AP BIOLOGY

UNIT 6

Gene Expression and Regulation

12–16%
AP EXAM WEIGHTING

~18–20
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Progress Checks** for this unit.

Whether assigned as homework or completed in class, the **Progress Checks** provide each student with immediate feedback related to this unit's topic and skills.

Progress Check 6

Multiple-choice: ~25 questions
Free-response: 2 questions

- Interpreting and Evaluating Experimental Results
- Analyze Model or Visual Representation

UNIT 6

12–16% AP EXAM WEIGHTING | **~18–20** CLASS PERIODS

Gene Expression and Regulation

BIG IDEA 3
Information Storage and Transmission

- How does gene regulation relate to the continuity of life?
- How is the genetic information of a species diversified from generation to generation?

Developing Understanding

Progressing from the continuity of life to gene expression, students gain in-depth knowledge about nucleic acids and their role in gene expression in this unit. There is also a finer focus on the comparison between the structures of DNA and RNA. This unit highlights how an individual's genotype is physically expressed through their phenotype, thus emphasizing the importance of protein synthesis (transcription and translation) in gene expression. Regulation of gene expression and cell specialization are instrumental in ensuring survival within an individual and across populations. Unit 7 moves on to cover natural selection.

Building Science Practices

1.C 2.B 2.C 2.D 6.A 6.B 6.D 6.E

The ability to describe, analyze, and create models and representations to explain or illustrate biological processes and make predictions about them is an important skill for students to grasp. The primary learning goal in this unit is to create or use a representation or model to communicate biological phenomena, use the model to solve a problem, and refine the model to analyze situations or solve problems.

Throughout the course, students should be given multiple opportunities to make a claim, support it with evidence, and provide reasoning to support the claim. In this unit and throughout the course, students should become proficient in argumentation by predicting the causes or effects of a change in, or disruption to, one or more components in a biological system.

Preparing for the AP Exam

Students often do not understand the difference between a gene and an allele. Gene expression occurs at many levels, all of which are crucial in producing an organism's phenotype. Students can use the lac operon in *E. coli* to help them understand the significance of positive gene regulation.

Often on the exam, students fail to provide reasoning when connecting a change on the molecular level (e.g., a mutation) to a change in phenotype (e.g., an increase or decrease in protein levels). Students should understand that the location of a mutation in the codon could affect the structure and function of a protein. Common errors include stating that mutations result in the denaturation of a protein or that point mutations cause frameshift mutations. Students also tend to describe all mutations as having negative effects; exposure to examples of mutations that have no impact on phenotype can help prevent this misunderstanding.

UNIT AT A GLANCE

Topic	Suggested Skills	Class Periods ~18–20 CLASS PERIODS
6.1 DNA and RNA Structure	1.C Explain biological concepts and processes in applied contexts.	
6.2 DNA Replication	2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.	
6.3 Transcription and RNA Processing	2.B Explain relationships between characteristics of biological models in both theoretical and applied contexts.	
6.4 Translation	2.D Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.E Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.	
6.5 Regulation of Gene Expression	6.A Make a scientific claim.	
6.6 Gene Expression and Cell Specialization	6.B Support a claim with evidence from biological principles, concepts, processes, and data.	
6.7 Mutations	2.C Explain how biological models relate to larger principles, concepts, processes, systems, or theories.	
6.8 Biotechnology	6.D Explain the relationship between experimental results and larger biological concepts, processes, or theories.	
Go to **AP Classroom** to assign the **Progress Check** for Unit 6. Review the results in class to identify and address any student misunderstandings.		

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or instructional approaches and are encouraged to adapt the activities to best support students in your classroom. The following examples were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 171 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	6.2	**Misconception Check** Distribute diagrams of nucleotides (which can be found on the internet and photocopied), and ask students to model the process of replication, explaining what is happening as they go. Circulate around the room as they're working and observe the results of replication that students produce. Correct any misunderstandings when you see them.
2	6.3	**Think-Pair-Share** Have students build a model of transcription using pool noodles (which can usually be purchased at a dollar store). Instruct pairs of students to use everyday materials, such as tape, colored paper, yarn (or string), and markers to identify the promoter region, TATA box, transcription start site, and terminal sequence. They should describe the process of transcription from the initial binding of the transcription factors to the production of the transcript. At the end of class, invite one student from each pair to share their model with the whole class.
3	6.4	**Construct an Argument** Ask students to develop a skit to demonstrate the process of translation. Once they have an understanding of the process, challenge them to act out what might happen if there were a change in the DNA sequence or if one of the needed components was unavailable. Debrief by having students explain the rationale for the modifications they made in their skit.

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts and processes in applied contexts.

