication Ethics Committee through Decision No. 54 taken at its 4th meeting on 06.02.2024. All procedures involving human participants were conducted in accordance with institutional and national ethical standards, the Helsinki Declaration, and applicable regulations. Informed consent was obtained from all participants.

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