Unit 4: Gene expression and regulation

From decoding DNA to groundbreaking biotechnology! Topics include:

- Role of genes and proteins in influencing traits.
- DNA's structure and replication.
- How protein structure influences its shape and function.
- Gene expression and cell specialization in multicellular organisms.
- Effects of mutations on gene structure and function.
- DNA technologies.

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<thead>
<tr>
<th>TEKS standards</th>
<th>Example phenomena</th>
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<tr>
<td>SCIENCE.BIO.6A</td>
<td>Explain the importance of the cell cycle to the growth of organisms, including an overview of the stages of the cell cycle and deoxyribonucleic acid (DNA) replication models.</td>
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<tr>
<td>SCIENCE.BIO.7A</td>
<td>Identify components of DNA, explain how the nucleotide sequence specifies some traits of an organism, and examine scientific explanations for the origin of DNA.</td>
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<td>SCIENCE.BIO.7B</td>
<td>Describe the significance of gene expression and explain the process of protein synthesis.</td>
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How do the characteristics of DNA, gene activity, and biotechnology advancements influence our insight and approach to genetic conditions?

*To align with student interest and class dynamics, the provided prompts can be modified to focus on sickle cell anemia or another genetic disorder.*

Globally, about 10,000 single-gene diseases affect 1 in every 100 people. Studying a specific DNA mutation-caused condition like cystic fibrosis provides insight into DNA structure, gene expression, and DNA modifications, as well as molecular technologies used in diagnosis and treatment. Small variations in DNA can result in numerous conditions impacting millions.

Prompts for students to consider:

- What causes cystic fibrosis at the DNA level, and how does this mutation affect the body from molecules to organs?
- How does DNA's structure encode genetic information, and how do changes in nucleotide sequence impact organism traits?
- How does cystic fibrosis’ DNA mutation impact gene expression, protein synthesis, and the development of its symptoms?
- How do biotechnologies diagnose conditions like cystic fibrosis, and can genetic engineering help treat it?
- What is the future potential of molecular technologies in diagnosing, researching, and treating genetic disorders?
How can understanding DNA structure and biotechnology advancements lead to GMO creations to address global malnutrition issues?

*This unit can focus on a specific GMO (Golden Rice, papaya, or another that interests your class) or be kept broad to focus on several GMOs or GMOs overall. The development of genetically modified organisms (GMOs), such as 'Golden Rice,' aimed at combating global malnutrition, opens a window into the intricate worlds of DNA structure, gene expression, and DNA modifications. This exploration also leads to an understanding of advanced molecular technologies that are pivotal in facilitating these biotechnological breakthroughs.

Prompts for students to consider:
- What is Golden Rice’s role in combating global malnutrition and how does its genetic modification help fight vitamin A deficiency?
- How does DNA structure enable genetic modifications in Golden Rice, and how do its nucleotide sequence changes lead to specific traits that can address malnutrition?
- How is gene expression in Golden Rice regulated to produce beta-carotene, and what roles do transcription and translation play in this process?
- How do PCR and gel electrophoresis verify Golden Rice's genetic modifications, and what other applications does genetic engineering have beyond creating GMOs like Golden Rice?
- How do Golden Rice's genetic modifications showcase molecular biology and biotechnology in action, and what other global issues could similar interventions address?

Unit resources

- For the videos in this unit, use the Learning summary video notetaking guide
- For the articles in this unit, use the Article notetaking guide
- For the exercises in this unit, use the Blank workspace template
- Vocabulary and notation notetaker.
### Lesson overview

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<th>Lesson</th>
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| **Lesson 1: Genes, proteins, and traits** <br>TEKS standard: BIO.7A | **Explain the fundamental relationship between genes, proteins, and traits.** | - Genes code for proteins that perform various functions in the body, ultimately determining the physical and biochemical traits of an organism.  
- Using a search engine, have students quickly find various genes, corresponding proteins, and traits. Categorize into a class list and save for future use.  
- Clarify that traits encompass more than physical attributes, including protein functions like lactase for lactose digestion, and can be polygenic (skin color) or caused by a single gene (freckles). |

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| **Lesson 2: DNA structure and replication** <br>TEKS standards: BIO.6A; BIO.7A | **Identify and describe the components of DNA (sugar-phosphate backbone and nitrogenous bases) and the significance of the double helix structure.**<br>**Understand the roles of complementary base-pairing in the conservation of the genetic code during DNA replication.**<br>**Describe the basic steps of DNA replication and the roles of key enzymes and proteins in the process.** | - DNA's double helix structure is key to its replication process, ensuring accurate genetic information transfer across cell generations.  
- Relate to previous cell cycle lessons, especially the S Phase, to show that DNA replication is not continuous but occurs at specific times.  
- Compare and contrast DNA structure and replication in prokaryotes vs. eukaryotes, understanding the similarities and differences.  
- Discuss when and why DNA replication is needed, explore different replication rates, and use examples like traumatic brain injuries to explain these variations. |

