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Eliminating Misconceptions in Biotechnology Using Concept Cards

By Fethi Ahmet Öner, ABE Türkiye

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Türkiye

Eliminating Misconceptions in Biotechnology Using Concept Cards

Author: Fethi Ahmet Öner - Murat Kantarcı Science and Art Center Biology Teacher, ABE Türkiye

Intended users/audience (students? teachers? others?):

This study is intended for students and teachers. It can be used in ABE applications or biotechnology related courses. It is planned as a course material applicable to students aged 12–16 years. It can be a teaching method that biology and science teachers and ABE teachers can use to reduce misconceptions.

Biotechnology subject and related scientific concepts:

There are various misconceptions about biotechnology in the related literature. Sıcaker and Öz Aydın (2015) identified misconceptions about concepts such as DNA fingerprinting, DNA analysis, stem cells, synthetic hormones and synthetic enzymes, biosafety protocol, and ethics in their study on the evaluation of secondary school biotechnology and gene engineering concepts by students. Duda et al., in their different studies in 2020, showed that student misconceptions on the concept of biotechnology were concentrated on concepts such as biotechnology, recombinant DNA technology, genetic engineering, tissue culture, bacterial technology applications, transgenic plants, negative effects of biotechnology, genetic modification, genetic manipulation of biotechnological products. According to this study, approximately 41% of the students had misconceptions in biotechnology concepts. Among the misconceptions about the recombination process, it is seen that there are misconceptions about the realization of PCR after transformation and the effects of plasmids on cell life (Halim et al., 2018).

Another study revealed that students' misconceptions in the field of biotechnology occurred in concepts such as the role of genes, totipotency, cloning, fermentation and biotechnological products. In their 2015 study, Pekel and Hasenekoğlu and showed that there are misconceptions about DNA, genes, chromosomes and some genetic information. The perception of genes and chromosomes as synonyms caused misunderstanding of heredity processes. In addition, the misconception that DNA is active only during cell division has also come to the fore (Ecevit & Şimşek, 2017).

In addition to the misconceptions revealed in the literature review, the following concepts were addressed as misconceptions related to biotechnology, which were planned to be addressed in this study, based on the misconceptions seen in students during the ABE biotechnology experiments conducted by the researcher and the misconceptions revealed in line with the interviews with other ABE teachers .

The concepts used in our study are DNA, Chromosome, Biotechnology, Genetic engineering, Gene cloning, Gene transfer, Recombinant DNA, DNA isolation, Plasmid, Restriction enzyme, Micropipette, Genetically modified organism (GMO), DNA fingerprint, Bioethics, Gel electrophoresis, Transgenic organism, Biotechnological products, Genetic engineering products, Stem cell, Polymerase chain reaction (PCR), Gene therapy.

Suggested courses and/or subject areas:

Biology, science and technology, chemistry, biotechnology, bioethics, gene and heredity, dna isolation, micropipette usage, gel electrophoresis usage, PCR skills, cognitive psychology

Areas covered in our study:

- Integration of Inquiry-Based Science Teaching
- Supporting Materials for ABE Teachers
- Use of concept cards
- Integration of STEM
- Adaptation of ABE Laboratories to Different Student Levels/Groups
- Differentiation with Non-Laboratory Based Practices
- Opportunities to Support Equal Access to STEM Education

What real-world problem(s) does this topic address?

As a result of literature reviews, ABE practices and interviews with other ABE teachers in Turkey, it is seen that there are misconceptions in understanding some biotechnological concepts. Our aim is to reduce or eliminate misconceptions about these biotechnological concepts.

Biotechnology, one of today's rapidly developing and controversial fields, offers solutions to many important problems concerning society. Topics such as genetic engineering, GMOs, biotechnological products and DNA technologies provide innovative approaches in critical areas such as health, agriculture and environment. However, lack of knowledge and misconceptions about these technologies make it difficult for society to engage in constructive discussions about scientific developments. Misconceptions often reinforce the view that biotechnology is a high-risk field and prevent individuals from understanding the benefits derived from these technologies.

In a complex subject such as biotechnology, misconceptions can prevent students from learning basic scientific concepts. For example, misinformation about the risks of genetic engineering can create an unnecessary fear of scientific advances. Inaccurate or incomplete knowledge prevents students from approaching scientific knowledge critically and can lead to unquestioning acceptance of information sources such as the media. Misconceptions make it difficult for students to understand biotechnology correctly and to evaluate the social, economic and environmental impacts of the technology. Conscious and erroneous decisions may be made about whether biotechnology products (e.g. genetically modified foods) should be used in daily life. Misconceptions about biotechnology may cause students to abandon their scientific career goals or lose interest in these fields.

These problems make it difficult for individuals to make informed decisions, gain scientific literacy and develop critical thinking skills. In particular, inaccurate or stereotypical media coverage of biotechnology, genetic engineering and gene cloning reinforces social prejudices and misconceptions. Efforts by the education system to fill gaps in the field of biotechnology, to increase students' and other citizens' knowledge of these technologies, and to correct misconceptions play an important role in helping individuals make a balanced assessment of the benefits and risks of biotechnology.

Contents

Overview

Concepts are the common names given to groups of things, events, people and ideas when they are grouped according to their similarities. Concepts are not concrete objects, events or entities, but abstract units of thought that are achieved by grouping them under certain categories. Concepts exist in our thoughts, not in our real world. Without concepts, we cannot effectively classify our knowledge and transfer this knowledge to others (Ecevit & Şimşek, 2017).

In the 1920s, Piaget started to work on the understanding of concepts (Meriç & Sarıkaya, 2002, as cited in Ecevit & Şimşek, 2017). People learn basic concepts from childhood, classify concepts and find the relationships between them. This process of learning and restructuring in the mind continues throughout life. Humans have a characteristic concept organization in which they structure the concepts they already have and in which they can also structure what they will learn (i.e., they make connections between previously learned concepts and the newly learned concept).

Misconceptions

A review of the literature reveals many definitions of misconceptions. Ecevit & Şimşek (2017) defined misconceptions as information that is formed as a result of personal experiences, contrary to scientific truth and preventing concept teaching, and students' misconceptions that are contrary to scientific facts and prevent the learning process. According to Kumandaş (2015), misconceptions are defined as faulty cognitive structures that occur as a result of students' misunderstanding or misinterpretation of scientific concepts. Duda et al. (2020) stated that misconceptions are the mismatch between students' conceptual knowledge and the correct conceptions accepted by the scientific community. According to Özsevgeç and Erdoğan (2012), misconceptions refer to individuals' understandings based on incorrect or incomplete knowledge that deviate from scientific truths. According to Tekkaya, Çapa, and Yılmaz (2000), misconceptions are concept definitions that students develop as an alternative to scientifically accepted concepts. Yağbasan (2003) defined misconceptions as “a person's perception of a concept that differs significantly from its commonly accepted scientific meaning”.

Misconceptions negatively affect meaningful and permanent learning and reduce students' academic achievement. It is emphasized that students' prior knowledge should be correctly associated with new learning. These misconceptions may arise from students' prior knowledge and experiences, incomplete information in textbooks, or misuse of everyday language (Ecevit and Şimşek, 2017). Misconceptions make it difficult for students to understand scientific phenomena and negatively affect the learning process. Misconceptions are more common especially in fields such as biology where complex and abstract concepts are intense (Kumandaş, 2015). This situation usually occurs when students misinterpret new experiences from their existing prior knowledge. Such misconceptions create serious difficulties in the learning process and are very difficult to correct, especially in areas such as biology where abstract concepts are dense. Misconceptions that students have a low level of confidence in can become permanent over time and make it difficult to learn new material (Duda et al., 2020). According to Özsevgeç and Erdoğan (2012), these misconceptions are usually caused by misinformation acquired from the environment, incomplete educational materials or deficiencies in teaching processes. Misconceptions are especially common in courses involving abstract concepts such as science. Students are influenced by their prior knowledge when trying to make sense of concepts, and this sometimes leads to the entrenchment of unscientific ideas and can disrupt the effective learning process and negatively affect students' future knowledge.

Causes of Misconceptions

In the literature review, it is seen that the sources of misconceptions, that is, their causes, are related to many factors. Sıcaker and Öz Aydın (2015) show that the reasons for misconceptions include inadequate textbooks, not teaching the subjects with enough applied and visualized materials in the classroom environment, keeping the concepts abstract for students and not associating them with concrete examples, and not integrating the information in the rapidly developing field of biotechnology into educational materials.

Some researchers have listed the reasons for the formation of conceptual judgments as follows:

- Differences between everyday language and scientific language
- Textbooks written with incomplete or inadequate explanations.
- Inadequacy of the educational environment, limited laboratory facilities and lack of experimentation.
- Misunderstanding or incomplete understanding of prior knowledge and contradictions between scientific knowledge.

Prejudices and misinformation from non-scientific sources:

- Inadequacy of teaching methods to concretize abstract concepts that cannot be associated with daily life (Ecevit & Şimşek, 2017; Kumandaş, 2015; Duda et al., 2020).

Pekel and Hasenekoğlu (2015) found that students' misconceptions about genetic concepts may occur when they receive incorrect information from their previous teachers, textbooks or the media. It was stated that especially abstract and complex molecular genetics topics make it difficult for students to understand.

