AP BIOLOGY

UNIT 6

Gene Expression and Regulation

12–16%
AP EXAM WEIGHTING

~18–21
CLASS PERIODS

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

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

Personal 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 | ~18–21 CLASS PERIODS

Gene Expression and Regulation

BIG IDEA 3
Information Storage and Transmission IST

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

Developing Understanding

Progressing from the continuity of life to gene expression, in Unit 6 students gain in-depth knowledge about nucleic acids and their role in gene expression. Students receive 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 that individual's phenotype. Understanding protein synthesis (transcription and translation) is vital to answering essential questions about 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.b 2.C 6.A 6.B 6.D 6.E.a

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

Throughout the course, students should have had multiple opportunities that involve making a claim, supporting it with evidence, and providing 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 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 can 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

Enduring Understanding	Topic	Suggested Skill	Class Periods ~18–21 CLASS PERIODS
IST-1	**6.1 DNA and RNA Structure**	1.C Explain biological concepts, processes, and/or models in applied contexts.	
	6.2 Replication	2.B.b Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.	
	6.3 Transcription and RNA Processing	2.B.b Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.	
	6.4 Translation	2.D.b Represent relationships within biological models, including diagrams. 6.E.a Predict the causes or effects of a change in, or disruption to, one or more components in a biological system based on biological concepts.	
IST-2	**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/or data.	
IST-2, IST-4	**6.7 Mutations**	2.C Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories. 3.D Make observations or collect data from representations of laboratory setups or results.	
IST-1	**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 **Personal 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 intended to give you ideas of ways to incorporate varied instructional approaches in the teaching of this course. You do not need to use these activities or approaches and are free to alter or edit them in any way you choose. 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** Using diagrams of nucleotides that can be found on the internet and photocopied, students can model the process of replication, explaining what is happening as they go. You can easily assess their understanding by observing the results of replication that students produce.
2	6.3	**Think-Pair-Share** Students build a model of transcription using pool noodles that can be purchased at a dollar store. Using everyday materials, such as tape, colored paper, yarn (or string), and markers, they identify the promoter region, TATA box, transcription start site, and terminal sequence. They describe the process of transcription from the initial binding of the transcription factors to the production of the transcript. This can be introduced or de-briefed using a Think-Pair-Share approach.
3	6.4	**Construct an Argument** Students 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.

Unit Planning Notes

Use the space below to plan your approach to the unit. Consider how you want to pace your course and your methods of instruction and assessment.

SUGGESTED SKILL

Concept Explanation

1.C

Explain biological concepts, processes, and/or models in applied contexts.

AVAILABLE RESOURCES

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

TOPIC 6.1
DNA and RNA Structure

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-1.K Describe the structures involved in passing hereditary information from one generation to the next.	**IST-1.K.1** DNA, and in some cases RNA, is the primary source of heritable information. **IST-1.K.2** Genetic information is transmitted from one generation to the next through DNA or RNA— a. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules. b. Prokaryotic organisms typically have circular chromosomes, while eukaryotic organisms typically have multiple linear chromosomes. **IST-1.K.3** Prokaryotes and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded, circular DNA molecules.
IST-1.L Describe the characteristics of DNA that allow it to be used as the hereditary material.	**IST-1.L.1** DNA, and sometimes RNA, exhibits specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G)— a. Purines (G and A) have a double ring structure. b. Pyrimidines (C, T, and U) have a single ring structure.

TOPIC 6.2
Replication

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.M

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

ESSENTIAL KNOWLEDGE

IST-1.M.1

DNA replication ensures continuity of hereditary information—

a. DNA is synthesized in the 5′ to 3′ direction.
b. Replication is a semiconservative process—that is, one strand of DNA serves as the template for a new strand of complementary DNA.
c. Helicase unwinds the DNA strands.
d. Topoisomerase relaxes supercoiling in front of the replication fork.
e. DNA polymerase requires RNA primers to initiate DNA synthesis.
f. DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand.
g. Ligase joins the fragments on the lagging strand.

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

SUGGESTED SKILL

Visual Representations

2.B.b

Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.

AVAILABLE RESOURCES

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

SUGGESTED SKILL

Visual Representations

2.B.b

Explain relationships between different characteristics of biological concepts, processes, or models represented visually in applied contexts.

AVAILABLE RESOURCES

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

TOPIC 6.3
Transcription and RNA Processing

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.N

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

ESSENTIAL KNOWLEDGE

IST-1.N.1

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

a. mRNA molecules carry information from DNA to the ribosome.
b. Distinct tRNA molecules bind specific amino acids and have anti-codon sequences that base pair with the mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.
c. rRNA molecules are functional building blocks of ribosomes.

IST-1.N.2

Genetic information flows from a sequence of nucleotides in DNA to a sequence of bases in an mRNA molecule to a sequence of amino acids in a protein.

IST-1.N.3

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

IST-1.N

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

ESSENTIAL KNOWLEDGE

IST-1.N.4

The DNA strand acting as the template strand is also referred to as the noncoding strand, minus strand, or antisense strand. Selection of which DNA strand serves as the template strand depends on the gene being transcribed.

IST-1.N.5

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.

IST-1.N.6

In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications—

a. Addition of a poly-A tail.
b. Addition of a GTP cap.
c. Excision of introns and splicing and retention of exons.
d. Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing.

