Domain 6: Communication

6.1: Cell communication processes share common features that reflect a shared evolutionary history. (EK3.D.1)

1. Introduction to Communication

Communication requires the generation, transmission, and reception of a signal.

In cellular systems, these signals are generally chemical molecules, but can also include direct detection of environmental conditions (eg. Light, sound, temperature). These pathways are referred to as "signal transduction" pathways.

All organisms engage have signal transduction pathways:

Signal transduction pathways are very important for the continued life of an organism, and are heavily adapted by natural selection.

Unicellular signaling pathways: In unicellular organisms, signaling pathways affect the responses of cells to their environment.

example- quorum sensing. Involves the generation of chemical signals in response to environmental variables, and they both operate by changing cell activity via regulating gene expression.

Multicellular signaling pathways: In multicellular organisms, signaling pathways affect responses that coordinate multiple populations of cells and support the functioning of the organism.

Example: epinephrine- a hormone signal produced by the adrenal glands. Triggers different responses in different tissues. In the liver, the reception of the epinephrine molecule causes the breakdown of glycogen in to glucose and the release of that glucose in to the bloodstream.

6.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling. (EK3.D.2)

1. Types of Cellular Signals

Cell communication always involves the production, exchange, and receipt of chemical messages.

Cell communication through cell-cell contact:

Ex. Immune System: Direct contact is needed for activation of the specific immune response (antigen presentation).

Ex. Plasmodesmata: Channels in the cell walls of plant-like cells which allow for direct passage of materials and signaling molecules from cell to cell.

Cell communication through local signaling:

Messages are produced by cells and diffuse to local cell populations

Ex. Neurotransmitters: chemicals released by one neuron are received by another neuron over the synaptic space, resulting in the propagation of the signal.

Ex. Plant Immune Response: chemicals produced by infected cells are received by nearby cells and result in activation of defense mechanisms in those cells.

Cell communication through distance signaling:

Endocrine system: the production of endocrine signaling molecules ("hormones") by glands are then transported through the circulatory system to all other parts of the body.

Ex. Insulin: produced by the pancreas, affects all cells in the body (specific liver effects).

Ex. Human growth hormone: produced by the pituitary gland in the brain, affects all cells in the body.

Ex. Sex hormones: FSH and LH- produced by the pituitary gland, affect the gonads (testes and ovaries). Estrogen, Testosterone- produced by the gonads, affect all cells of the body.

6.3: Signal transduction pathways link signal reception with cellular response. (EK3.D.3)

1. Signal Transduction Pathways

Signal transduction begins with reception.

Signal reception is accomplished through receptor proteins.

Depending on the chemistry of the ligand, receptor proteins will be located at the cell membrane, or

in the cytoplasm.

Receptor proteins have a diversity of structures, depending on the signal they receive, but there are some general features:

An area of the protein that interacts with the signaling molecule (the "ligand")

An area of the protein that transmits ("transduces") the signal to another protein.

When the ligand interacts with the receptor protein, it causes a conformational change in the receptor, which results in the activation of the transduction pathway in the cell.

Example: G-protein linked receptor- a membrane receptor. When the ligand binds to the GPL-receptor, the conformational change causes phosphorylation (activation) of a g-protein, which then phosphorylates the next protein in the response pathway, etc.

Example: Ligand-gated ion channels- another membrane receptor. When the ligand binds to the channel, the conformational change causes the channel to open, and ions to move freely in to the cell. This change in ion concentration will then trigger cellular responses by changing the shape of various proteins.

Transduction of a chemical signal results in the conversion of signal reception in to cellular response.

Transduction is accomplished via activation of a protein through phosphorylation, or a change in intracellular conditions (a change in ion concentration).

Signal transduction activates a cascading response, which can result in the amplification of the original signal (one ligand - > exponentially increasing activated proteins).

The complexities of cellular responses that result from signal reception are due to the interconnected structure of transduction pathways inside a cell.

Most signaling pathways involve the activation of "second messenger" response pathways inside a cell.

Second messengers are internal signaling molecules, often activated by multiple external signals:

Ex. Cyclic AMP -> when present in a cell, activates various catabolic metabolic pathways.

The modification of proteins in a signal transduction pathway is akin to turning them "on" and "off". This is often accomplished by the addition of phosphates to activate proteins (by "kinase" enzymes) and the removal of phosphates to deactivate proteins (by "phosphatases").

Cellular responses involve changes in gene expression, and the activation of already present, inactive
proteins.

6.4: Changes in signal transduction pathways can alter cellular response. (EK3.D.4)

1. Alterations to Signaling Pathways

Alterations in signal transduction pathways will affect the functioning of cells, and the homeostasis of the organism.

Many diseases result from alterations to signal transduction pathways:

Ex. Diabetes: Type 1- failure to produce the insulin hormone. Type 2- failure to activate the insulin response in target cells. Immediate effects- inability of the body to effectively regulate blood-glucose concentration. Long-term effects: vascular system problems, poor wound healing, blindness, neurological degeneration, death.

Ex. Neurological disease: Parkinson's Syndrome- death of neurons in the brain that produce the dopamine neurotransmitter. Results in degeneration of the muscular system.