Some of the difficulties in learning concepts in secondary school students stem from the inadequate content of textbooks and some stem from the methods used by teachers in lessons. In the textbooks, definitions of some concepts are given incompletely or only superficially. For example, the concept of DNA fingerprinting is explained, but how it is processed is not mentioned. Teachers' inability to keep up with the rapid developments in biotechnology and the lack of practical work contributed to the formation of misconceptions. Students generally find biotechnology and gene engineering abstract and complex. This was associated with the lack of concretization and visualization of the concepts. Some students stated that biotechnology topics are not given enough importance because they are not included in university exams (Sıcaker & Öz Aydın, 2015).

To reduce and prevent misconceptions, methods such as laboratory studies and experiments, virtual laboratories and simulations, teaching with real-life examples, using videos, animations and documentaries, concept maps and diagrams, analogy and drama techniques, concept cards, prediction-observation-explanation (TGA) method, methods that increase student participation, training teachers with updated information, improving the content of textbooks, enriching teaching methods can be applied. I have chosen the concept card method here because concept cards are one of the powerful tools used in education. These cards are particularly effective in learning abstract concepts. It is especially suitable for students between the ages of 12–15.

Concept Cards

Concept cards are an effective teaching tool that facilitates the learning of abstract and complex concepts and helps students organize information and perform meaningful learning. They were used to

help students understand conceptual relationships and visualize concepts. These cards contain both visual and textual information. Thus, it facilitates students' learning by creating mental images faster and corrects misunderstandings.

How the Concept Cards Contribute to Education

- **Provide Fast and Permanent Learning**: Concept cards accelerate the learning process by quickly activating students' mental images.
- **Make Learning Fun:** By offering gamification-based learning, it increases students' interest in lessons.
- **Provide Emotional Bonding**: The visuals and expressions on the concept cards allow students to emotionally connect with the topics, which makes learning more effective and long-lasting.
- **Enable Student-Centered Learning**: Concept cards allow students to express concepts in their own words and provide active participation in learning.
- **Enable Gamification and Interactivity**: Students consolidate knowledge better by playing matching games or group discussions with the concept cards.
- **They can be used with Concept Maps**: Students organize the information better by adding the terms on the concept cards to their concept maps (Kurt & Sarı, 2023).

Structure and Use of Concept Cards

- Front of card: Key terms, images, key concepts or important events.
- Back of card: May include definitions, examples, explanations and sometimes graphs or visuals, concept-related activities.

In conclusion, concept cards are a powerful teaching tool that develops students' conceptual thinking skills, makes learning fun and helps them acquire lasting knowledge. This method, which facilitates the understanding of abstract subjects, stands out as an effective and efficient approach in education.

Biotechnology and Misconceptions in Biotechnology

The roots of biotechnology can be traced back to the selective breeding of farm animals and plant species with the start of agriculture around 10,000 years ago. This is one of the earliest examples of biotechnological applications.

Biotechnology is the study of the application of biology, biochemistry and engineering principles to the processing of materials, utilizing biological systems and their components to develop a variety of products and services (Duda et al., 2020). Biotechnology includes genetic engineering, molecular biology, microbiology, microbiology, biochemistry and many other disciplines. Biotechnology utilizes genetic engineering, cell culture, protein production and many other techniques to develop various applications based on life sciences. These applications affect human life in many fields such as health, agriculture, industry, energy and environment. In order to reveal the genetic structure of plant species with biotechnological applications and to compare them with other species, DNA isolation, micropipette use, gel electrophoresis and PCR applications should be known.

The fact that biotechnology is effective in many areas of life makes it compulsory to include this science in the education curriculum. In Turkey, biotechnology topics are included in the units “Genetic Code” in the 8th grade science course and “Genetics and Biotechnology” in the 11th grade biology program. However, according to studies, both in Turkey and worldwide, students have incomplete knowledge and conceptual problems in biotechnology and genetic engineering (Sıcaker & Öz Aydın, 2015).

Biotechnology has been defined as a difficult field to learn due to its complex interdisciplinary structure. Especially abstract concepts (e.g. genome project, recombinant DNA technology) are among the difficult topics for students to understand. The lack of content in textbooks and teachers' inability to keep up with the rapid development of this technology also contribute to learning difficulties. Biotechnology stands out as an important educational subject due to its rapid development and multifaceted nature.

The misconceptions identified in the research conducted by Sıcaker and Öz Aydın (2015) can be listed as follows:

- **DNA Fingerprinting and DNA Analysis:** Students had difficulty in understanding the concept of DNA fingerprinting correctly. Although it was stated what the concept was used for, misunderstandings were observed because the process steps of how it was done were missing. Similarly, the processes used in DNA analysis were explained, but students had difficulties with this concept because the process was not discussed in detail.
- **Genome Project:** Students had difficulty understanding the scope of the Genome Project. The definition of the concept was treated superficially in the textbooks and most of the students could not grasp the technical details of this term.
- **Stem Cell Therapy:** The concept of stem cell therapy is another concept that students had difficulty with. The reason for this is that these treatment methods are only described in general terms and not in detail.
- **Recombinant DNA Technology:** Recombinant DNA technology was considered difficult by the students. Especially how this technology works and its application areas were not fully understood.
- **Synthetic Hormones and Synthetic Enzymes:** Concepts such as synthetic hormones and synthetic enzymes were ranked among the most difficult concepts by students. The lack of elaboration of these concepts in the textbooks led to misconceptions.
- **Biosafety Protocol:** Students mostly did not understand the concept of biosafety protocol and had a serious lack of knowledge on this subject. Although this concept was included as a reading text in the textbooks, it was not covered effectively.
- **Polyploidy:** Although the concept of polyploidy was defined and examples were given in the textbooks, students had difficulty understanding this concept. This is due to a lack of familiarity with genetic terms.
- **The Concept of Bioethics:** It was discussed in the context of biotechnological applications, but students found it abstract and had difficulty making sense of it.

Dorji et al. (2025) state that genes and chromosomes are often perceived as synonymous terms. Students are unable to distinguish the location and role of genes on chromosomes. They stated that misconceptions are frequently observed in cellular genetic processes, especially in the transfer and expression of genetic material.

Kumandaş (2015) revealed in his study that especially topics such as genetics and cell division were found to be abstract and complex by students, which led to the formation of misconceptions.

The proportions of students categorized as having misconceptions, not knowing the concepts and knowing the concepts in the concepts within the scope of biotechnology are 26%, 31% and 43%, respectively. For the concepts of recombinant DNA technology, the percentages of students categorized as having misconceptions, not knowing the concepts and knowing the concepts are 40%, 29% and 31%,

respectively. From the data on both concepts, it is seen that the percentage of students with misconceptions on the concept is still quite high (Duda et al., 2020).

In another study conducted by Duda et al. in 2020, approximately 41% of students had misconceptions about biotechnology concepts. Some of these misconceptions are as follows;

- **Tissue Culture:** For example, the stages of tissue culture are often understood in the wrong order. Genetic Engineering: There are misconceptions about the main purposes of genetic engineering and gene transfer techniques.
- **Transgenic Plants:** Misinformation about the effects and uses of transgenic plants is widespread.
- **Applications of Bacterial Technology:** The use of bacteria such as *Bacillus thuringensis* (Bt) to produce pesticides is often misunderstood.
- **Definition and Purposes of Biotechnology:** For example, the differences between genetic engineering and transplantation are misunderstood.
- **Negative Impacts of Biotechnology:** For example, incorrect generalizations are made about the effects of biotechnological applications on human health; some students talk about effects such as headaches or flu, when the correct information is “allergic reactions”.
- **Genetic Modification Techniques:** Students often confuse genetic modification techniques with natural processes. For example, some equate gene transfer with natural mutation.
- **Biotechnological Products:** Students may have difficulty understanding the differences between genetically engineered plant species (e.g. transgenic plants) and naturally produced hybrid plants.

Franke et al. (2013), in their study on the examination of students' alternative conceptions of gene technology terms and processes, stated that some of the prominent misconceptions focused on concepts such as gene concept, genetic engineering, cloning, enzymes, genetic processes. These misconceptions may prevent students from fully understanding the scientific concepts of gene technology.

On the other hand, Idris, Hidayat, and Rahmat (2024) found that misconceptions about biotechnology are quite common and only 19.07% of the students have a correct understanding of the topics. In the basic concepts of biotechnology, 55.63% of the students had misconceptions. Especially cell biology and metabolism were found to be difficult to understand. In the understanding of biotechnological processes, 64.38% of the students exhibited misconceptions in biotechnological processes (totipotency, fermentation, recombinant DNA, genetic engineering). For example, misconceptions such as that totipotency is not possible in animal cells were observed. In the topics of modern and traditional biotechnology, 59.38% of the students had misconceptions. Serious misconceptions about genetic engineering and transgenic applications were noted. About biotechnological products, 43.13% of students had misconceptions. For example, serious gaps in knowledge about vaccines were observed. Idris et al. (2024) emphasized that these misconceptions should be addressed by developing the infrastructure that will enable practical applications of modern biotechnology.

These misconceptions seen in the literature review can also be encountered in the interviews and the researcher's practices that ABE teachers encounter between their practices. Including these misconceptions and the misconceptions that are deemed appropriate to be encountered frequently, a total of 21 misconceptions were identified. It was decided that the number of 21 concepts was sufficient because they were the most frequently encountered concepts and these concepts would be transformed into concept cards as course materials.

