Enduring understanding 3.A: Heritable information provides for continuity of life.

Essential knowledge 3.A.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. Noneukaryotic 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.

b. DNA and RNA molecules have structural similarities and differences that define function.

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 demonstrate student understanding of this concept, make sure you can explain:
   i. Addition of a poly-A tail
   ii. Addition of a GTP cap
   iii. 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. 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 demonstrate student understanding of this concept, make sure you can explain:

- Enzymatic reactions
- Transport by proteins
- Synthesis
- Degradation

Student Objectives:

- Explain how contributions from each of the following scientists led to an understanding of DNA structure and function:
  - Griffith
  - Avery McCarty & McLeod
  - Hershey & Chase
  - Erwin Chargaff
  - Watson, Crick, Franklin, & Wilkins

- Diagram a molecule of DNA and explain how its features allow for both heredity and protein synthesis.
- Explain how RNA and DNA differ in structure and function.
- Explain the role of mRNA, tRNA and rRNA in protein synthesis.
- Explain the relationship between DNA, RNA, Protein, Cells and the Organism.
- Explain the evidence that demonstrates the relationship between phenotype and protein activity.
- Diagram the process of DNA replication. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes.
- Diagram the process of transcription. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes.
- Diagram the process of translation. Discuss all inputs, processes, and outputs. Explain the roles of all pertinent enzymes, the ribosome, and relevant RNA molecules.
- Compare replication, transcription, and translation among prokaryotes and eukaryotes. Explain the functions of all differences.

Learning Objectives:

- 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.
- 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.
- The student is able to describe representations and models that illustrate how genetic information is copied for transmission between generations.
- The student is able to describe representations and models illustrating how genetic information is translated into polypeptides.
- The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.


Essential knowledge 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.

- Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression.

Evidence of student learning is a demonstrated understanding of each of the following:
1. Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.  
  To demonstrate student understanding of this concept, make sure you can explain:  
  i. Promoters  
  ii. Terminators  
  iii. Enhancers  

2. A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA.  

b. Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.  
Evidence of student learning is a demonstrated understanding of each of the following:  
1. The expression of specific genes can be turned on by the presence of an inducer.  
2. The expression of specific genes can be inhibited by the presence of a repressor.  
3. Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory sequences.  
4. Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative control).  
5. Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function.  
6. Certain genes are continuously expressed; that is, they are always turned “on,” e.g., the ribosomal genes.  

c. In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.  
Evidence of student learning is a demonstrated understanding of each of the following:  
1. Transcription factors bind to specific DNA sequences and/or other regulatory proteins.  
2. Some of these transcription factors are activators (increase expression), while others are repressors (decrease expression).  
3. The combination of transcription factors binding to the regulatory regions at any one time determines how much, if any, of the gene product will be produced.  

d. Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.  

Student Objectives:  
- Compare regulation of gene expression in prokaryotes and eukaryotes.  
- Diagram inducible and repressible operons. Give examples of each.  
- Compare the function of transcription factors and enhancers.  
- Explain the structures, processes, and functions of regulation that operate at all stages of gene expression in eukaryotes.  
- Explain the relationship between gene expression and differentiation in eukaryotes.  
- Explain the relationship between gene expression and differences in phenotypes in eukaryotes.  

Learning Objectives:  
- The student is able to describe the connection between the regulation of gene expression and observed differences between different kinds of organisms.  
- The student is able to describe the connection between the regulation of gene expression and observed differences between individuals in a population.  
- The student is able to explain how the regulation of gene expression is essential for the processes and structures that support efficient cell function.  
- The student can use representations to describe how gene regulation influences cell products and function.  

Essential knowledge 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.  

a. Signal transmission within and between cells mediates gene expression.  
To demonstrate student understanding of this concept, make sure you can explain:  
- Mating pheromones in yeast trigger mating gene expression.  
- Levels of cAMP regulate metabolic gene expression in bacteria.  

Student Objectives:  
- Using examples from cellular communication, explain how signal transduction can effect gene expression in organisms.  

Learning Objectives:
● The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production.

● The student can use representations to describe mechanisms of the regulation of gene expression.

**Enduring understanding 3.C: The processing of genetic information is imperfect and is a source of genetic variation.**

**Essential knowledge 3.C.1: 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.

*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.

**Student Objectives:**

● Explain the cause and effect of mutations at the DNA sequence level. Provide examples of all types.

