BIG IDEA III

Living systems store, retrieve, transmit and respond to information essential to life processes.

Enduring Understanding 3.D
Cells communicate by generating, transmitting and receiving chemical signals.

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

- Learning Objectives:
  - (3.31) The student is able to describe basic chemical processes for cell communication shared across evolutionary lines of descent.
  - (3.32) The student is able to generate scientific questions involving cell communication as it relates to the process of evolution.
  - (3.33) The student is able to use representations and models to describe features of a cell signaling pathway.
Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.

- Organisms share many conserved core processes and features that are widely distributed among organisms today.

- These processes provide evidence that all organisms (Archaea, Bacteria, and Eukarya, both extant and extinct) are linked by lines of descent from common ancestry.

- The existence of these properties in organisms today implies that they were present in a universal ancestor and that present life evolved from a universal ancestor.

- Cell-to-cell communication is a component of higher-order biological organization and responses.
Correct and appropriate signal transduction processes are generally under strong selective pressure.

- 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.
In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.

- Unicellular organisms gather information about their environment and respond to it by using signaling pathways triggered by chemicals in the environment.

- These chemicals can relay information about how close a food source is, how many of the same bacteria are nearby, or the location of a favorable environment.

- Chemical substances produced by unicellular organisms can also be used to communicate between individual cells and influence their cellular processes.

- Illustrative Examples include:
  - The use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing).
  - Response to external signals by bacteria that influences cell movement (chemotaxis).
**Quorum Sensing in Unicellular Organisms**

http://www.youtube.com/watch?v=YJWKWYQfSi0

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Cell density dependent gene expression in quorum sensing (e.g. virulence expression)

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Chemotaxis in Unicellular Organisms

http://highered.mcgraw-hill.com/sites/007337525x/student_view0/exercises_35-90/chemotaxis_in_e_coli.html
In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.

- As with unicellular organisms, multicellular organisms usually communicate via chemical messengers targeted for cells that may or may not be immediately adjacent.

- Cells may communicate via direct contact, or communication may involve chemical signaling over short and long distances.

- Illustrative Examples include:
  - Epinephrine stimulation of glycogen breakdown in mammals.
  - Temperature determination of sex in some vertebrate organisms.
  - DNA repair mechanisms.
Epinephrine Stimulation of Glycogen Breakdown in Animals

http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter17/animation_second_messenger_camp.html
Temperature Determination of Sex in Some Vertebrate Organisms
DNA Repair Mechanism

READ ARTICLE (selected pages):

- Molecular mechanisms of mammalian DNA repair and the DNA damage checkpoints.
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Enduring Understanding 3.D
Cells communicate by generating, transmitting and receiving chemical signals.

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

- **Learning Objectives:**
  - (3.34) The student is able to **construct explanations** of cell communication through cell-to-cell direct contact or through chemical signaling.
  - (3.35) The student is able to **create representations** that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signaling.
Types of Cell Communication

• 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.

• Chemical signals, however, allow cells to communicate without physical contact.
  – Chemical signal pathways are determined by the properties of the molecules involved, the concentration of signal and receptor molecules, and the binding affinities (fit) between signal and receptor – often a protein.
  – Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.
Direct Contact vs. Chemical Signaling

• Remember, cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.

  – **Direct cell-to-cell contact:**
    • Immune cell interaction via antigen-presenting cells.
    • Plasmodesmata between plant cells that allow material to be transported from cell to cell.

  – **Communication over short distance:**
    • Quorum sensing in bacteria.
    • Neurotransmitters.

  – **Long distance signaling:**
    • Hormones are produced in one area of the body, released into the bloodstream, and can travel long distances to initiate response in another area of the body (insulin, HGH, testosterone, estrogen).
Cells communicate by **cell-to-cell contact**.

- **Cell Junctions:** both animals and plants have cell junctions that allow molecules to pass readily between adjacent cells without crossing plasma membranes.

- **Cell-cell Recognition:** Two cells in an animal may communicate by interaction between molecules protruding from their surface.