Creating concept cards about these concepts and reducing or preventing misconceptions are among the objectives of the study. Here, concept cards are one of the most powerful tools used in concept teaching and consist of two sides, front and back. The front side is for teaching terms and the back side is for reinforcing learning. Since concept cards contain both visual and textual information, they facilitate students' learning and correct misunderstandings by creating mental images faster (Kurt & Sarı, 2023).

Concept cards were prepared for the 12–16 age group. This is a stage in which students begin to think logically and understand concepts. A biotechnological term is written on one side of the concept cards and an explanation or example is written on the other side. These cards can be used with gamification: Matching, sorting or question-answer activities. This allows students to learn concepts quickly and in a fun way. It supports learning based on understanding rather than memorization. For example, “Genetically Modified Organism (GMO)” can be written on the front side of the card and “Organism whose properties have been improved by changing its DNA” on the back side.

In this program, it is aimed that students learn biotechnology subjects and methods correctly through biotechnological concepts determined by creating concept cards in order to reduce or eliminate common misconceptions in biotechnology. One side of the concept cards, which is one of the efforts to reduce conceptual misconceptions, is written with the visual of the concept and the name of the concept. On the other side, the definition, example and additional information about the concept are given. If necessary, an activity application related to that concept can be given.

This method can be introduced to the educational world as an educational material in teaching abstract biotechnology basic concepts that are difficult to learn and this data can be used in the prevention of misconceptions. In this study, it will be determined whether misconceptions are eliminated with concept cards and presented to the international scientific literature as a course material.

By reducing misconceptions in biotechnology, students will develop their questioning skills with peer collaboration in this process in order to fully and accurately comprehend biotechnology and will create data for field teachers. As a result, students will be provided with meaningful and fun learning, conceptual cards are effective in improving conceptual perceptions and reducing misconceptions, and thanks to their features such as activating students' mental images quickly, students learn concepts in a fun and interesting learning environment and can associate them with their personal experiences.

If necessary, a link or video link can be provided to each card by creating a QR code related to that concept and prevent mislearning of the concept.

The Research Study

Research question: Do concept cards have an effect on students' perception of concepts related to biotechnology and reduce misconceptions?

Key concepts: Misconception, concept cards, DNA, Chromosome, Biotechnology, Genetic engineering, Gene cloning, Gene transfer, Recombinant DNA, DNA isolation, Plasmid, Restriction enzyme, Micropipette, Genetically modified organism (GMO), DNA fingerprinting, Bioethics, Gel electrophoresis, Transgenic organism, Biotechnological products, Genetic engineering products, Stem cell, Polymerase chain reaction (PCR), Gene therapy.

Objective: The aim of this study was to identify the misconceptions that students may have about biotechnology topics and to eliminate these misconceptions by using concept cards. It is aimed to improve students' scientific thinking skills by providing them with accurate information about

biotechnology. In this process, it is aimed to strengthen students' critical thinking, problem solving and conceptual learning skills.

At the end of this study, students are expected to acquire

- Understand the basic concepts of biotechnology correctly and correct their misinformation.
- Recognize various applications of biotechnology.
- Recognize the usage areas of biotechnology in daily life.
- Learn scientific concepts more effectively through concept cards.
- Develop critical-thinking and problem-solving skills.

Students in the cognitive domain to which the study is related;

- Define the basic concepts related to biotechnology.
- Analyze biotechnological processes through concept cards.
- Distinguish the differences between genetic engineering, biotechnology and traditional biotechnology applications.
- Explain biotechnological processes using scientific concepts.
- Identifies misinformation about biotechnology and compares it with the correct ones.

Students in the affective domain related to the study;

- Gain the ability to question scientific knowledge and think critically.
- Can think about and discuss the ethical dimensions of biotechnology.
- Develop social skills by cooperating in group work.
- Develop a positive attitude towards biotechnology and develop an interest in working in this field in the future.
- Be willing to follow and research scientific developments.

Students in the psychomotor area related to the study;

- Learn biotechnological concepts effectively by using concept cards.
- Gains the ability to analyze and evaluate scientific data.
- Model the basic methods used in biotechnology applications in classroom activities.
- Apply peer education techniques to correct misconceptions.
- Use scientific thinking processes in daily life.

What are the relevant tools, technologies, or applications in this regard?

The tools, technologies and practices used in reducing and preventing misconceptions are listed below.

Conceptual Change Strategies

Special strategies such as conceptual change texts have been developed to eliminate misconceptions. These texts help students question their existing misinformation and make sense of new information (Ayvacı & Devecioğlu, 2002 as cited in Ecevit & Şimşek, 2017; Yılmaz, Tekkaya, Geban & Özden, 1999, as cited in Ecevit & Şimşek, 2017).

- **Prediction-Observation-Explanation (TGA) Strategy:** Students are first made to make a prediction, then they are asked to conduct an experiment or observation, and finally they are expected to compare their predictions with their observations (Bilgin & Geban, 2001).

- **Concept Analysis and Concept Networks:** They are teaching techniques that visualize the relationships between concepts (Ecevit & Şimşek, 2017).
- **Diagnostic Branched Tree:** It is an assessment tool used to guide students' thinking processes (Ecevit & Şimşek, 2017).
- **Interactive Educational Technologies and Digital Tools:** With the developing technology, educational software and digital environments are used to prevent misconceptions.
- **Simulation and Virtual Laboratories:** It enables students to learn abstract concepts by experiencing them (Pekel & Hasenekoğlu , 2015).
- **Smart Boards and Interactive Presentations:** Animations and videos that support conceptual change can be used in lectures.
- **Online Concept Tests and Feedback Systems:** They are digital assessment tools for determining students' misconceptions (Ecevit & Şimşek, 2017).

Alternative Teaching Methods and Materials

Teachers try to eliminate misconceptions by using student-centered and active learning-based methods.

- **Use of Drama and Analogy:** Allows abstract concepts to be associated with daily life
- **Worksheets and Problem-Based Learning:** Supports meaningful learning by increasing students' active participation.
- **Concept Cartoons:** It can be used to enable students to recognize and correct misconceptions (Ecevit & Şimşek, 2017).

Assessment and Recognition Tools

It is of great importance to identify students' prior knowledge in order to prevent misconceptions. Two and Three Tier Concept Tests are tests developed to identify misconceptions. Open-ended questions and brainstorming help students to reveal their misconceptions. Assignments that provide logical explanations encourage students to think and help them recognize misconceptions (Ecevit & Şimşek, 2017).

Teacher Education and Professional Development

Training teachers on new teaching methods and technologies is critical to prevent misconceptions. In-service training programs should ensure that teachers adopt the inquiry-based learning approach in science teaching. In order to prevent misconceptions by revising textbooks, it is recommended to increase the scientific accuracy of textbooks.

Concept Cards are generally included in active learning methods and constructivist learning approaches. Concept cards enable students to organize the information learned and visualize the relationships between concepts. This method can be very effective in eliminating misconceptions because

- **Visualizes Misconceptions:** Concept cards help to identify misconceptions. As students make connections between concepts through the cards, they can become aware of misconceptions.
- **Makes Conceptual Connections:** The cards allow students to associate concepts in a meaningful way. This supports students' deeper learning.
- **Provides Feedback:** While working on the concept cards, students can correct their misconceptions by interacting with teachers or peers.

- **Encourages Active Participation:** Students actively participate in learning through cards, which enables them to consolidate their knowledge (Tekkaya et al., 2000, Tatar & Demirtaş, 2010).

In general, in preventing biotechnological misconceptions:

- **Applied Studies:** Experiments and applications that will ensure active participation of students are recommended. For example, simple biotechnological experiments such as plant cloning can help concretize abstract concepts.
- **Visual Materials:** The use of visual materials such as videos, animations and documentaries in the lessons provides a better understanding of abstract concepts. In addition, field trips where biotechnological applications can be observed on site are recommended.
- **Drama and Analogy:** Analogies and dramatic reenactments can be used to relate concepts to daily life. For example, describing DNA as a construction plan.
- **Open-ended questions and brainstorming:** Allows students to share their ideas, so that misconceptions can be uncovered and corrected.

These methods are recommended to improve students' understanding of biotechnology and gene engineering topics and to reduce misconceptions.

In this study, concept cards designed by using artificial intelligence tools can be presented as course materials in classrooms to be used in 2 different categories.

Some of these concept cards can be applied to senior middle school and high school students who are familiar with biotechnology concepts that we assume that they are familiar with from previous courses. For each concept, concept cards with dimensions of 9x12 cm were created. In general, a key term, name, idea or word is written on the front side, taking into account the characteristics of concept cards in the literature. This side of the card helps the student to recognize the concept they need to learn. On the reverse side there are short and clear explanations of the concept. There are 3–5 knowledge items that explain the main features of the concept. In addition to these features, the related concept is written on the front side and an image related to the concept is added. On the back side, the definition of the concept, a sample situation related to the concept, and additional information about the concept are given. In addition, the students are asked to do an activity related to the concept.

As the second category, information about the misconception expressions and correct knowledge expressions that cause misconceptions are given and the question “Which of these do you agree with and why?” is asked. By asking the question, both the misconception is identified and the misconception is corrected.

In addition to these concept cards, correct and misconception-free flashcards were also prepared. Thanks to these cards, students will be distanced from their misconceptions about the concepts and their correct learning and understanding will be ensured. With the help of visual materials, interactive open-ended questions and brainstorming, misconceptions are revealed and eliminated.