SUGGESTED SKILLS

Argumentation

6.E.a

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

Visual Representations

2.D.b

Represent relationships within biological models, including diagrams.

AVAILABLE RESOURCES

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

TOPIC 6.4
Translation

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.0

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

ESSENTIAL KNOWLEDGE

IST-1.0.1

Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells and on the rough endoplasmic reticulum of eukaryotic cells.

IST-1.0.2

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

IST-1.0.3

Translation involves energy and many sequential steps, including initiation, elongation, and termination.

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

IST-1.0.4

The salient features of translation include—

a. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon.

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

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LEARNING OBJECTIVE

IST-1.0

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

ESSENTIAL KNOWLEDGE

c. 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.

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

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

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

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

h. The process terminates by release of the newly synthesized polypeptide/protein.

EXCLUSION STATEMENT—*Memorization of the genetic code is beyond the scope of the course and the AP Exam.*

IST-1.0.5

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 becomes transcribed and translated for the assembly of new viral progeny.

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

SUGGESTED SKILL

Argumentation

6.A

Make a scientific claim.

AVAILABLE RESOURCES

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

TOPIC 6.5
Regulation of Gene Expression

Required Course Content

ENDURING UNDERSTANDING

IST-2

Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-2.A Describe the types of interactions that regulate gene expression.	**IST-2.A.1** Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. **IST-2.A.2** Epigenetic changes can affect gene expression through reversible modifications of DNA or histones. **IST-2.A.3** The phenotype of a cell or organism is determined by the combination of genes that are expressed and the levels at which they are expressed— a. Observable cell differentiation results from the expression of genes for tissue-specific proteins. b. Induction of transcription factors during development results in sequential gene expression.
IST-2.B Explain how the location of regulatory sequences relates to their function.	**IST-2.B.1** Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated— a. In prokaryotes, groups of genes called operons are transcribed in a single mRNA molecule. The *lac* operon is an example of an inducible system. b. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.

TOPIC 6.6
Gene Expression and Cell Specialization

Required Course Content

ENDURING UNDERSTANDING

IST-2

Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE

IST-2.C

Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism.

ESSENTIAL KNOWLEDGE

IST-2.C.1

Promoters are DNA sequences upstream of the transcription start site where RNA polymerase and transcription factors bind to initiate transcription.

IST-2.C.2

Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.

LEARNING OBJECTIVE

IST-2.D

Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.

ESSENTIAL KNOWLEDGE

IST-2.D.1

Gene regulation results in differential gene expression and influences cell products and function.

IST-2.D.2

Certain small RNA molecules have roles in regulating gene expression.

SUGGESTED SKILL

Argumentation

6.B

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

AVAILABLE RESOURCES

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

SUGGESTED SKILLS

Visual Representations

2.C

Explain how biological concepts or processes represented visually relate to larger biological principles, concepts, processes, or theories.

Questions and Methods

3.D

Make observations or collect data from representations of laboratory setups or results.

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

IST-2.E.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.

IST-4.B.1

- Antibiotic resistance mutations
- Pesticide resistance mutations
- Sickle cell disorder and heterozygote advantage

TOPIC 6.7
Mutations

Required Course Content

ENDURING UNDERSTANDING

IST-2

Differences in the expression of genes account for some of the phenotypic differences between organisms.

LEARNING OBJECTIVE

IST-2.E

Describe the various types of mutation.

ESSENTIAL KNOWLEDGE

IST-2.E.1

Changes in genotype can result in changes in phenotype—

a. The function and amount of gene products determine the phenotype of organisms.
   i. The normal function of the genes and gene products collectively comprises the normal function of organisms.
   ii. Disruptions in genes and gene products cause new phenotypes.

IST-2.E.2

Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be positive, negative, 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.

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ENDURING UNDERSTANDING

IST-4

The processing of genetic information is imperfect and is a source of genetic variation.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
IST-4.A Explain how changes in genotype may result in changes in phenotype.	**IST-4.A.1** Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random mutations in the DNA— a. Whether a mutation is detrimental, beneficial, or neutral depends on the environmental context. b. Mutations are the primary source of genetic variation. **IST-4.A.2** Errors in mitosis or meiosis can result in changes in phenotype— a. Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy, and increased vigor of other polyploids. b. Changes in chromosome number often result in human disorders with developmental limitations, including Down syndrome/ Trisomy 21 and Turner syndrome.
IST-4.B Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	**IST-4.B.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— a. The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked 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 variation. b. Related viruses can combine/recombine genetic information if they infect the same host cell. c. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

SUGGESTED SKILL

Argumentation

6.D

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

AVAILABLE RESOURCES

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

ILLUSTRATIVE EXAMPLES

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

TOPIC 6.8
Biotechnology

Required Course Content

ENDURING UNDERSTANDING

IST-1

Heritable information provides for continuity of life.

LEARNING OBJECTIVE

IST-1.P

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

ESSENTIAL KNOWLEDGE

IST-1.P.1

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

a. Electrophoresis separates molecules according to size and charge.
b. During polymerase chain reaction (PCR), DNA fragments are amplified.
c. Bacterial transformation introduces DNA into bacterial cells.
d. DNA sequencing determines the order of nucleotides in a DNA molecule.

X EXCLUSION STATEMENT—*The details of these processes are beyond the scope of this course. The focus should be on the conceptual understanding of the application of these techniques.*