- In multi-celled organisms, individual cells must communicate and join with one another to create a harmonious organism.

- Cell junctions can be classified in four functional groups:
  1. Tight junctions
  2. Desmosomes
  3. Gap junctions
  4. Plasmodesmata
Tight junctions prevent fluid from moving across a layer of cells.
Plasmodesmata

- Plant cell walls
- Vacuole
- Cytosol
- Plasma membrane
- Plant cell wall layers:
  - Middle lamella
  - Primary wall
  - Secondary wall

CELL 1
- Primary wall
- Three layers of secondary wall
- Middle lamella

CELL 2

1 µm
Cell-to-Cell Recognition

[Diagram of cell-to-cell recognition with labels for fibers of extracellular matrix (ECM), carbohydrate, extracellular fluid, glycoprotein, filaments of cytoskeleton, cholesterol, peripheral protein, integral protein, and cytoplasm.]
Illustrative Examples – Cells communicate by cell-to-cell contact.

- **Immune Cell Interaction**
  - [http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter22/animation_the_immune_response.html](http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter22/animation_the_immune_response.html)

- **Plasmodesmata**
  - [http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::600::480::/sites/dl/free/007353224x/788092/Water_Uptake.swf::Water+Uptake](http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::600::480::/sites/dl/free/007353224x/788092/Water_Uptake.swf::Water+Uptake)
Cells communicate over *short distances* by using local regulators that target cells in the vicinity of the emitting cell.

- **Illustrative Examples Include:**
  - **Neurotransmitters**
    - [Link](https://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter14/animation__transmission_across_a_synapse.html)
  - **Plant Immune Responses**
    - [Link](http://bcs.whfreeman.com/thelifewire/content/chp40/4001s.swf)
  - **Quorum Sensing in Bacteria**
    - [Link](http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf::500::500::/sites/dl/free/0073375225/594358/QuorumSensing.swf::Quorum+Sensing)
  - **Morphogens in Embryonic Development**
    - [Link](http://nortonbooks.com/college/biology/animations/ch29a08.htm)
A secreting cell acts on nearby target cells by discharging molecules of a **local regulator** (a growth factor, for example) into the extracellular fluid.

A nerve cell releases **neurotransmitter** molecules into a synapse, stimulating a target cell.

Specialized endocrine cells secrete **hormones** into body fluids, often the blood. Hormones may reach virtually all body cells.
Signals released by one cell type can travel long distances to target cells of another cell type.

- Both animals and plants use chemicals called hormones for long-distance signaling.
- **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.

Illustrative Examples Include:
- Insulin: [http://vcell.ndsu.edu/animations/insulinsignaling/movie-flash.htm](http://vcell.ndsu.edu/animations/insulinsignaling/movie-flash.htm)
- Human Growth Hormone
- Testosterone & Estrogen
Review: The Cellular Internet

http://www.biopsychology.com/6e/activity0502.html

Figure 16-3  Essential Cell Biology, 2/e. (© 2004 Garland Science)
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Living systems store, retrieve, transmit and respond to information essential to life processes.

Enduring Understanding 3.D
Cells communicate by generating, transmitting and receiving chemical signals.

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

• Learning Objectives:
  
  - (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.
Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein.

- Different receptors recognize different chemical messengers, which can be peptides, small chemicals or proteins, in a specific one-to-one relationship.

- A receptor protein recognizes signal molecules, causing the receptor protein’s shape to change, which initiates transduction of the signal.

- Illustrative Examples Include:
  - G-protein linked receptors: [http://bcw.whfreeman.com/thelifewire/content/chp15/15020.html](http://bcw.whfreeman.com/thelifewire/content/chp15/15020.html)
  - Ligand-gated ion channels: [http://www.youtube.com/watch?v=Du-BwT0UL2M](http://www.youtube.com/watch?v=Du-BwT0UL2M)
Signal transduction is the process by which a signal is converted to a cellular response.