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| **Lesson 3: Gene expression and regulation** <br>TEKS standard: BIO.7.B | **Explain how the structure of a protein determines its function and the importance of protein folding.**<br>**Illustrate the sequential flow and underlying purposes and processes of DNA replication, transcription, and translation.**<br>**Describe the basic steps of transcription and the roles of key enzymes and proteins in the process.** | - Protein structure, determined by amino acid sequences, is crucial for its specific functions in biological processes and organism health.  
- Revisit intro activity's protein list, analyzing each protein's structure, and compare across categories to understand structure-function relationship.  
- Use animations and videos to illustrate protein synthesis, folding, and function, connecting with current research updates from notable labs and universities for real-world relevance.  
- Offer options to use a genetic code chart or wheel when translating mRNA sequences → amino acids. |

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Describe the translation process, including the role of key enzymes and proteins, and the significance of codons.

Understand the universal genetic code and its role in protein synthesis in various organisms.

Understand how genes encode information for creating proteins that lead to specific physical and physiological traits.

Examine how the differential expression of genes drives the specialization of cells, leading to the formation of different cell types with specific functions.

- Gene expression regulates cell specialization, where different genes are activated or silenced, leading to diverse cell types and functions.
- Begin with a broad view of genetic information flow, then dive into specifics like replication, transcription, and translation, regularly link back to the big picture to keep the overall concept clear.
- Map it out. Create visuals as a class detailing locations, key proteins, enzymes, and inputs/outputs for DNA replication, transcription, and translation, using these for frequent reference.
- Use a 3-way Venn diagram to differentiate DNA replication, transcription, and translation, including examples and when + where each process occurs.
- Analogy: construction site workers (cells) follow specific blueprints (genes) for their tasks, each cell type specializes by using only certain genetic instructions, despite having the same genome.

### Lesson 4: Mutations

**TEKS standard:** BIO.7.C

Identify and illustrate how specific DNA changes occur at the molecular level.

Analyze the potential impacts of DNA changes on protein structure and function.

- Mutations are changes in DNA, impacting gene function and protein formation, and can lead to various biological and health outcomes.
- Maintain focus on gene mutations; chromosome mutations will be covered in future units.
- Explain that a “mutation” is simply a change and not inherently negative. Use a codon chart to show that many mutations do not alter the resulting amino acid sequence.
- Have students create a concept map of the various gene level mutations including diagrams and impacts at the DNA, protein, and organismal level.

### Lesson 5: DNA technologies

**TEKS standard:** BIO.7.D

Discuss the significance, applications, and fundamental principles and processes of key molecular technologies.

Explore real-world examples where molecular technologies are applied in current research and engineering practices.

- DNA technologies encompass tools like PCR, gel electrophoresis, next-gen sequencing, CRISPR.
- Have students investigate current GMOs and the molecular development techniques behind them.
- Engage with your community (i.e. local labs, police stations) or use video conferencing for diverse perspectives on DNA technologies.
**Best practices**

COMMON MISCONCEPTIONS AND HOW TO ADDRESS THEM

"One gene codes for one protein, determining a single trait."

Students may view gene → protein → trait as a linear process; broaden understanding by exploring polygenic traits and epigenetics, and environmental gene expression impact.

**How to address this misconception**

Build a concept map with the gene-to-trait pathway at the center, branching out to the concepts listed above. Give students a basic overview of each concept and extend with: (1) gene-trait matching to explore genes affecting multiple traits, (2) examples of polygenic traits, (3) videos modeling of alternative splicing, and (4) examine environmental influences on gene expression in plants and animals. Conclude with peer reviews and written reflections on completed concept maps.

"All DNA sequences code for proteins."

Most of the human genome consists of non-coding DNA, crucial for gene regulation and cellular functions. Non-coding RNAs like tRNA and rRNA play key roles in cells but aren't translated into proteins.

**How to address this misconception**

Non-coding DNA is key for gene regulation and chromosome stability, controlling gene expression timing and protein production for proper cell function. When practicing transcription, have students color stretches of DNA to signify non-coding regions. When introducing tRNA and rRNA, stress that these are RNA that never become a protein. Note: *Scientists are actively researching the unknown functions of most non-coding DNA.*

"Specialized cells are different because they have different sets of genes."

All cells in a multicellular organism (except, for example, sex and red blood cells), have the same DNA and genes; cell diversity arises from differential gene expression, where specific genes are activated or deactivated based on cell type, regulated by transcription factors and epigenetic modifications.

**How to address this misconception**

Students can use colored stickers on cell diagrams to represent active and inactive genes, showing gene expression variation in different cells. Discuss how stem cell differentiation and tissue engineering demonstrate diverse cell functions from identical genes, highlighting real-world applications like regenerative medicine that depend on this gene regulation understanding.

"DNA technologies are solely for genetic manipulation."

DNA technologies have a broad range of applications beyond bringing extinct species back to life.

