Domain 5: Regulation

5.1: Timing and coordination of specific events are necessary for the normal development of an organism, and these events are regulated by a variety of mechanisms. (EK2.E.1)

1. Development

The development of an organism is coordinated by sequential changes in gene expression.

Starting as an undifferentiated cell, a multi-cellular organism possessing many different types of cells is produced.

Differentiation requires the expression of cell type-specific proteins.

Several major processes accomplish differentiation:

Pattern formation: Established by positional cues, usually protein gradients (ex. Bicoid, Hox genes). Once body plan axes are established, morphogenesis can begin.

Induction: local signals communicated among populations of cells to control their specific development.

Environmental cues: Particular molecules and conditions must be present in the local environment for development to proceed properly (ex. The conditions of the uterus, or the role of temperature and moisture in triggering seed development).

Evidence from experiments and nature have informed thinking about development:

Developmental mutants: mutations in normal developmental pathways lead to malformations in embryonic development.

Genetic transplantation experiments: removing/moving regions of the developing embryo to other areas affect pattern formation. The use of reporter genes help to determine which genes are active when and where during organism development.

Silencing of specific genes is also important for normal development.

It's not just what you turn on, it's also what you turn off.

The presence of specific microRNA's during development will prevent certain genes from being expressed.

Programmed cell death is required for normal development:

Apoptosis: programmed cell death. The cell breaks itself down in to small "blebs", which are absorbed by surrounding cells.

Required for many different aspects of development. One example: digit formation in vertebrates.

5.2: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs. (EK4.A.3)

1. Differentiation

Differentiation is controlled by internal cues (ex. Hox gene products) and external cues (ex. Temperature, or the presence/absence of specific signaling molecules). These all work to regulate protein expression by turning on/off genetic "switches" through controlling the presence/absence of regulatory genes that allow or block transcription.

Differentiation of the gene products present in cells leads to structural and functional divergence in the roles that those cells play in the organism (ex. Neuron vs. blood cell)

The environment plays a major role in controlling gene expression in mature cells (ex. Changes in UV radiation leading to melanin production, presence of insulin leading to increased glucose intake).

5.3: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes. (EK2.C.1)

1. Feedback Loops

Feedback is a universal characteristic of open systems.

Feedback loops are seen at all levels of organization in living systems.

Negative feedback loops are regulatory in nature.

Negative feedback: any situation where the output of a process decreases the occurrence of that process.

Example: lac operon- the presence of lactose activates a metabolic pathway that results in the digestion of lactose.

Example: Temperature regulation in animals- if animals get too cold, they shiver and increase metabolic rate to generate heat. If animals get too hot, they sweat to cool down.

Example: Population growth- As a population grows, resource are depleted to the point where the population can no longer continue to grow.

Negative feedback maintains homeostasis.

Positive feedback loops are amplifying in nature

Positive feedback: any situation where the output of a process increases the occurrence of that process.

Example: labor- contractions of the uterus increase pressure on the cervix, which triggers the release of oxytocin by the pituitary gland, which increases the rate of contractions of the uterus.

Example: fruit ripening- controlled by the hormone ethylene. As a fruit ripens, it produces more ethylene, which causes the fruit to ripen more rapidly

Positive feedback causes transformation in the system.

5.4: Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments. (EK2.D.2)

Discussion 1:

Divergence in homeostatic mechanisms is due to the requirements of different environments

Examples:

Respiratory systems of aquatic and terrestrial animals- external vs. internal respiratory surfaces.

Respiration (the exchange of gases) must occur over a thin, moist membrane.

Animals that live in aquatic environments can use external structures to respire (gills in fish, or
skin in frogs).

Animals that live on land must use internal structures to respire (lungs/alveoli in terrestrial
tetrapods, spiracles in insects)

Nitrogenous waste production in aquatic and terrestrial animals-

The waste products from digesting proteins/nucleic acids must be excreted from the body of the organism.

Animals that live in water convert nitrogenous waste directly in to ammonia, which is highly toxic but can be heavily diluted and easily excreted in to the watery environment along.

Animals that live on land can not afford to lose as much water when excreting nitrogenous waste.

Mammals are able to convert nitrogenous waste into urea which is less toxic than ammonia, so

it does not need to be as diluted with water, and can be stored for periodic elimination from the body.

Birds, reptiles, and many insects convert nitrogenous waste to uric acid, which is the least toxic, and requires the least dilution with water.

Discussion 2:

Similarities in homeostatic control systems are due to common ancestry and convergent evolution.

Example: Excretory systems in animals. Differences are due

All excretory systems in animals involve filtration, reabsorption, secretion, and elimination

Examples: Flame bulb/nephridium/kidney(nephron)

Example: Circulatory systems in vertebrates-

All vertebrate circulatory systems are closed, and use a single heart to pump blood from the body to the respiratory surface and back.

Examples: Fish/Reptile/Mammal/Bird- Mammal and Bird 4 chamber heart is an example of convergent evolution.

5.5: Biological systems are affected by disruptions to their dynamic homeostasis. (EK2.D.3)

1. Effects of Disruptions

The effects of disruptions to biological systems can be seen at all levels of organization.