- The *signal transduction pathway* relies on plasma membrane proteins in a multi-step process in which a small number of extracellular signal molecules produce a major (amplified) cellular response.

- Essentially, these pathways convert signals on a cell’s surface into cellular responses.

- Three stages occur in this type of cell signaling:
  1. Reception
  2. Transduction
  3. Response
Steps of Signal Transduction

- In **reception**, the signal molecule, commonly a protein that **does not enter the cell**, binds to a specific receptor **on the cell surface**, causing the receptor molecule to undergo a **change in conformation**.

- This conformational change leads to **transduction** – a change in signal form, **where the receptor relays a message to a secondary messenger**.

- This secondary messenger, such as cyclic AMP (cAMP), induces a **response within the cell**.
Visual Overview of Cell Signaling

**Figure 11.5**

The diagram illustrates the process of cell signaling, showing the steps: Reception, Transduction, and Response. The signaling process begins with the reception of a signal molecule, which triggers the transduction of a signal within the cell. This transduction leads to the activation of cellular responses. The diagram uses color-coded elements to differentiate between extracellular fluid and cytoplasm, with a focus on the plasma membrane as the barrier between the two.

**Key Elements**
- **Reception**: Initial interaction with a receptor on the cell membrane.
- **Transduction**: Chain of reactions that occur in the cytoplasm.
- **Response**: Activation of cellular responses.

**Signaling Pathway**
- **Signal molecule** binds to the **Receptor**.
- **Relay molecules** in the signal transduction pathway are activated.
- The **Response** is the final activation of cellular responses.
G-Protein Linked Receptor

http://bcs.whfreeman.com/thelifewire/content/chp15/15020.html

Figure 11.7
Tyrosine-Kinase Receptor

Ligand-Gated Ion-Channel Receptors

http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__receptors_linked_to_a_channel_protein.html

- Specific signal molecules cause **ligand-gated ion channels** in a membrane to open or close, regulating the flow of specific ions.

- This receptor is a transmembrane protein in the plasma membrane that opens to allow the flow of a specific kind of ion across the membrane when a specific signal molecule binds to the extracellular side of the protein.

Figure 11.7
Multistep pathways allow a **small number** of extra-cellular signaling molecules to be **amplified** to produce a **large** cellular response.

They also provide opportunity for regulation and coordination (cellular response v. nuclear response).

**Relay molecules** are usually proteins kinases.

**Kinases** are enzymes that **transfer phosphate groups** from ATP to proteins (producing a shape change) that activates each enzyme.

**Phosphatases** are enzymes that remove phosphate groups and therefore shut down signal transduction pathways.

Small molecules or ions often function as **second messengers**, which **rapidly relay** the signal from the membrane-bound “first messenger” into a cell’s interior.
Response: Cell signaling leads to regulation of transcription or cytoplasmic activities.

- Signal transduction pathways may lead to the activation of transcription factors, which regulate the expression of specific genes.
- They may also activate existing cytoplasmic enzymes, open or close protein channels in membranes, or rearrange the cytoplasm.
Fine-Tuning of the Response

• A signal transduction pathway can **amplify** a signal in an enzyme cascade:
  – This is because successive enzymes in the pathway can process multiple molecules that then activate the next step.

• As a result of their particular set of receptor proteins, relay proteins, and response proteins:
  – **Different cells can respond to different signals or can exhibit different responses to the same molecular signal.**
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Enduring Understanding 3.D
Cells communicate by generating, transmitting and receiving chemical signals.

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

- **Learning Objectives:**
  - (3.37) The student is able to justify claims based on scientific evidence that changes in signal transduction pathways can alter cellular response.
  - (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.
  - (3.39) The student is able to construct an explanation of how certain drugs affect signal reception and, consequently, signal transduction pathways.
Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.

- Illustrative Examples Include:
  - Diabetes, heart disease, neurological disease, autoimmune disease, cancer, cholera.
  - Effects of neurotoxins, poisons, pesticides.
  - Drugs (anesthetics, antihistamines, birth control).