

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.

Learning Objectives:

**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**]

### Enduring understanding 3.D: Cells communicate by generating, transmitting and receiving chemical signals.

For cells to function in a biological system, they must communicate with other cells and respond to their external environment. Cell-to-cell communication is ubiquitous in biological systems, from archaea and bacteria to multicellular organisms. The basic chemical processes by which cells communicate are shared across evolutionary lines of descent, and communication schemes are the products of evolution. Cell-to-cell communication is a component of higher-order biological organization and responses. In multicellular organisms, cell-to-cell and environment-to-cell chemical signaling pathways direct complex processes, ranging from cell and organ differentiation to whole organism physiological responses and behaviors. Certain signal pathways involve direct cell-to-cell contact, operate over very short distances, and may be determined by the structure of the organism or organelle, including plasmodesmata in plants and receptor-to-recognition protein interaction in the vertebrate immune system.

Chemical signals allow cells to communicate without physical contact. The distance between the signal generating cell(s) and the responding cell can be small or large. In this type of signaling pathway, there is often a gradient response, and threshold concentrations are required to trigger the communication pathway.

Chemical signaling pathways in cells are determined by the properties of the molecules involved, the concentrations of signal and receptor molecules, and the binding affinities (fit) between signal and receptor. The signal can be a molecule or a physical or environmental factor. At the cellular level, the receptor is a protein with specificity for the signal molecule; this allows the response pathway to be specific and appropriate. The receptor protein often is the initiation point for a signal cascade that ultimately results in a change in gene expression, protein activity, or physiological state of the cell or organism, including cell death (apoptosis). Defects in any part of the signal pathway often lead to severe or detrimental conditions such as faulty development, metabolic diseases, cancer or death.

Understanding signaling pathways allows humans to modify and manipulate biological systems and physiology. An understanding of the human endocrine system, for example, allowed the development of birth control methods, as well as medicines that control depression, blood pressure and metabolism. Other examples include the ability to control/modify ripening in fruit, agricultural production (growth hormones) and biofilm control.

Essential knowledge 3.D.1: Cell communication processes share common features that reflect a shared evolutionary history.

- a. Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment. [See also **1.B.1**]
- b. Correct and appropriate signal transduction processes are generally under strong selective pressure.
- c. In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.

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

- Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing)
  - Use of pheromones to trigger reproduction and developmental pathways
  - Response to external signals by bacteria that influences cell movement
- d. In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.

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

- Epinephrine stimulation of glycogen breakdown in mammals
- Temperature determination of sex in some vertebrate organisms
- DNA repair mechanisms

Learning Objectives:

**LO 3.31** The student is able to describe basic chemical processes for cell communication shared across evolutionary lines of descent. [See **SP 7.2**]

**LO 3.32** The student is able to generate scientific questions involving cell communication as it relates to the process of evolution. [See **SP 3.1**]

**LO 3.33** The student is able to use representation(s) and appropriate models to describe features of a cell signaling pathway. [See **SP 1.4**]

Essential knowledge 3.D.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.

a. Cells communicate by cell-to-cell contact.

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

- Immune cells interact by cell-cell contact, antigen-presenting cells (APCs), helper T-cells and killer T-cells. [See also **2.D.4**]
- Plasmodesmata between plant cells that allow material to be transported from cell to cell.

b. Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.

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

- Neurotransmitters
- Plant immune response
- Quorum sensing in bacteria
- Morphogens in embryonic development

c. Signals released by one cell type can travel long distances to target cells of another cell type.

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

1. Endocrine signals are produced by endocrine cells that release signaling molecules, which are specific and can travel long distances through the blood to reach all parts of the body.

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

- Insulin
- Human growth hormone
- Thyroid hormones
- Testosterone
- Estrogen

**X** *No specific system, with the exception of the endocrine system, is required for teaching the concepts in 3.D.2. Teachers are free to choose a system that best fosters student understanding. Study of the nervous and immune systems is required for concepts detailed in 3.E.2 and 2.D.4.*

Learning Objectives:

**LO 3.34** The student is able to construct explanations of cell communication through cell-to-cell direct contact or through chemical signaling. [See **SP 6.2**]

**LO 3.35** The student is able to create representation(s) that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signaling. [See **SP 1.1**]

Essential knowledge 3.D.3: Signal transduction pathways link signal reception with cellular response.