**How to address this misconception**

Have students explore different aspects of DNA technologies by creating mini TedTalks. Encourage them to investigate both the scientific principles and the broader applications, including medical diagnostics, forensic analysis, evolutionary studies, conservation, tracing evolutionary paths, and studying ecological interactions. As a class dive, into the role of DNA technology in social justice through the Innocence Project. Check out the documentary, “Human Nature.”
CLASSROOM ACTIVITIES
Modeling the central dogma
In this activity, students will model DNA replication, transcription, and translation using index cards to represent nitrogenous bases.

**Materials:** ~25 index cards per student (if not available, have students cut printer paper to create cards), rubber band or plastic bag for each student, 1 piece of colored paper, marker, codon chart for translation.

- **Set up:** Have students create three arrow cutouts labeled: DNA, RNA, protein on the colored construction paper. Next, students label individual cards with A, T, G, C, U until they run out of cards.
- **Overview:** Students will be modeling DNA replication, transcription, and translation using index cards to represent nitrogenous bases. Prior to and following each round of modeling, review the key concepts and locations of each process.

- **Replication:** Start by writing a 6-base DNA sequence vertically on the board and have each student recreate the sequence on their desk, with the first base should be placed at the top of their desk and the last base at the bottom of their desk. Have students place the DNA arrow pointing at this sequence. Next, have students follow DNA-base pairing rules to make the single-strand, double-stranded by placing the corresponding base-pair next to the base of the template strand. To replicate, have students say, "helicase!" and push the cards apart from each other and then say, "DNA polymerase add!" as they add corresponding bases to each strand to make two double stranded molecules of DNA. Have students check for mutations in their replication and fix them accordingly. You can have students push desks together and work in pairs to create their own original extra long template strand and complete the full replication process together.

- **Transcription:** Begin by writing a 6-base DNA sequence vertically on the board and have each student recreate the sequence on their desk. Have students place the DNA arrow pointing at this sequence. Next, have students place the RNA arrow to the right of the DNA strand. Following the RNA base-pairing rules, have students create a single strand of RNA.

- **Translation:** Continuing off the transcription set-up above, have students place the arrow labeled protein to the right of the RNA arrow and use a codon chart to translate the RNA into an amino acid sequence. Students can write the amino acid on an index card or a half-sheet of paper and place it under the protein arrow and adjacent to the RNA sequence.

- **Mutations:** After completing any of the above, using the same original sequence have students intentionally swap out one of their correctly paired bases for a mispairing, inciting a mutation. Have students complete the DNA → RNA → protein process and reflection on the effect of the mutation.
VIP- Very Important Protein
Uncover the crucial role of proteins! Students will research and debate the importance of various proteins by writing and presenting claim, evidence, reasoning (CER) statements. Students will defend their choices and engage in critical discussions, connecting to concepts of protein functions and their applications.

☐ **Part 1: Writing claim, evidence, reasoning.** Pose the question, "Which protein is the most important protein? The VIP of proteins." Have students do a quick search to narrow down which protein they believe to be the most important based on its function in the human body, its role in the ecosystem, or its use in medicine or industry. Have students write a clear CER statement defending their choice. Students should use paper or a slide to present their argument with supporting images.

☐ **Part 2: Present and defend.** Have students present their CER to the class, clearly articulating why they believe their chosen protein is the VIP of proteins. Allow classmates to ask clarification questions. After all presentations, facilitate a class discussion to explore different perspectives and the vital roles of proteins in biology.

**Molecular technology timeline**
Have students journey through history and advancements in understanding DNA. Students will explore the pivotal milestones in molecular technologies and the transformative effects on science and our society.

☐ Have students research and create a comprehensive timeline (digital or paper-based) highlighting the historical development and key breakthroughs in molecular technologies such as PCR, gel electrophoresis, and genetic engineering. Students can include the discovery of DNA's structure, the development of PCR techniques, the first uses of gel electrophoresis, and the advent of CRISPR-Cas9 gene editing. Encourage students to include significant scientific figures, pivotal experiments, and the introduction of these technologies into practical applications.

**Extension:** Have students create questions they would pose to the scientists highlighted in their timelines.

**PRO TIPS**

**Frequent Formative and Summative Assessment**
This unit contains substantial content and new vocabulary. To monitor student understanding, regularly use formative assessments like bell ringers and exit tickets after each lesson. Consider mini-summative quizzes after grouped lessons, such as lessons 1-2 and 3-4, followed by a comprehensive test covering lessons 1-5. Adjust the grouping of lessons or the timing of assessments based on what works best for your students' learning needs. This approach helps in tracking progress and reinforces learning at manageable intervals.

**GENERAL CLASSROOM IMPLEMENTATION RESOURCES:**

- [Weekly Khan Academy Quick Planning Guide](#): Use this template to easily plan your week using Khan Academy.
- [Student Learning Templates](#): Choose a template for students to record their learning. There are templates for watching videos, reading articles, and doing exercises.
- [Using Khan Academy in the Classroom](#): Learn about teaching strategies and structures to support your students in their learning with Khan Academy.
- [Differentiation Strategies for the Classroom](#): Strategies to support the learning of all students.