AVAILABLE RESOURCES

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective
- AP Central > Classroom Resources > Rosalind Franklin: She's Worth Another Look

TOPIC 6.1
DNA and RNA Structure

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.1.A Describe the structures involved in passing hereditary information from one generation to the next.	**6.1.A.1** Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules. i. Prokaryotic organisms typically have circular chromosomes. ii. Eukaryotic organisms typically have multiple linear chromosomes that are comprised of DNA. These chromosomes are condensed using histones and associated proteins. **6.1.A.2** Prokaryotes and eukaryotes can contain plasmids, which are extra-chromosomal circular molecules of DNA.
6.1.B Describe the characteristics of DNA that allow it to be used as hereditary material.	**6.1.B.1** Nucleic acids exhibit specific nucleotide base pairing that is conserved through evolution. i. Purines (guanine and adenine) have a double ring structure. ii. Pyrimidines (cytosine, thymine, and uracil) have a single ring structure. iii. Purines pair with pyrimidines: adenine with thymine (or uracil in RNA) and guanine with cytosine.

TOPIC 6.2
DNA Replication

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.2.A

Describe the mechanisms by which genetic information is copied for transmission between generations.

ESSENTIAL KNOWLEDGE

6.2.A.1

DNA replication ensures continuity of hereditary information.

i. DNA is synthesized in the 5′ to 3′ direction.

ii. Replication is a semiconservative process, meaning one strand of DNA serves as the template for a new strand of complementary DNA.

iii. Helicase unwinds the DNA strands.

iv. Topoisomerase relaxes supercoiling in front of the replication fork.

v. DNA polymerase requires RNA primers to initiate DNA synthesis.

vi. DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand.

vii. Ligase joins the fragments on the lagging strand.

EXCLUSION STATEMENT—*The names of the steps and particular enzymes involved, excluding DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase, are beyond the scope of the AP Exam.*

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between characteristics of biological models in both theoretical and applied contexts.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein – A Historical Perspective

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between characteristics of biological models in both theoretical and applied contexts.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

TOPIC 6.3
Transcription and RNA Processing

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.3.A

Describe the mechanisms by which genetic information flows from DNA to RNA to protein.

ESSENTIAL KNOWLEDGE

6.3.A.1

The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.

i. Messenger RNA (mRNA) molecules carry information from DNA in the nucleus to the ribosome in the cytoplasm.

ii. Distinct transfer RNA (tRNA) molecules bind specific amino acids and have anticodon sequences that base pair with the codons of mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.

iii. Ribosomal RNA (rRNA) molecules are functional building blocks of ribosomes.

6.3.A.2

RNA polymerases use a single template strand of DNA to direct the inclusion of bases in the newly formed RNA molecule. This process is known as transcription.

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LEARNING OBJECTIVE

6.3.A

Describe the mechanisms by which genetic information flows from DNA to RNA to protein.

ESSENTIAL KNOWLEDGE

6.3.A.3

The enzyme RNA polymerase synthesizes mRNA molecules in the 5′ to 3′ direction by reading the template DNA strand in the 3′ to 5′ direction.

6.3.A.4

In eukaryotic cells the mRNA transcript undergoes a series of enzyme-mediated modifications.

i. The addition of a poly-A tail makes mRNA more stable.

ii. The addition of a GTP cap helps with ribosomal recognition.

iii. The excision of introns, along with the splicing and retention of exons, generates different versions of the resulting mature mRNA molecule. This process is known as alternative splicing.

SUGGESTED SKILLS

Visual Representations

2.D

Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Argumentation

6.E

Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

TOPIC 6.4
Translation

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.4.A

Explain how the phenotype of an organism is determined by its genotype.

ESSENTIAL KNOWLEDGE

6.4.A.1

Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells, as well as the cytoplasmic surface of the rough ER of eukaryotic cells.

6.4.A.2

In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.

6.4.A.3

Translation involves many sequential steps, including initiation, elongation, and termination. The salient features of translation include:

i. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine).

ii. The sequence of nucleotides on the mRNA is read in triplets, called codons.

iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.

iv. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms.

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LEARNING OBJECTIVE

6.4.A

Explain how the phenotype of an organism is determined by its genotype.

ESSENTIAL KNOWLEDGE

v. tRNA brings the correct amino acid to the place specified by the codon on the mRNA.

vi. The amino acid is transferred to the growing polypeptide chain.

vii. The process continues along the mRNA until a stop codon is reached.

viii. Translation terminates with the release of the newly synthesized protein.

EXCLUSION STATEMENT—*The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the AP Exam.*

EXCLUSION STATEMENT—*Memorization of the genetic code, with the exception of the start codon AUG, is beyond the scope of the AP Exam.*

6.4.A.4

Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and is transcribed and translated for the assembly of new viral progeny.

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

TOPIC 6.5
Regulation of Gene Expression

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.5.A

Describe the types of interactions that regulate gene expression.

ESSENTIAL KNOWLEDGE

6.5.A.1

Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. Some genes are constitutively expressed, and others are inducible.

6.5.A.2

Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.