- a. Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein.

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

1. Different receptors recognize different chemical messengers, which can be peptides, small chemicals or proteins, in a specific one-to-one relationship.
2. A receptor protein recognizes signal molecules, causing the receptor protein's shape to change, which initiates transduction of the signal.

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

- G-protein linked receptors
- Ligand-gated ion channels
- Receptor tyrosine kinases

**X** *No particular system is required for teaching the concepts above. Teachers are free to choose a system that best fosters student understanding.*

- b. Signal transduction is the process by which a signal is converted to a cellular response.  
*Evidence of student learning is a demonstrated understanding of each of the following:*
1. Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, with the result of appropriate responses by the cell.
  2. Second messengers are often essential to the function of the cascade.  
*To foster student understanding of this concept, instructors can choose an illustrative example such as:*
    - Ligand-gated ion channels
    - Second messengers, such as cyclic GMP, cyclic AMP calcium ions ( $\text{Ca}^{2+}$ ), and inositol triphosphate ( $\text{IP}_3$ )
  3. Many signal transduction pathways include:
    - i. Protein modifications (an illustrative example could be how methylation changes the signaling process)
    - ii. Phosphorylation cascades in which a series of protein kinases add a phosphate group to the next protein in the cascade sequence

Learning Objectives:

**LO 3.36** The student is able to describe a model that expresses the key elements of signal transduction pathways by which a signal is converted to a cellular response.  
 [See **SP 1.5**]

Essential knowledge 3.D.4: Changes in signal transduction pathways can alter cellular response.

- a. Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.  
*To foster student understanding of this concept, instructors can choose an illustrative example such as:*
- Diabetes, heart disease, neurological disease, autoimmune disease, cancer, cholera
  - Effects of neurotoxins, poisons, pesticides
  - Drugs (Hypertensives, Anesthetics, Antihistamines and Birth Control Drugs)
- ✗ *Specific mechanisms of these diseases and action of drugs are beyond the scope of the course and the AP Exam.*

## Learning Objectives:

**LO 3.37** The student is able to justify claims based on scientific evidence that changes in signal transduction pathways can alter cellular response. [See **SP 6.1**]

**LO 3.38** The student is able to describe a model that expresses key elements to show how change in signal transduction can alter cellular response. [See **SP 1.5**]

**LO 3.39** The student is able to construct an explanation of how certain drugs affect signal reception and, consequently, signal transduction pathways. [See **SP 6.2**]

### Enduring understanding 3.E: Transmission of information results in changes within and between biological systems.

Evolution operates on genetic information that is passed to subsequent generations. However, transmission of nonheritable information also determines critical roles that influence behavior within and between cells, organisms and populations. These responses are dependent upon or influenced by underlying genetic information, and decoding in many cases is complex and affected by external conditions. For example, biological rhythms, mating behaviors, flowering, animal communications and social structures are dependent on and elicited by external signals and may encompass a range of responses and behaviors.

Organ systems have evolved that sense and process external information to facilitate and enhance survival, growth and reproduction in multicellular organisms. These include sensory systems that monitor and detect physical and chemical signals from the environment and other individuals in the population and that influence an animal's well-being. The nervous system interacts with sensory and internal body systems to coordinate responses and behaviors, ranging from movement to metabolism to respiration. Loss of function and coordination within the nervous system often results in severe consequences, including changes in behavior, loss of body functions and even death.

Knowledge and understanding of the structures and functions of the nervous system are needed to understand this coordination. The features of an animal's nervous system are evolutionarily conserved, with the basic cellular structure of neurons the same across species. The physiological and cellular processes for signal formation and propagation involve specialized membrane proteins, signaling molecules and ATP. Neurological signals can operate and coordinate responses across significant distances within an organism. The brain serves as a master neurological center for processing information and directing responses, and different regions of the brain serve different functions. Structures and associated functions for animal brains are products of evolution, and increasing complexity follows evolutionary lines.

Populations of organisms exist in communities. Individual behavior influences population behavior, and both are the products of information recognition, processing and transmission. Communication among individuals within a population may increase the long-term success of