If we carry this study to further stages as we find the opportunity, we will be able to ensure that students understand the concept correctly and learn it deeply by linking a video (videos that the researcher can create or videos taken from different sources on the subject), web address link or labxchange information about the concept by giving a QR code on the back or front side.

It can also be used as a course material for biology, science and ABE teachers in the field of biotechnology.

For each concept, the information included on the concept cards ***at the senior middle and high school level*** is given below.

1. DNA

Front of card: Write “DNA”. An image can be attached (e.g. a picture of the double helix structure).

Back of card: Definition: Deoxyribonucleic acid is a molecule that carries genetic information.

- **Example:** Human genetic information is carried by DNA sequences.
- **Additional Information:** It has a double helix structure discovered by Watson and Crick.
- **Activity:** Using the card, students make a short presentation explaining the structure and function of DNA.

2. BİOTECHNOLOGY

Front of card: “Biotechnology”. A symbol showing the use of biotechnology in agriculture, health and environment can be added.

Back of card: Definition: A set of technological applications that meet human needs using living organisms and biological processes.

- **Example:** Development of GMOs.
- **Additional Information:** The cornerstones of modern biotechnology are genetic engineering and DNA technologies.
- **Activity:** Students examine the card and discuss the effects of biotechnology in daily life.

3. GENETİC ENGİNEERİNG

Front of card: “Genetic Engineering”. A drawing depicting a scientist working with genetic material can be added.

Back of card: Definition: The scientific practice of altering the genetic structure of organisms.

- **Example:** Development of genetically modified organisms (GMOs).
- **Additional Information:** Technologies such as CRISPR-Cas9 are commonly used for gene editing.
- **Activity:** Students classify genetic engineering products using the information on the card.

4. GENE CLONİNG

Front of card: Write “Gene Cloning”. A diagram of the laboratory process that replicates a genetic sequence can be added.

Back of card: Definition: The process of producing more than one copy of a particular gene.

- **Example:** Cloning the human insulin gene into bacteria.
- **Additional Information:** Gene cloning is a fundamental technique in the production of biopharmaceuticals.
- **Activity:** Students using the card explain the gene cloning process step by step.

5. GENE TRANSFER

Front of card: “Gene Transfer” is written. An image showing gene transfer to a plant can be added.

Back of card: Definition: The process of transferring genetic material from one organism to another.

- **Example:** Gene transfer for drought tolerant plants.
- **Additional Information:** Gene transfer is usually done using plasmids or viruses.
- **Activity:** Students discuss the tools used in the process of gene transfer.

6. RECOMBİNANT DNA

Front of card: “Recombinant DNA”. A diagram of a laboratory-assembled version of a DNA molecule can be added.

Back of card: Definition: DNA created by combining DNA fragments from two different organisms.

- **Example:** Integration of the human insulin gene into a bacterium.
- **Additional Information:** This technique is the cornerstone of genetic engineering.
- **Activity:** Students examine the card and list the applications of recombinant DNA in health and agriculture.

7. DNA İSOLATİON

Front of card: “DNA Isolation” is written. An image showing the process of DNA extraction in the laboratory can be added.

Back of card: Definition: The process of extracting and purifying DNA from cells.

- **Example:** DNA isolation is a critical step in the human genome project.
- **Additional Information:** Can be applied with simple experiments at high school level.
- **Activity:** Students prepare a DNA isolation protocol with the information on the card.

8. GMO (GENETİCALLY MODİFİED ORGANİSM)

Front of card: “GMO” is written. An image showing examples of GMO products can be added.

Back of card: Definition: Organisms whose genetic material has been modified.

- **Example:** Pest-resistant corn.
- **Additional Information:** GMOs can cause environmental and ethical controversy.
- **Activity:** Using the card, students compare the benefits and risks of GMOs.

9. PLASMİD

Front of card: “Plasmid” is written. Attached is a diagram showing the circular DNA structure of a plasmid extracted from a bacterium.

Back of card: Description: Double-stranded, circular DNA molecules found in bacteria that carry genetic material.

- **Example:** Vector plasmids used in genetic engineering.
- **Additional Information:** Plasmids are important tools for gene transfer in genetic engineering.

- **Activity:** Students discuss the role of plasmids in genetic engineering and list their application areas.

10. RESTRİCTİON ENZYMES

Front of card: "Restriction Enzyme" is written. An image showing DNA cutting sites is added.

Back of card: Definition: Enzymes that recognize and cut specific DNA sequences.

- **Example:** Restriction enzymes such as EcoRI, HindIII.
- **Additional Information:** These enzymes are used in recombinant DNA technology and Genetic engineering to cleave target genes.
- **Activity:** Students explain the mechanism of restriction enzymes and discuss their application areas.

11. MİCROPİPETTE

Front of card: "Micropipette" is written. A drawing of a micropipette being used for measurement is added.

Back of card: Description: A laboratory device used to measure and transfer microliter-level liquids.

- **Example:** Use of a micropipette in DNA isolation and PCR preparation.
- **Additional Information:** Micropipettes are an essential tool in genetic experiments that require precise measurement.
- **Activity:** Students do a simulation activity on the use of a micropipette.

12. DNA FİNGERPRİNTİNG

Front of card: "DNA Fingerprinting" is written. An image showing DNA fingerprint analysis is added.

Back of card: Definition: A unique genetic profile obtained by analyzing DNA sequences specific to an individual.

- **Example:** Forensic genetic applications in the identification of criminals.
- **Additional Information:** Widely used to analyze human genetic diversity.
- **Activity:** Students discuss the role of DNA fingerprinting in forensic science.

13. BİOETHİCS

Front of card: "Bioethics" is written. An icon showing the ethical balance is added.

Back of card: Definition: The discipline concerned with the ethical aspects of scientific endeavors such as biotechnology and genetic engineering.

- **Example:** Ethical evaluation of genetically modified organisms.
- **Additional Information:** Debates about human genetics are central to bioethics.
- **Activity:** Students conduct a debate representing two opposing views in the bioethics debate.

14. GEL ELECTROPHORESİS

Front of card: "Gel Electrophoresis" is written. A diagram showing the separation of DNA fragments on a gel is attached.

Back of card: Description: A laboratory method in which DNA or proteins are separated according to their molecular size.

- **Example:** Analysis of PCR products.
- **Additional Information:** Under an electric field, small DNA fragments move faster in the gel.
- **Activity:** Students explain the working principle and applications of gel electrophoresis to their classmates.

15. TRANSGENİC ORGANİSM

Front of card: "Transgenic Organism" is written. A picture of a genetically modified plant or animal is attached.

Back of card: Definition: Organisms that have had genes from another species added to their genetic makeup.

- **Example:** Drought resistant plants.
- **Additional Information:** Obtained through genetic engineering techniques.
- **Activity:** Students discuss the advantages and disadvantages of transgenic organisms.

16. BİOTECHNOLOGİCAL PRODUCTS

Front of card: "Biotechnological Products" is written. Images of sample products (e.g. insulin, biofuel) are added.

Back of card: Definition: Products produced by biotechnological processes.

- **Example:** Human insulin, biofuels.
- **Additional Information:** Widely used in agriculture, health and industry.
- **Activity:** Students discuss the environmental and economic impacts of biotechnological products.

17. GENETİC ENGİNEERİNG PRODUCTS

Front of card: "Genetic Engineering Products" is written. An image of a product produced with genetic engineering is added.

Back of card: Definition: Products developed by altering genetic materials.

- **Example:** GMO corn, insulin.
- **Additional Information:** Revolutionizing human health and agriculture.
- **Activity:** Students design a survey to examine the social acceptance of these products.

18. STEM CELL

Front of card: "Stem Cell" is written. A diagram showing a differentiation process of stem cells is attached.

Back of card: Definition: Cells that can differentiate into different types of cells in the body.

- **Example:** Embryonic stem cells.
- **Additional Information:** Stem cells have great potential for regenerative medicine.
- **Activity:** Students discuss ethical issues in stem cell research.

19. POLYMERASE CHAİN REACTİON (PCR)

Front of card: “PCR” is written. A diagram showing the PCR cycle is attached.

Back of card: Definition: A laboratory method that amplifies specific regions of DNA.

- **Example:** DNA analysis of crime scene evidence.
- **Additional Information:** Produces millions of copies of DNA in a short period of time.
- **Activity:** Students give a presentation explaining the use of PCR in forensic science.

20. GENE THERAPY

Front of card: “Gene Therapy” is written. A diagram showing gene transfer into a sick cell is attached.

Back of card: Definition: The process of replacing or restoring genes for the treatment of genetic diseases.

- **Example:** Gene therapy for the treatment of cystic fibrosis.
- **Additional Information:** Offers great hope for human genetics.
- **Activity:** Students write a paper on the future implications of gene therapy.

21. CHROMOSOME

Front of card: “Chromosome” is written. An X-shaped figure of a chromosome in the cell nucleus is added.

Back of card: Definition: DNA and protein strands in the cell nucleus that carry genetic information.

- **Example:** Humans have 46 chromosomes, which pass on hereditary traits from generation to generation.
- **Additional Information:** Chromosomes become visible during cell division.
  The number of chromosomes is constant for each species. The genes on the chromosomes determine the structural and functional characteristics of the organism.
- **Activity:** After examining the card, students discuss the effects of changes in chromosome number (e.g. Down syndrome) on living organisms.

