**Unit 5: Molecular Genetics Unit Guide HSPVA AP Biology**

**5.1:DNA, and in some cases RNA, is the primary source of heritable information.**

a. Genetic information is transmitted from one generation to the next through DNA or RNA.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.

2. Non eukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.

3. Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules.

4. The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include:

i. Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA

ii. Avery-MacLeod-McCarty experiments

iii. Hershey-Chase experiment

5. DNA replication ensures continuity of hereditary information.

i. Replication is a semiconservative process; that is, one strand serves as the template for a new, complementary strand.

ii. Replication requires DNA polymerase plus many other essential cellular enzymes, occurs bidirectionally, and differs in the production of the leading and lagging strands.

6. 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. [See also **3.C.3**]

b. DNA and RNA molecules have structural similarities and differences that define function. [See also **4.A.1**]

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Both have three components — sugar, phosphate and a nitrogenous base — which form nucleotide units that are connected by covalent bonds to form a linear molecule with 3' and 5' ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.

2. The basic structural differences include:

i. DNA contains deoxyribose (RNA contains ribose).

ii. RNA contains uracil in lieu of thymine in DNA.

iii. DNA is usually double stranded, RNA is usually single stranded.

iv. The two DNA strands in double-stranded DNA are antiparallel in directionality.

3. Both DNA and RNA exhibit 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).

i. Purines (G and A) have a double ring structure.

ii. Pyrimidines (C, T and U) have a single ring structure.

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

i. mRNA carries information from the DNA to the ribosome.

ii. tRNA molecules bind specific amino acids and allow information in the mRNA to be translated to a linear peptide sequence.

iii. rRNA molecules are functional building blocks of ribosomes.

iv. The role of RNAi includes regulation of gene expression at the level of mRNA transcription.

c. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. The enzyme RNA-polymerase reads the DNA molecule in the 3' to 5' direction and synthesizes complementary mRNA molecules that determine the order of amino acids in the polypeptide.

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

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Addition of a poly-A tail
* Addition of a GTP cap
* Excision of introns

3. Translation of the mRNA occurs in the cytoplasm on the ribosome.

4. In prokaryotic organisms, transcription is coupled to translation of the message.

5. Translation involves energy and many steps, including initiation, elongation and termination. The salient features include:

i. The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon.

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 have more than one codon.

iv. tRNA brings the correct amino acid to the correct place on the mRNA.

v. The amino acid is transferred to the growing peptide chain.

vi. The process continues along the mRNA until a “stop” codon is reached.

vii. The process terminates by release of the newly synthesized peptide/protein.

d. Phenotypes are determined through protein activities.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Enzymatic reactions
* Transport by proteins
* Synthesis
* Degradation

e. Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Electrophoresis
* Plasmid-based transformation
* Restriction enzyme analysis of DNA
* Polymerase Chain Reaction (PCR)

f. *Illustrative examples of products of genetic engineering include:*

* Genetically modified foods
* Transgenic animals
* Cloned animals
* Pharmaceuticals, such as human insulin or factor X

**LO 3.1** The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, that RNA are the primary sources of heritable information. [See **SP 6.5**]

**LO 3.2** The student is able to justify the selection of data from historical investigations that support the claim that DNA is the source of heritable information. [See **SP 4.1**]

**LO 3.3** The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations. [See **SP 1.2**]

**LO 3.4** The student is able to describe representations and models illustrating how genetic information is translated into polypeptides. [See **SP 1.2**]

**LO 3.5** The student can justify the claim that humans can manipulate heritable information by identifying *at least two* commonly used technologies. [See **SP 6.4**]

**LO 3.6** The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression. [See **SP 6.4**]

**5.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.**

a. Signal transmission within and between cells mediates gene expression.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Cytokines regulate gene expression to allow for cell replication and division.
* Mating pheromones in yeast trigger mating gene expression.
* Levels of cAMP regulate metabolic gene expression in bacteria.
* Expression of the SRY gene triggers the male sexual development pathway in animals.
* Ethylene levels cause changes in the production of different enzymes, allowing fruits to ripen.
* Seed germination and gibberellin.

b. Signal transmission within and between cells mediates cell function.

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Mating pheromones in yeast trigger mating genes expression and sexual reproduction.
* Morphogens stimulate cell differentiation and development.
* Changes in p53 activity can result in cancer.
* HOX genes and their role in development.