Ex. Cancer- failure of cells to respond to the normal apoptosis pathway that should be triggered when cell cycle mutations accumulate. Results in uncontrolled cell growth.

Many drugs work by altering signal transduction pathways:

Ex. Antihistamines: block the release of histamine signaling molecules by mast cells. Results in decreased inflammatory response.

Ex. Birth Control: Provide hormones that prevent ovulation and normal menstrual cycle progression.

6.5: Individuals can act on information and communicate it to others. (EK3.E.1)

1. Communication Between Organisms

Organisms are able to acquire information about their environment and exchange that information with others.

Stimuli: Anything that triggers a response. Stimuli are external to the organism.

The ability of organisms to respond to signals from the environment and other organisms ("behavior") will lead to greater or lesser reproductive success.

Ex. Predator warnings- when the presence of a predator in the environment is detected, members of a population will often signal that presence to other members.

Ex. Herbivory responses- The detection of chemicals associated with hebivores by plants results in a variety of defenses including the production of toxic chemicals, and the recruitment of herbivore parasites/predators.

Animals have highly developed sensory systems, which can detect and communicate via visual, auditory, tactile, chemical, and electrical signals.

Ex. Bee Dances: A tactile signal to other bees that relates the position of food sources to the location of the hive.

Ex. Swarming Behavior: The result of positive feedback in chemical signaling pathways ("pheromones").

Ex. Prey detection by electrical signals in snakes and fish.

As long as behaviors have a genetic component, and increase/decrease survival and reproductive success of organisms, natural selection can adapt them for an organism's particular environment.

Natural selection will favor any behavior that increases survival and reproductive success.

Ex. Courtship and mating rituals.

Ex. Foraging behaviors in animals.

Natural selection will allow for the evolution of cooperative behavior if it increases the fitness of the individual OR genetically related individuals:

Ex. Schooling in fish

Ex. Colonial insects

6.6: Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses. (EK3.E.2)

1. Neurons

The neuron is the structural unit of the nervous system:

A neuron is a highly-specialized cell used by the nervous system to detect signals and transmit them to other neurons/response effectors (muscles or glands).

Neuron structure allows for neuron function:

Dendrites: connect to other neurons or sensory receptors at synapses. Detect signals across the synapse.

Cell Body: Contains the majority of the neuron's organelles.

Axon: Conducts an electrochemical signal to the next neuron/effector in the neural pathway.

Most axons are surrounded by a layer of highly myelinated Schwann cells that insulate the neuron and increase the rate of signal transmission.

Neuron signals move from dendrites to the axon to the nerve terminals.

The structure of particular neurons depends on the role of the neuron in the nervous system.

Neurons allow for signals to be generated, detected, transmitted, and integrated by animals.

Neuron signals are electrochemical "action potentials."

The membrane of a neuron is polarized, with active maintenance of different concentrations of ions inside and outside of the cell (the "resting potential"). Na+ is at a higher concentration outside the cell. K+ is at a higher concentration inside the cell

An action potential results from the depolarization of a neuronal membrane's resting potential.

When the membrane is depolarized to a "threshold" potential, voltage gated channels in the axon open, and a rapid exchange of ions occurs:

Na+ moves in to the cell, triggering a massive depolarization (inside the cell becomes more positive relative to outside the cell).

At the peak of the depolarization, K+ ion channels also open, allowing K+ ions to move out of the cell.

Peak depolarization triggers the closing of the Na^+ channels, K^+ ion channels remain open. As K^+ continues to move out of the cell, the membrane becomes hyperpolarized.

The action of Na+/K+ pump proteins restores the polarization of the membrane back to the resting potential.

Once the resting potential is restored, the neuron can send another action potential.

Action potentials are binary ("all or nothing"), self-propagating, and unidirectional. The initial depolarization of the membrane triggers the depolarization of the next area of the membrane. The hyperpolarization following an action potential prevents the action potential from moving backwards along the axon.

Myelination greatly increases the speed of action potential transmission, as the signal moves along nodes ("saltatory conduction").

Neurons transmit signals to other neurons across synapses.

The arrival of an action potential at the terminal of an axon triggers the release of neurotransmitter molecules in to the synaptic space.

Different neurotransmitters will have different effects on different types of neurons.

Ex. Acteylcholine: Released by motor neurons at the "neuromuscular junction" (the synapse between them and muscle cells. Triggers contraction of the muscle

Ex. Serotonin: Released by neurons in the brain involved in emotional responses.

These effects can be excitatory (make the next neuron more likely to send an action potential), or inhibitory (make the next neuron less likely to send an action potential).

Transmission of information along neurons will ultimately result in a response (the operation of muscles, or the secretion of signaling molecules by a gland).

2. Nervous Systems

Animal Nervous Systems have varying levels of complexity.
Evolutionary trends towards centralization and "cephalization" are demonstrated.

In vertebrates, the brain is the central unit for integrating nervous system information and coordinating
responses.

Different regions of the brain serve different functions:
Ex. Medulla/Cerebellum/Cerebrum
Ex. Right/left hemisphere separation.
Ex. Vision and Hearing centers.

Ex. Motor movement.

Ex. Abstract thought and emotion.

Ex. Right/left hemisphere separation.