Figure 1: *General view of the concept cards created for senior middle and high school students.*

NOTE: These cards are not for printing or implementation. They are used as a visual example of AI-generated cards.

In this way, concept cards are prepared and applied by determining appropriate hours according to the lesson plans.

Another part of the concept cards designed in this study was created for a group of students who have never encountered biotechnology before, have never heard of biotechnological concepts, or have heard little or never heard of biotechnological concepts, and do not address such issues in their lessons. This group of students *can be applied to students at the levels of primary* and *middle school first grades.* The features of these cards are that for each concept, 9x12 cm concept cards are created and on the front side of these cards there are visuals with the related concept with the help of artificial intelligence tools. The front side of the card will help the student to recognize the concept they need to learn. On the back side, the researcher's experiences in the ELA activities that he has been conducting for 5 years and the misconceptions that lead to misconceptions that emerged from the literature review and the correct knowledge statement belonging to that concept are included. Students are asked the questions “which one do you fold, why?” from the explanations on the cards. The students' answers are taken one by one and the teacher asks the students to read the blue-toned flashcards containing correct information without explaining the concepts. Then the students are asked the following question again: “Do you

agree with the explanations you agreed with again?". If the students who agree with the correct explanation have learned the concept, but continue to agree with the wrong perception explanations, the teacher will step in and provide examples and explanations about why this is the correct information and why the wrong information is wrong, and will ensure that these students learn correctly by eliminating their misconceptions. Thus, both teaching activity and measurement and evaluation are carried out in the process, saving time for the teacher.

The blue-toned flashcards were created in 9x12 dimensions horizontally. On the front side, the names of the concepts are written in large fonts, and on the back side, the correct information consisting of 3–5 sentences, including the correct information in the concept cards prepared for students in the first grades of primary and middle school, is included. These cards will be distributed to the students during the implementation to help them understand whether the information they agree with or defend is correct or not.

In determining the colors of the flashcards, it is stated in the literature review that the conscious use of colors in the design of educational materials can positively affect the learning process. Colors are powerful tools to attract students' attention, increase their motivation and transfer knowledge more effectively. They explained that the color blue symbolizes trust, loyalty and peace. Research shows that shades of blue can increase productivity and performance. For example, environments painted in shades of blue and light blue have been found to contribute to students achieving higher grades. In addition, it has been observed that notes written in blue are more permanent in memory (Erim, 2000; Sakıcı & Bal, 2022; Çalışkan & Kılıç, 2014). In the light of this information, the colors of the flashcards were decided to be composed of blue tones.

For each concept, the information that should be on the concept cards *at the elementary and/or middle school first grade level* is given below. The correct information about one of these concepts is marked as **"*"** and is shown in the explanations below. However, this marking is not present on the concept cards. Apart from this correct information, the other information consists of erroneous perceptions that lead to misconceptions. At the end, the question "Which of these statements do you agree with and why?" is asked.

Again, if we continue to work on these concept cards in the future, we will be able to ensure students' correct understanding and deep learning of that concept by linking the relevant video, web address link or the relevant information on the labxchange platform by giving a QR code on the back or front side.

For each concept, the information that should be on the concept cards ***at the level of elementary and/or middle school beginner grades*** is given below. Statements marked with * are statements of correct knowledge about the concepts.

1. DNA

- DNA contains only the information that comes from the mother and can change it.
- DNA is the molecule that carries all the information.
- DNA is the molecule that carries genetic information and determines our characteristics. *
- DNA sequences are the same in every living thing.
- Mutations in DNA are always harmful!

Which of these statements do you agree with and why?

2. BIOTECHNOLOGY

- Biotechnology is only concerned with drug production.
- Biotechnology is only applied in the laboratory.
- Biotechnology is the science of developing new products using living organisms. *
- Biotechnology is science used only for commercial purposes.

Which of these statements do you agree with and why?

3. GENETIC ENGINEERING

- Genetic engineering is only done in the laboratory with plants
- Genetic engineering always produces artificial genes.
- Genetic engineering is the science of modifying genes to give them new characteristics. *
- Genetic Engineering is only concerned with GMO production

Which of these statements do you agree with and why?

4. GENE CLONING

- Gene Cloning is the process of replicating a single cell.
- Gene cloning is used in genetic research and medicine. *
- It is possible to produce organs with Gene Cloning.
- Gene Cloning can only be done in a laboratory environment.

Which of these statements do you agree with and why?

5. GENE TRANSFER

- Gene transfer is the name for the entire DNA.
- Gene transfer is the transfer of an organism's genetic information. *
- Gene transfer always produces positive results.
- Gene transfer is only used to treat genetic diseases.
- Gene transfer is only carried out for the production of GMOs.

Which of these statements do you agree with and why?

6. RECOMBINANT DNA

- Recombinant DNA is only used to make medicines.
- Recombinant DNA is only used in genetic diseases
- Recombinant DNA is the process of combining genetic material from different organisms to give them new properties. *
- Recombinant DNA always gives successful results.

Which of these statements do you agree with and why?

7. DNA ISOLATION

- DNA isolation is only done in the laboratory.
- DNA isolation is only done in plants.
- DNA isolation is always done in the same way.

- DNA isolation allows structurally pure DNA molecules to be obtained from cells. *

Which of these statements do you agree with and why?

8. GMO (GENETICALLY MODIFIED ORGANISM)

- Eating GMO crops alters human DNA
- All GMOs are harmful to health and cause cancer
- Once planted, GMO seeds remain in nature forever, destroying all natural species.
- GMOs are organisms developed under scientific control and subjected to various health and environmental tests before use. *

Which of these statements do you agree with and why?

9. PLASMİD

- Plasmids are found in the cell nucleus.
- Plasmids only cause harmful diseases in our bodies.
- Plasmids are only found in disease-causing bacteria.
- The genetic information carried by plasmids is always harmful, genetic engineering is harmful.
- Plasmids are small DNA molecules that carry genetic information and are used in genetic engineering.

Which of these statements do you agree with and why?

10. RESTRICTION ENZYME

- Restriction enzymes are harmful and always damage DNA.
- Restriction enzymes are enzymes that cut DNA at specific points. *
- Each of the restriction enzymes can only cut one type of DNA.
- The use of restriction enzymes is always a complex and difficult process.

Which of these statements do you agree with and why?

11. MICROPIPETTE

- Micropipettes are only used in laboratories.
- The size of micropipettes is fixed and cannot be changed.
- Micropipettes are precision instruments used in laboratories to pick up and transport the right amount of liquid. *

Which of these statements do you agree with and why?

12. DNA FINGERPRINTING

- DNA fingerprinting is the isolation of DNA from a fingerprint.
- DNA fingerprinting is done by analyzing only a few genes
- DNA fingerprinting can only be used for humans
- DNA fingerprinting is only used in forensic medicine
- DNA fingerprinting is a unique and unrepeatable technique used to identify an individual's genetic characteristics. *

- DNA fingerprinting is only used to find genetic diseases.

Which of these statements do you agree with and why?

13. BIOETHICS

- Bioethics is the work of doctors and scientists only.
- Bioethics is a discipline that examines ethical issues and human rights in scientific and medical fields. *
- Bioethics only includes the biological rights of humans.
- Bioethics only covers controversial issues such as genetic engineering and cloning.

Which of these do you agree with and why?

14. GEL ELECTROPHORESIS

- Gel electrophoresis is only used for samples from large organisms.
- Gel electrophoresis separates all molecules equally.
- Gel electrophoresis is only used to analyze DNA samples
- In gel electrophoresis, all DNA molecules move at the same speed.
- Gel electrophoresis is a technique used to separate DNA, RNA or proteins based on their molecular size. *

Which of these do you agree with and why?

15. TRANSGENIC ORGANISM

- Transgenic organisms can only be made for animals.
- Transgenic organisms are always harmful to human health.
- Transgenic organisms are organisms that have been genetically modified by taking a gene from another organism. *
- Transgenic organisms are usually very short-lived and cannot participate in evolutionary processes.

Which of these statements do you agree with and why?

16. BIOTECHNOLOGICAL PRODUCTS

- Most biotech products are harmful.
- Biotechnological products are products produced by biological processes and facilitate human life. *
- Biotech products are artificial and do not exist in nature.
- Biotech products always give better results than naturally produced ones.
- Antibiotics, vaccines, cheese production are biotechnological products. *

Which of these statements do you agree with and why?

17. GENETIC ENGINEERING PRODUCTS

- Genetically engineered products are only used in pharmaceutical production.
- Genetic engineering products are products obtained by changing the genetic structure of organisms and are used in many fields such as agriculture, health and food production. *
- Genetic engineering products are produced only for human health.
- Products of genetic engineering are always genetically modified organisms.
- Genetic engineering products can be applied to all living things in the same way.
- Creating more durable and productive crops such as corn, cotton and soy, producing insulin hormone from bacteria, and obtaining disease-resistant crops in plants and animals are products of genetic engineering. *

Which of these statements do you agree with and why?

18. STEM CELL

- Stem cells are only used to treat diseases.
- All stem cell types work the same way in the body.
- Stem cell therapy is only used for cancer.
- Stem cells are cells that have the capacity to differentiate into different types of cells. *
- Stem cell therapy is always successful.

Which of these statements do you agree with and why?

