Unit 07: Gene Expression and Regulation

Content Area: **Science**
Course(s): **AP Biology**
Time Period: **February**
Length: **6 weeks**
Status: **Published**

Transfer Skills

Progressing from the continuity of life to gene expression, in this unit 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 8 moves on to cover natural selection.

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.

Enduring Understandings

Heritable information provides for continuity of life.

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

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

Essential Questions

How does gene regulation relate to the continuity of life?

How is a species' genetic information diversified from generation to generation?

Content

DNA structure and function

DNA replication

PCR and DNA sequencing

Gene expression (transcription RNA processing, translation)

Point mutations (substitution and frameshifts)

Chromosomal mutations during mitosis or meiosis (non-disjunction, polyploidy)

Prokaryotic gene regulation (operons)

Eukaryotic gene regulation (transcription factors, epigenetics, alternative splicing, miRNA)

Genetics of viruses (lytic vs. lysogenic, retroviruses)

Restriction enzymes, gel electrophoresis and DNA fingerprinting

Bacterial transformation and screening for transformants

Learning Objectives

IST-1.K Describe the structures involved in passing hereditary information from one generation to the next.
IST-1.L Describe the characteristics of DNA that allow it to be used as the hereditary material.
IST-1.M Describe the mechanisms by which genetic information is copied for transmission between generations.
IST-1.N Describe the mechanisms by which genetic information flows from DNA to RNA to protein.
IST-1.O Describe how the phenotype of an organism is determined by its genotype.
IST-2.A Describe the types of interactions that regulate gene expression.
IST-2.B Explain how the location of regulatory sequences relates to their function.
IST-2.C Explain how the binding of transcription factors to promoter regions affects gene expression and/or the phenotype of the organism.
IST-2.D Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.
IST-2.E Describe the various types of mutation
IST-4.A Explain how changes in genotype may result in changes in phenotype
IST-4.B Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.
IST-1.P Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

Standards

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.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.
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.
X *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.*
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.
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.
IST-1.O.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.O.2 In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.
IST-1.O.3 Translation involves energy and many sequential steps, including initiation, elongation, and termination.

X *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.O.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.
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.

X *Memorization of the genetic code is beyond the scope of the course and the AP Exam.*

IST-1.O.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.

X *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.*

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 tissuespecific proteins.
b. Induction of transcription factors during development results in sequential gene expression.

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.

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.
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.
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.
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.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 in prokaryotes primarily via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), and conjugation (cell-to-cell transfer of DNA) 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.
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 fragements are amplified.
c. Bacterial transformation introduces DNA into bacterial cells.
d. DNA sequencing determines the order of nucleotides in a DNA molecule.

X *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.*

Resources

College Board AP Central: https://apcentral.collegeboard.org/courses/ap-biology/course

College Board AP Biology course and exam description manual: https://apcentral.collegeboard.org/pdf/ap-biology-course-and-exam-description-0.pdf

AP Biology Lab Manual:

https://apcentral.collegeboard.org/pdf/ap-biology-teacher-lab-manual-fall-2019.pdf?course=ap-biology

AP Biology Classroom Resources: https://apcentral.collegeboard.org/courses/ap-biology/classroom-resources?course=ap-biology

Khan Academy AP Biology: https://www.khanacademy.org/science/ap-biology

Bozeman Science AP Biology videos: http://www.bozemanscience.com/ap-biology

HHMI Biointeractive: https://www.biointeractive.org/