6.5.A.3

The phenotype of a cell or an organism is determined by the combination of genes that are expressed and the levels at which they are expressed.

i. Observable cell differentiation results from the expression of genes for tissue-specific proteins.

ii. Induction of transcription factors during development results in sequential gene expression.

iii. The function and amount of gene products determine the phenotype of organisms.

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LEARNING OBJECTIVE

6.5.B

Explain how the location of regulatory sequences relates to their function.

ESSENTIAL KNOWLEDGE

6.5.B.1

Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated.

i. Prokaryotes regulate operons in an inducible or repressible system.

ii. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

SUGGESTED SKILL

Argumentation

6.B

Support a claim with evidence from biological principles, concepts, processes, and data.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

TOPIC 6.6
Gene Expression and Cell Specialization

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.6.A Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism.	**6.6.A.1** RNA polymerase and transcription factors bind to promoter or enhancer DNA sequences to initiate transcription. These sequences can be upstream or downstream of the transcription start site. **6.6.A.2** Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.
6.6.B Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.	**6.6.B.1** Gene regulation results in differential gene expression and influences cell products and functions. **6.6.B.2** Certain small RNA molecules have roles in regulating gene expression.

TOPIC 6.7
Mutations

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.7.A

Describe the various types of mutation.

ESSENTIAL KNOWLEDGE

6.7.A.1

Alterations in a DNA sequence are mutations that can cause changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be beneficial, detrimental, or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein.

i. Point mutations occur when one nucleotide has been substituted for a different nucleotide.

ii. Frameshift mutations occur when one or more nucleotides are inserted or deleted, causing the reading frame to be shifted.

iii. Nonsense mutations occur when there is a point mutation that causes a premature stop.

iv. Silent mutations occur when the change in the nucleotide sequence has no effect on the amino acid sequence.

EXCLUSION STATEMENT—*Knowledge of specific mutations and their effects is beyond the scope of the AP Exam.*

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SUGGESTED SKILL

Visual Representations

2.C

Explain how biological models relate to larger principles, concepts, processes, systems, or theories.

AVAILABLE RESOURCE

- AP Central > Classroom Resources > From Gene to Protein—A Historical Perspective

ILLUSTRATIVE EXAMPLES

EK 6.7.A.1

- Mutations in the CFTR gene disrupt ion transport and result in cystic fibrosis.
- Mutations in the MC1R gene give adaptive melanism in pocket mice.

EK 6.7.C.1

- Sickle cell anemia

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.7.B Explain how changes in genotype may result in changes in phenotype.	**6.7.B.1** Errors in DNA replication or DNA repair mechanisms as well as external factors, including radiation and reactive chemicals, can cause random mutations in the DNA. i. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context. ii. Mutations are a source of genetic variation. **6.7.B.2** Errors in mitosis or meiosis can result in changes in phenotype. i. Changes in chromosome number resulting from nondisjunction often result in new phenotypes caused by triploidy (aneuploidy). ii. Changes in chromosome number often result in disorders with developmental limitations. iii. Alterations in chromosome structure lead to genetic disorders. **EXCLUSION STATEMENT**—*Knowledge of specific disorders related to changes in chromosome number is beyond the scope of the AP Exam.*
6.7.C Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	**6.7.C.1** Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected for by environmental conditions. i. The horizontal acquisitions of genetic information in prokaryotes via transformation (uptake of DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase genetic variation. ii. Related viruses can recombine genetic information if they infect the same host cell. iii. Reproductive processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

TOPIC 6.8
Biotechnology

Required Course Content

BIG IDEA 3

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.

LEARNING OBJECTIVE

6.8.A

Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

ESSENTIAL KNOWLEDGE

6.8.A.1

Genetic engineering techniques can be used to analyze and manipulate DNA and RNA.

i. Gel electrophoresis is a process that separates DNA fragments by size and charge.

ii. During polymerase chain reaction (PCR), DNA fragments are amplified by denaturing DNA, annealing primers to the original strand, and extending the new DNA molecule.

iii. Bacterial transformation introduces foreign DNA into bacterial cells.

iv. DNA sequencing technology determines the order of nucleotides in a DNA molecule. Typically, these techniques result in a DNA fingerprint that allows for the comparison of DNA sequences from various samples.

EXCLUSION STATEMENT—*Knowledge of the details of each of these genetic engineering techniques is beyond the scope of the AP Exam.*

SUGGESTED SKILL

Argumentation

6.D

Explain the relationship between experimental results and larger biological concepts, processes, or theories.

AVAILABLE RESOURCES

- AP Central > AP Biology Lab Manual > Gel Electrophoresis Lab
- AP Central > AP Biology Lab Manual > Transformation Lab
- AP Central > Classroom Resources > Visualizing Information

ILLUSTRATIVE EXAMPLES

EK 6.8.A.1

- Amplified DNA fragments can be used to identify organisms and perform phylogenetic analysis.
- Analysis of DNA can be used for forensic identification.
- Genetically modified organisms include transgenic animals.
- Gene cloning allows propagation of DNA fragments.