**Learning Objectives:**

● 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.

● 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.

● The student is able to explain the connection between genetic variations in organisms and phenotypic variations in populations.

**Essential knowledge 3.C.2: 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.

**Student Objectives:**

● Provide examples of all processes discussed in this course (to this point in time) that illustrate the generation of genetic variation in prokaryotes and eukaryotes.

**Learning Objectives:**

● The student is able to compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains.

● The student is able to construct an explanation of the multiple processes that increase variation within a population.
Exam 2:

Enduring understanding 3.A: Heritable information provides for continuity of life.

Essential knowledge 3.A.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 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.

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

To demonstrate student understanding of this concept, make sure you can explain:

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

c. Illustrative examples of products of genetic engineering include:

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

Student Objectives:

- **Describe the inputs, processes, and outputs of all biotechnological tools and techniques discussed in this course. Provide multiple examples of the applications of each of these tools.**

- **Explain the aspects of molecular biology and DNA that each tool and technique discussed in this course utilizes.**

- **Discuss the ethical and legal considerations that the biotechnology revolution has generated. Provide multiple real-life examples of these issues. Offer multiple lines of evidence to support and refute these considerations.**

Learning Objectives:
● 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.
● The student can justify the claim that humans can manipulate heritable information by identifying at least two commonly used technologies.
● The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.

**Enduring understanding 3.B: Expression of genetic information involves cellular and molecular mechanisms.**
**Essential knowledge 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.**

*a. Signal transmission within and between cells mediates cell function.*

*To demonstrate student understanding of this concept, make sure you can explain:*

● 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.

**Student Objectives:**
● Explain the relationship between signal transduction and cellular differentiation.
● Describe how morphogens and HOX genes contribute to the development of an animal.

**Learning Objectives:**
● The student is able to explain how signal pathways mediate gene expression, including how this process can affect protein production.
● The student can use representations to describe mechanisms of the regulation of gene expression.

**Enduring understanding 3.C: The processing of genetic information is imperfect and is a source of genetic variation.**
**Essential knowledge 3.C.3: 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.*

*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.
2. To foster student understanding of this concept, instructors can choose an illustrative example such as:
3. Transduction in bacteria
4. Transposons present in incoming DNA
5. 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.

**Student Objectives:**
● Diagram all modes of viral replication discussed in this course and provide example viruses that follow each course of replication.
● Compare prokaryotic viruses and eukaryotic viruses.
● Explain the structure and function of HIV.
● Describe how viral processes increase genetic variation in prokaryotes and eukaryotes.
Diagram and describe the structure and function of transposons and retrotransposons.

Learning Objectives:
- The student is able to construct an explanation of how viruses introduce genetic variation in host organisms.
- The student is able to use representations and appropriate models to describe how viral replication introduces genetic variation in the viral population.

Enduring understanding 4.A: Interactions within biological systems lead to complex properties.
Essential knowledge 4.A.3: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.
- Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA.
- Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type.
- Environmental stimuli can affect gene expression in a mature cell.

Student Objectives:
- Explain the process of cellular divergence and differentiation.
- Provide examples of external and internal cues that direct divergence and differentiation.

Learning Objective:
- 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.

Enduring understanding 4.C: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.
Essential knowledge 4.C.1: Variation in molecular units provides cells with a wider range of functions.
- Multiple copies of alleles or genes (gene duplication) may provide new phenotypes.
  To demonstrate student understanding of this concept, make sure you can explain:
  1. A heterozygote may be a more advantageous genotype than a homozygote under particular conditions, since with two different alleles, the organism has two forms of proteins that may provide functional resilience in response to environmental stresses.
  2. Gene duplication creates a situation in which one copy of the gene maintains its original function, while the duplicate may evolve a new function.
  To demonstrate student understanding of this concept, make sure you can explain:
    - The antifreeze gene in fish

Student Objectives:
- Describe the evolutionary processes that are seen in genomic analysis and how these processes affect the structure of genomes.
- Explain the structure and function of all major segments of the human genome.
- Explain how gene duplication can lead to an increase in genetic information in an organism.
- Cite evidence from genomic analysis that relates to the evolution of the human lineage.

Learning Objective:
- The student is able to construct explanations based on evidence of how variation in molecular units provides cells with a wider range of functions.