**LO 3.22** The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production. [See **SP 6.2**]

**LO 3.23** The student can use representations to describe mechanisms of the regulation of gene expression. [See **SP 1.4**]

**5.3: Changes in genotype can result in changes in phenotype.**

a. Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype. [See also **3.A.1**]

*Evidence of student learning is a demonstrated understanding of the following:*

1. 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.

b. Errors in DNA replication or DNA repair mechanisms, and external factors, including radiation and reactive chemicals, can cause random changes, e.g., mutations in the DNA.

*Evidence of student learning is a demonstrated understanding of the following:*

1. Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context. Mutations are the primary source of genetic variation.

d. Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions. [See also **1.A.2, 1.C.3**]

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

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

*Evidence of student learning is a demonstrated understanding of the following:*

1. Selection results in evolutionary change.

**LO 3.24** The student is able to predict how a change in genotype, when expressed as a phenotype, provides a variation that can be subject to natural selection. [See **SP 6.4, 7.2**]

**LO 3.25** The student can create a visual representation to illustrate how changes in a DNA nucleotide sequence can result in a change in the polypeptide produced. [See **SP 1.1**]

**LO 3.26** The student is able to explain the connection between genetic variations in organisms and phenotypic variations in populations. [See **SP 7.2**]

**5.4: Biological systems have multiple processes that increase genetic variation.**

a. The imperfect nature of DNA replication and repair increases variation.

b. 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) and transposition (movement of DNA segments within and between DNA molecules) increase variation. [See also 1.B.3]

**LO 3.27** The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains. [See **SP 7.2**]

**LO 3.28** The student is able to construct an explanation of the multiple processes that increase variation within a population. [See **SP 6.2**]

**5.5: Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.**

a. Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms. [See also **1.B.3**]

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Viruses have highly efficient replicative capabilities that allow for rapid evolution and acquisition of new phenotypes.

2. Viruses replicate via a component assembly model allowing one virus to produce many progeny simultaneously via the lytic cycle.

3. Virus replication allows for mutations to occur through usual host pathways.

4. RNA viruses lack replication error-checking mechanisms, and thus have higher rates of mutation.

5. Related viruses can combine/recombine information if they infect the same host cell.

6. HIV is a well-studied system where the rapid evolution of a virus within the host contributes to the pathogenicity of viral infection.

b. The reproductive cycles of viruses facilitate transfer of genetic information.

*Evidence of student learning is a demonstrated understanding of each of the following:*

1. Viruses transmit DNA or RNA when they infect a host cell. [See also **1.B.3**]

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Transduction in bacteria
* Transposons present in incoming DNA

2. Some viruses are able to integrate into the host DNA and establish a latent (lysogenic) infection. These latent viral genomes can result in new properties for the host such as increased pathogenicity in bacteria.

**LO 3.29** The student is able to construct an explanation of how viruses introduce genetic variation in host organisms. [See **SP 6.2**]

**LO 3.30** The student is able to use representations and appropriate models to describe how viral replication introduces genetic variation in the viral population. [See **SP 1.4**]

**5.6: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.**

a. Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA. [See also **3.B.1, 3. B.2**]

b. Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type. [See also **3.B.1, 3.B.2**]

c. Environmental stimuli can affect gene expression in a mature cell. [See also **3.B.1, 3.B.2**]

**LO 4.7** The student is able to refine representations to illustrate how interactions between external stimuli and gene expression result in specialization of cells, tissues and organs. [See **SP 1.3**]

**5.7: Variation in molecular units provides cells with a wider range of functions.**

a. Variations within molecular classes provide cells and organisms with a wider range of functions. [See also **2.B.1**, **3.A.1**, **4.A.1**, **4.A.2**]

*To foster student understanding of this concept, instructors can choose an illustrative example such as:*

* Different types of phospholipids in cell membranes
* Different types of hemoglobin
* MHC proteins
* Chlorophylls
* Molecular diversity of antibodies in response to an antigen

**LO 4.22** The student is able to construct explanations based on evidence of how variation in molecular units provides cells with a wider range of functions. [See **SP 6.2**]

Untested:

✘ *The names of the steps and particular enzymes involved in DNA replication, beyond DNA polymerase, ligase, RNA polymerase, helicase and topoisomerase, are outside the scope of the course for the purposes of the AP Exam.*

✘ *The details and names of the enzymes and factors involved in protein synthesis of these steps are beyond the scope of the course and the AP® Exam.*

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