19. POLYMERASE CHAIN REACTION (PCR)

- PCR is only used to treat diseases.
- The PCR process amplifies all DNA.
- PCR is only used to diagnose genetic diseases.
- PCR is sufficient to discover all the features of DNA.
- PCR is a technique used to rapidly amplify specific sections of DNA. *

Which of these statements do you agree with and why?

20. GENE THERAPY

- Gene therapy can completely cure genetic diseases.
- Gene therapy is only used for congenital diseases.
- Health treatments with gene therapy are always successful.
- Gene therapy is only used for congenital diseases.
- Gene Therapy is a method used in the treatment of genetic diseases. *

Which of these statements do you agree with and why?

21. CHROMOSOME

- Chromosomes come only from the mother and father and cannot be changed.
- Chromosomes are the packaged form of DNA in cell division. *
- Chromosome numbers are constant in all cells of all living things.

Which of these statements do you agree with and why?

In this study, various concept cards were prepared for the concepts given above. The visuals of the prepared concept cards are given below (Figure 2).

Scientific Discovery for the Classroom

Figure 2: *General view of the concept cards created for students in the beginning grades of primary and/or secondary school.*

NOTE: These cards are not for printing or implementation. They are used as a visual example of AI-generated cards.

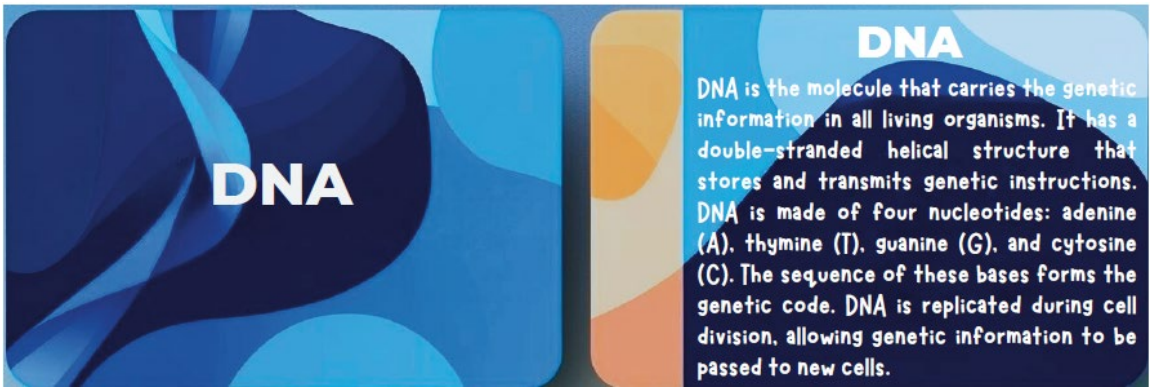
Thanks to these cards, students will be able to move away from their misconceptions about the concepts and learn and understand them correctly. Through visual materials, interactive open-ended questions and brainstorming, misconceptions are revealed and eliminated.

The correct information on the blue-toned flashcards was obtained by using artificial intelligence tools and by confirming the information from Campbell's *Introduction to Biology and Biotechnology*. These cards will then be distributed to the students so that they can understand whether the information they agree with or defend is correct or not.

The information that should be on the correct information concept cards for each concept is given below, shown with an example of each card.

1. DNA

DNA is the molecule that carries the genetic information of all living organisms. It is composed of four bases called nucleotides: adenine (A), thymine (T), guanine (G) and cytosine (C). The sequence of these bases determines the genetic code of the organism, DNA is copied during cell division and allows the transfer of genetic information to new cells.



2. BIOTECHNOLOGY

Biotechnology is a branch of science that involves the use of living organisms or biological systems in industrial and other applications. Modern biotechnology applies production processes quickly and safely using recombinant DNA technology. Vaccine production, genetic engineering and biomedical research are among the application areas of biotechnology. This technology offers innovative solutions in various sectors such as agriculture, health and the environment, including biotechnological processes such as bioremediation.

3. GENETIC ENGINEERING

Genetic engineering is a branch of science that aims to provide new traits through direct manipulation of the genetic material of organisms. This process involves adding, removing or modifying genes. Genetic engineering can provide plants, animals and microorganisms with desired traits. For example, with this technique it is possible to insert disease-resistant genes into plants.

4. GENE CLONING

Gene cloning is a method used to create copies of a specific gene. In this process, the desired gene is inserted into a vector (usually a plasmid) and transferred into a host cell. The host cell replicates the gene and produces it in large quantities. Gene cloning is used in areas such as research, drug production and gene therapy.

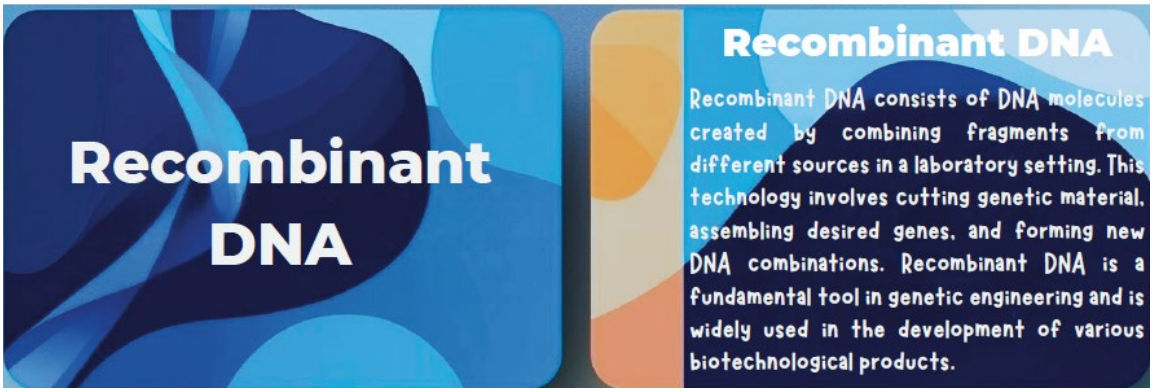
5. GENE TRANSFER

Gene transfer is the process of transferring genetic material from one organism to another.

This process allows new traits to be acquired by transferring desired genes to plants, animals or microorganisms. For example, “Golden Rice” was produced by transferring the gene responsible for vitamin A production from the daffodil plant to rice. This rice contributes to overcoming vitamin A deficiency.

6. RECOMBINANT DNA

Recombinant DNA is DNA molecules created in the laboratory by combining DNA fragments from different sources. This technology involves cutting genetic material, combining desired genes and creating new combinations. Recombinant DNA is an important tool in genetic engineering applications and is used in the development of various biotechnological products.



7. DNA ISOLATION

DNA isolation is the process of purifying DNA from cells. This process involves lysing the cell membrane, removing proteins and other components and precipitating the DNA. The resulting pure DNA is used in molecular biology techniques such as genetic analysis.

8. GMO (GENETICALLY MODIFIED ORGANISM)

Genetically modified organisms (GMOs) are living organisms whose DNA has been modified in the laboratory by genetic engineering techniques. These changes are usually made to give an organism new characteristics such as insect resistance, herbicide tolerance or increased nutritional value. GMOs are most commonly used in agriculture: For example, crops such as insect-resistant corn or drought-resistant soybeans have been developed. There is an ongoing global debate about GMOs due to food safety, environmental impacts and ethical issues. Some countries impose strict regulations on the production and consumption of GMOs, while others use this technology widely.

9. PLASMIDS

Plasmids are small, self-dividing circular DNA molecules found outside the chromosome in bacteria. They are used as vectors in gene cloning and play an important role in transporting foreign genes. Plasmids can carry specific traits, such as antibiotic resistance genes, and can be easily manipulated in the laboratory.

10. RESTRICTION ENZYMES

Restriction enzymes are enzymes that cut DNA molecules at specific sequences. They occur naturally in bacteria and are used in recombinant DNA technology to cut DNA at desired locations. Each restriction enzyme recognizes a specific DNA sequence and makes a cut at that site.

11. MICROPIPETTE

Micropipettes are devices that allow the precise transfer of very small volumes of liquids in a laboratory environment. They are widely used in molecular biology and biochemistry studies . Micropipettes are capable of attracting and releasing liquids of different volume ranges and should be calibrated regularly for accurate measurement.

12. DNA FINGERPRINTING

DNA fingerprinting is a method of determining or identifying genetic relationships by analyzing unique sequences in an individual's DNA. This technique is used in forensic science, genealogical research and the diagnosis of genetic diseases. Because each individual has a different DNA sequence, DNA fingerprinting provides highly accurate personal identification.