Disruptions to molecular pathways and cellular structure can adversely affect the homeostasis of the

organism:

Example: Response to toxins

Toxins usually interfere with specific metabolic pathways (ex. Cyanide, Carbon Monoxide), or cause major damage to cells (ex. Snake venom cytotoxins, Concentrated acids). This interference can lead to major injury or death.

Example: Dehydration

The loss of water causes the tonic environment of cells to become less than optimal for continuing cellular work. The changes in concentrations of molecules can lead to organ failure or death.

Disruptions to ecosystems can adversely affect the balance of the ecosystem.

Example: Invasive species-

If an invasive species is able to outcompete a native species, or place a rapid stress on a native species (e.g. predation), the trophic structure of the ecosystem can be degraded (e.g. decrease in the diversity and abundance of native species) or collapse.

Example: Disturbance-

Natural disturbances include disasters like fires, earthquakes, etc. These massive, rapid changes to the environment can eliminate major populations from the ecosystem, leading to degradation or collapse of the ecosystem.

In all cases, biological systems are able to adjust to the disruptions and rebound (your immune system might be able to produce venom antibodies—Bill Haast, you can drink more water, the populations in an ecosystem can adapt to the presence of an invasive, or an ecosystem can gradually undergo successional changes to return to the pre-disturbance state), IF the disruptions are not too large and too rapid for the homeostatic feedback loops to function. If the disruptions are too large scale, and too rapid, disease, degradation, and death are unavoidable.

5.6: Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis. (EK2.D.4)

1. Immune Systems.

Nonspecific immune responses are found in all multicellular organisms.

Plants: Have the ability to recognize pathogens by their effects, and trigger responses that destroy infected tissue and protect uninfected tissue.

Invertebrates: Toll-receptor systems that recognize specific molecules usually associated with pathogens (ex. Lipid A- component of bacterial cell walls) and trigger immune responses.

Vertebrates: Multiple external and internal nonspecific defenses

External: skin, mucous, tears, sweat (lysozyme)

Internal: Inflammatory response: When pathogens are present inside the body, nearby cells recruit non-specific phagocytic white blood cells to the area of infection. These phagocytes engulf and destroy the pathogens, and present molecules from them ("antigens") to the specific immune system.

Mammals have a highly developed specific immune response:

There are two major divisions of the specific immune system. They both involve the lymphocytes (B-cells
and T-cells):

Cell-mediated response: specific T-cells are developed to target specific antigens on the surface of specific pathogens. These T-cells trigger the destruction of those pathogens, and infected cells through cell-cell interactions.

Humoral response: specific B-cells are developed that produce and secrete antibodies that bind to specific antigens on the surface of specific pathogens. These antibodies bind to the antigens on pathogens and target them for destruction by the non-specific immune system, or prevent them from continuing their life cycle.

Clonal selection: The process by which specific lymphocytes are produced by the immune system. When presented with a particular antigen, a large variety of lymphocytes are produced, each with a different variation of receptor. Only the cells who react with the specific antigen are allowed to reproduce (the other cells undergo apoptosis). The next generation of lymphocytes undergoes another round. This process continues until a population of lymphocytes with a very specific receptor for a particular antigen is produced.

Immunological Memory: Once a specific immune response is generated, a small population of lymphocytes that react to the triggering antigen remain in the lymphatic system for the remainder of the life of the individual. When the same antigen is presented in a subsequent infection, the immune response is much faster and larger, which controls the infection more rapidly. This assumes that the pathogen has not evolved so that its antigens are no longer recognized by the immune system. Memory is also the basis of vaccination, which presents antigens to the immune system without the pathogen present, so that the immune system can develop its response prior to infection.

5.7: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection. (EK2.E.2)

Discussion 1:

Changes in the environment are able to cause changes in behavior.

The interaction between the environment and internal signals regulate plant responses.

Example: Phototropism- Growth in response to light. Controlled by the production and unequal distribution of the hormone auxin. Auxin production is highest in dark cells, which causes them to lengthen. Unequal lengthening results in movement toward light sources.

Example: Photoperiodism- Flowering in response to periods of light and dark of specific length. Controlled by phytochrome molecules, which alternate between active and inactive forms as a result of exposure to light for periods of "critical" length.

The interaction between the environment and internal signals regulate and synchronize animal
responses with the cycles of the environment.

Example: circadian rhythms- internal physiological cycles present in all eukaryotes, which last for 24 hours (ex. Sleep/wake cycle). These cycles are present even when environmental cues are removed, but in their absence the cycles lose their calibration to the day/night cycle of the environment (ex. Jet lag).

Example: Hibernation/estivation/migration- periods of dormancy, or relocation in response to seasonal variations in productivity of an environment.

The interaction between the environment and internal signals regulate and synchronize fungal, bacterial, and protist responses with the cycles of the environment.

Example: Fruiting Body Formation- the development of reproductive structures in fungi, some protists, and some bacteria. Controlled by the sensing of appropriate external conditions, and subsequent gene expression.

Example: Quorum Sensing- changes in bacterial behavior once a specific population density is reached. (ex. Bioluminescence in V. fisherii)

In all cases, interactions between environmental signals and internal signals are required to evoke a particular behavior.

In as much as any behavior can be inherited, it can be adapted by natural selection.