13. BIOETHICS

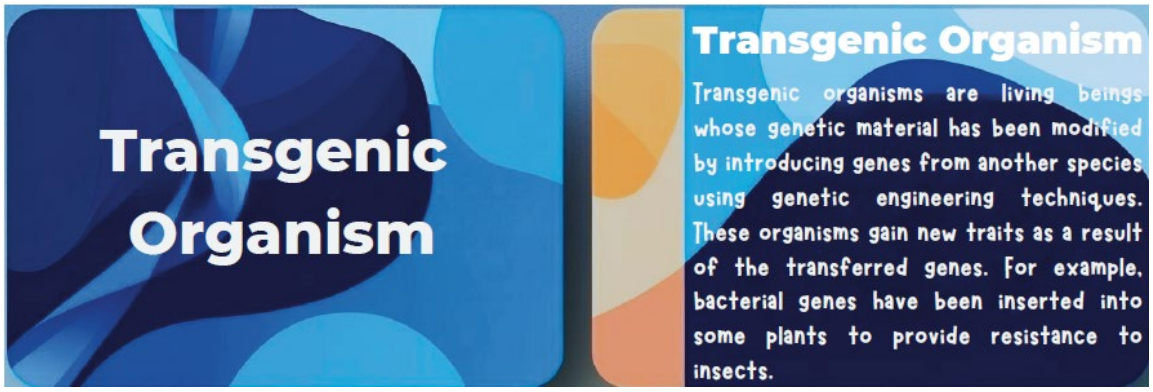
Bioethics is a discipline that examines ethical issues in biology and medicine. It evaluates the ethical dimensions of issues such as genetic engineering, organ transplantation, cloning and genetically modified organisms. Bioethics aims to ensure that scientific developments are compatible with human rights, justice and social values.

14. GEL ELECTROPHORESIS

Gel electrophoresis is a laboratory technique that allows DNA, RNA or proteins to be separated according to their size. In this method, samples are exposed to an electric field in a gel matrix and the molecules move at different speeds according to their size. The results are analyzed to determine the size and quantity of the molecules.

15. TRANSGENIC ORGANISM

Transgenic organisms are organisms that have been genetically transferred from another species by genetic engineering methods. These organisms gain new characteristics thanks to the transferred gene. For example, bacterial genes have been inserted into some plants to confer insect resistance.



16. BIOTECHNOLOGICAL PRODUCTS

Biotechnological products are substances produced using biotechnology methods.

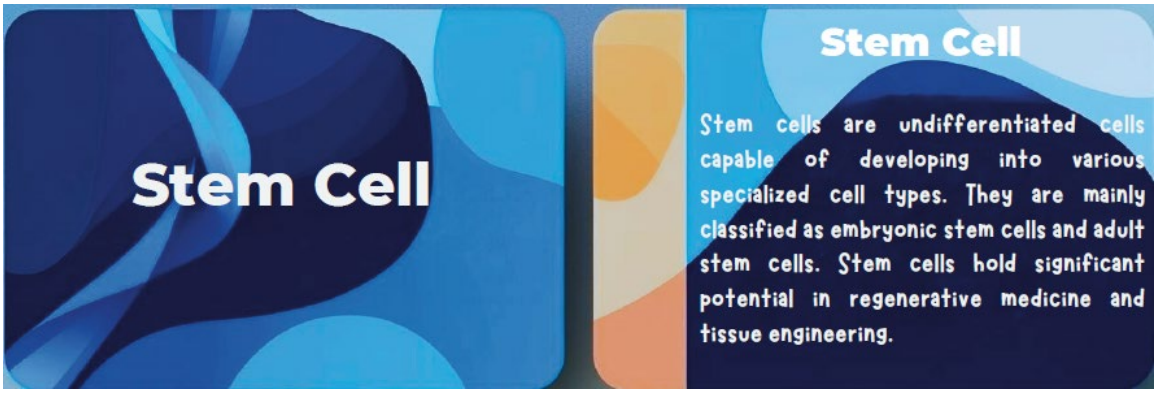
These include recombinant proteins, monoclonal antibodies, gene therapy products and genetically modified organisms. These products are used in various fields such as medicine, agriculture and industry.

17. GENETIC ENGINEERING PRODUCTS

Genetic engineering products are products obtained by altering the genetic makeup of organisms. These include genetically modified plants, animals and microorganisms and substances derived from these organisms. For example, bacteria modified to produce the hormone insulin are products of genetic engineering.

18. STEM CELL

Stem cells are specialized cells that have the ability to differentiate into different cell types. They fall into two main categories: embryonic stem cells and adult stem cells. Stem cells have great potential in regenerative medicine and tissue engineering.



19. POLYMERASE CHAIN REACTION (PCR)

PCR is a technique used to produce millions of copies of specific DNA sequences in a laboratory setting. This method is widely used in fields such as genetic research, disease diagnosis and forensic science. PCR allows DNA to be replicated quickly and precisely.

20. GENE THERAPY

Gene therapy is the process of transferring genetic material directly into cells to treat or prevent diseases. It is used to correct genetic disorders, build resistance to disease or repair damaged tissues. Gene therapy is a promising approach to treat cancer, inherited diseases and some infections.

21. CHROMOSOME

Chromosomes are structures made up of DNA and proteins and are located in the cell nucleus. Human cells contain 46 chromosomes: These carry genetic information and pass it on from parents to children. Chromosomes ensure the proper distribution of DNA during cell division. Each chromosome contains specific genes and plays a critical role in the development and functions of the organism.

Access the printed versions of the flashcards shown above, created by the researcher with the help of technological tools.

Test Questions

For both level groups, test questions were prepared for the teacher to make a final evaluation by applying a pre-test before the activity and post-test at the end of the activity.

These tests were created by the researcher. Access the pre-test and post-test questions translated into English, please click on the link below.

Assessment Tools

These assessment tools were created by the researcher specifically to measure the process that encourages students to recognize misconceptions and reach correct knowledge.

CONCEPT CARDS ACTIVITY EVALUATION FORM (STUDENT OBSERVATION FORM)

Student's Name-Surname:
Class/Group:
Date
Concept Name

A. Level of Participation and Understanding

Evaluation Indicator	Yes	Partially	No
Carefully examined the image on the card.	☐	☐	☐
They tried to distinguish between correct and incorrect explanations about the concept.	☐	☐	☐
Justified the explanation he/she agreed with.	☐	☐	☐
Read the correct information card and tried to understand its content.	☐	☐	☐
Changed his/her opinion or explained why he/she did not change his/her opinion.	☐	☐	☐

B. Observation Note / Feedback (To be filled in by the teacher):

.....
.....
.....

CONCEPT CARD EVALUATION SCALE (SCORING FORM)

Concept: .....
Student Name: .....

Criteria	Score Range (1-5)	Score
Recognizing the concept from the visual related to the concept	1-5	
Distinguish correct information from incorrect explanations	1-5	
Making a reasoned explanation	1-5	
Developing attitudes after reaching the right information	1-5	
Level of engagement and communication	1-5	

Total Points ..... / 25

I EVALUATE MYSELF - “WHAT DO I THINK?” (STUDENT FORM)

Concept Name: .....
Student Name: .....

Today I learned the following about this concept:

1. .....
2. .....
3. .....

Among the statements on the card, the one I agreed with the most was the following:
.....
Why I agreed with this statement:
.....

Did my opinion change after reading the statement of correct information on the card?
( ) Yes ( ) No

If it has changed, explain why:
.....

“WHAT HAVE I LEARNED AND WHAT DO I KNOW?”

BIOTECHNOLOGY CONCEPTS EVALUATION FORM

Student's Full Name: .....
Class / Group: .....
Date: .....

Objective: To measure the level of knowledge about frequently encountered concepts in the field of biotechnology; to recognize misconceptions and to evaluate the correct information learned.

Subject: To determine whether the concepts commonly encountered in biotechnology have been learned with the correct information.

A. Make a drawing representing each of the following concepts (can be a symbol, process diagram, icon, etc.)

Concept	Your drawing
DNA	
DNA isolation	
Biotechnology	
Genetic Engineering	
Plasmid	
Restriction Enzymes	
Chromosome	
Gel Electrophoresis	
Biotechnology Products	

Concept	Your drawing
Genetic Engineering Products	
Bioethics	
DNA Fingerprinting	
Gene Cloning	
Gene Therapy	
Gene Transfer	
GMO	
Micropipette	
PCR	
Recombinant DNA	
Stem Cell	
Transgenic Organism	

B. Explain the basic information you have learned about each concept in 2–3 sentences.

DNA:

DNA Isolation

Biotechnology:

Genetic Engineering:

Plasmid

Restriction Enzymes

Chromosome

Gel Electrophoresis:

Biotechnology Products:

Genetic Engineering Products:

Bioethics:

DNA Fingerprinting:

Gene Cloning:

Gene Therapy

Gene Transfer:

GMO:

Micropipette

PCR:

Recombinant DNA

Stem Cell

Transgenic Organism

C. Evaluation Table (To be filled in by the teacher)

Description-Criteria	Score (1-5)
Are the definitions correct, is there missing information?	
Can the student make logical connections between concepts?	
Is it superficial or detailed?	
Organization, clarity and presentation of drawings	
Is there an original idea, original presentation style?	
Total Score	

Note: Each criterion will be scored from 1 (poor) to 5 (very good)

Biotechnology Concepts Assessment Form was adapted from Küçükaslan 2024 ABE curriculum development study and created as subject-specific.

SELF-ASSESSMENT FORM

Name: _____ Date: _____

1. Evaluating my knowledge

Expressions related to biotechnological concepts	Strongly disagree	Disagree	Undecided	I agree	Absolutely agree
I understand the structure of DNA and why it is important for living things.					
I understand what chromosomes are and their role in the cell.					
I can understand what biotechnology is.					
I can understand what genetic engineering is.					
I can explain how DNA isolation is done and why it is necessary.					
I understand how GMOs are created and for what purpose they are produced.					
I understand what transgenic organisms are and how they are produced					
I understand what biotechnological products are and can give examples.					
I can explain what DNA fingerprinting is and how it is used.					
I know what gene cloning is and how it is done.					
I understand what gene transfer is and how it is used.					
I can explain what recombinant DNA technology is.					
I can describe what plasmids are and how they are used in gene transfer.					
I know what restriction enzymes are and what they are used for					
I know what a micropipette is and how it is used.					
I can explain what gel electrophoresis is and where and how it is used.					
I understand what genetic engineering products are and can give examples.					
I can explain what stem cells are and how they can be used.					
I know what the PCR technique is and how and where it is used.					
I can understand what gene therapy is and how it can be used to treat diseases.					
I know what bioethics is and what it covers.					

2. Evaluating my process

- What did I learn the most from this activity?
- What were the most challenging parts?
- How can I do better next time?

PEER EVALUATİON FORM

Reviewer _____
Evaluated Person _____

1. Evaluating my friend

Related statements	Strongly disagree	Disagree	Undecided	I agree	Absolutely agree
Actively participated in group work.					
He supported his ideas with scientific evidence					
Provided accurate information on relevant biotechnological concepts					
Respectful and supportive in discussions					

2. Feedback about my peer

- In which subject was this student most successful?
- In which areas can this student improve?
- What would I recommend to him/her next time?

NOTE: The Self-Assessment and Peer Assessment Forms were created by the researcher as unique to the study.

Depending on the level of the student group and the type of concept cards to be used, the teacher can use either all of them or one or more of them in his/her lessons. They can ensure that they are included in the lesson plans appropriately in relation to the concepts. They can make a measurement and evaluation by examining the answers given by the students. The aim here is to conclude whether students' misconceptions have been eliminated during and at the end of the process. In addition, in terms of academic evaluation, teachers can evaluate the results by using pre- and post-tests at the end of all activities.

SAMPLE LESSON PLANS UNİQUE TO THE STUDY

Sample Lesson Plan 1

DNA, Chromosome, and DNA Isolation
Grade Level: Ages 11–16
Duration: 80 minutes
Focus: Addressing misconceptions about DNA and chromosomes
Approach: Inquiry-based learning – aligned with the ABE (Amgen Biotech Experience) model

Learning Objectives

By the end of the lesson, students will be able to:

- Describe the structure and function of DNA.
- Explain how DNA carries hereditary information.
- Clarify the relationship between DNA and chromosomes.
- Identify and correct misconceptions related to the topic.
- Visualize conceptual relationships using a concept map.

Required Materials

- Concept cards (DNA, chromosome, and DNA isolation) with correct/incorrect explanations
- Whiteboard, sticky notes, colored markers
- Self-assessment and peer-assessment forms
- Concept map template

Lesson Flow

Intro Activity (15 minutes) – Identifying Misconceptions
Objective: Elicit students' prior knowledge

- Teacher asks:
  - "What is DNA, and what does it do?"
  - "Are chromosomes and DNA the same thing?"
- Students write their answers on sticky notes and place them on a "Facts / Myths" board.
- Concept cards are distributed, and students try to guess the meanings.

Main Activity (45 minutes) – Exploring Scientific Concepts
Objective: Understand DNA structure and relate concepts

- Teacher displays and explains DNA concept card.
- Students participate in the "Which one do you agree with? Why?" activity, debating the truthfulness of concept cards.
- The class analyzes the relationship between DNA and chromosomes.
- Students discuss the purpose and contexts of DNA isolation.
- Each student creates a concept map showing the relationships between the concepts.

Final Activity (20 minutes) – Reflection and Assessment
Objective: Reinforce learning and correct misconceptions

- Students revisit their initial sticky notes and reclassify them using their new understanding.
- Self-assessment forms are completed: "What did I learn in this lesson?"
- Students evaluate each other using peer-assessment forms.
- Final discussion questions:
  - "What is the difference between DNA and a chromosome?"
  - "Why is it important to know the structure of DNA?"

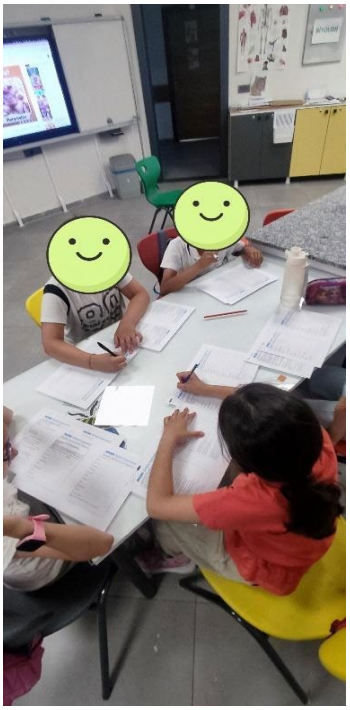
Expected Learning Outcomes

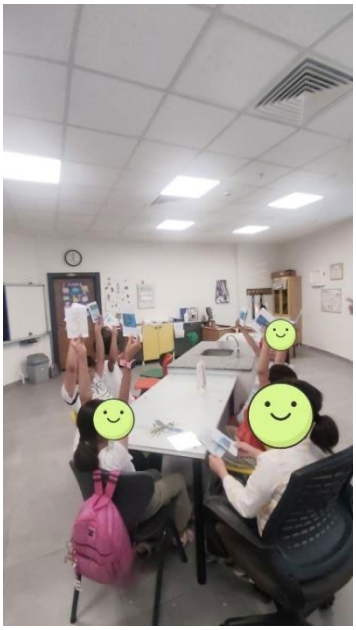
- Students will accurately define DNA and chromosome concepts.
- Recognize and correct misconceptions.
- Visualize conceptual relationships via concept mapping.
- Apply critical thinking in discussions.
- Internalize their learning process through individual and peer evaluations.

Figure 3: *A sample lesson plan created by the researcher*

Access other sample lesson plans designed by the researcher and prepared for students at different levels using concept cards materials.

Visuals of the activities implemented by the researcher in the lessons are shown below.





What kind of inputs (or questions) do you expect from industry experts in this field?

While misconceptions encountered in the industry increase the need for feedback in the education and training process, inputs based on the knowledge and experience of industry experts are of great importance for correct concept learning in the field of biotechnology and preparation for future technological developments. Accordingly, in order to prevent misconceptions and develop effective

teaching strategies, the following questions are expected from industry experts based on their field-specific experiences.

Misconceptions Encountered in Industry:

- What are the most common misconceptions encountered by employees or recent graduates in the field of biotechnology?
- In which processes or technologies do these misconceptions lead to the biggest mistakes?

Feedback in terms of Education and Training:

- Is incomplete or incorrect information frequently encountered in the materials used in the training of industrial workers?
- Do you think that visual and interactive tools such as concept cards can be effective in vocational training and orientation processes?

Concept Learning in Biotechnology:

- How does a correct understanding of concepts affect production, R&D and quality processes?
- Which teaching approaches would be more effective for employees to internalize the basic concepts of biotechnology?

Strategies to Prevent Misconceptions:

- Are there existing strategies to reduce misconceptions in the industry?
- Do you have any suggestions on how concept cards should be structured or used in this process?

Future Technological Developments and Concepts:

- Among the new concepts and technologies emerging in biotechnology, which are most vulnerable to misunderstanding?
- How can educators and researchers better communicate these concepts?

Strategies to Increase Access, Engagement, and Success

What strategies can you incorporate to increase access, engagement and success for the intended users/audiences (widen participation, differentiate for different learners, provide multiple assessment methods, etc.)?

- The content of the concept cards could be further elaborated and targeted at high school or university students.
- For those who do not speak English well, the content can be digitized and translated into different languages for easy access.
- By creating a QR code, links can be given for deeper information.
- In addition to biotechnology information, you can discuss biotechnologies in areas such as plants, agriculture and food.

LabXchange Support

The interactive DNA ladder (in Turkish) explaining the double helix molecular structure of DNA can be used to remind students of their prior knowledge on the subject before DNA isolation.
https://www.labxchange.org/library/items/lb:LabXchange:fe858409:lx_simulation:1

The interactive introduction to micropipette, describing the parts of a micropipette and how to use them, can be shown to students before using a micropipette.
https://www.labxchange.org/library/items/lb:LabXchange:c96c60f7:lx_simulation:1

The micropipetting solutions simulation allows students to practice using a micropipette in a virtual laboratory environment. It can be used for students to practice after using the micropipette.
https://www.labxchange.org/library/items/lb:LabXchange:21e5de32:lx_simulation:1

Polymerase Chain Reaction, also known as PCR, is an interactive exercise with various applications of the laboratory technique known as Polymerase Chain Reaction (PCR) and is used before the PCR application.
https://www.labxchange.org/library/items/lb:LabXchange:9e990446:lx_simulation:1

Can be used to introduce gel electrophoresis to students before the use of gel electrophoresis.
https://www.labxchange.org/library/items/lb:LabXchange:86ca9198:html:1

Can be used to explain to students the role of each piece of equipment needed to perform DNA gel electrophoresis. https://www.labxchange.org/library/items/lb:LabXchange:9ad2ad4e:html:1

Gel electrophoresis simulation is used to introduce students to the gel electrophoresis technique used to separate biological molecules.
https://www.labxchange.org/library/items/lb:LabXchange:16e7a6a9:lx_simulation:1

The Separating DNA by Gel Electrophoresis interactive is used to introduce students to gel electrophoresis and discuss the results.
https://www.labxchange.org/library/items/lb:LabXchange:eead0f7b:lx_simulation:1

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