A.P. Biology College Board Curriculum

Big Idea 1: The process of evolution drives the diversity and unity of life.
- 1.A: Change in the genetic makeup of a population over time is evolution.
  - 1.A.1: Natural selection is a major mechanism of evolution.
  - 1.A.2: Natural selection acts on phenotypic variations in populations.
  - 1.A.3: Evolutionary change is also driven by random processes.
  - 1.A.4: Biological evolution is supported by scientific evidence from many disciplines, including mathematics.
- 1.B: Organisms are linked by lines of descent from common ancestry.
  - 1.B.1: Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.
  - 1.B.2: Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.
- 1.C: Life continues to evolve within a changing environment.
  - 1.C.1: Speciation and extinction have occurred throughout the Earth's history.
  - 1.C.2: Speciation may occur when two populations become reproductively isolated from each other.
  - 1.C.3: Populations of organisms continue to evolve.
- 1.D: The origin of living systems is explained by natural processes.
  - 1.D.1: There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence.
  - 1.D.2: Scientific evidence from many different disciplines supports models of the origin of life.

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.
- 2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.
  - 2.A.1: All living systems require constant input of free energy.
  - 2.A.2: Organisms capture and store free energy for use in biological processes.
  - 2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.
- 2.B: Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.
  - 2.B.1: Cell membranes are selectively permeable due to their structure.
  - 2.B.2: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.
  - 2.B.3: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.
- 2.C: Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.
  - 2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.
  - 2.C.2: Organisms respond to changes in their external environments.
- 2.D: Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.
  - 2.D.1: All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.
  - 2.D.2: Homeostatic mechanisms reflect both common ancestry and divergence due to adaptation in different environments.
  - 2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis.
  - 2.D.4: Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis.
- 2.E: Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.

- 2.E.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.
- Essential knowledge 2.E.2: Timing and coordination of physiological events are regulated by multiple mechanisms.
- 2.E.3: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.

Big Idea 3: Living systems store, retrieve, transmit and respond to information essential to life processes.
- 3.A: Heritable information provides for continuity of life.
  - 3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.
  - 3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.
  - 3.A.3: The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.
  - 3.A.4: The inheritance pattern of many traits cannot be explained by simple Mendelian genetics.
- 3.B: Expression of genetic information involves cellular and molecular mechanisms.
  - 3.B.1: Gene regulation results in differential gene expression, leading to cell specialization.
  - 3.B.2: A variety of intercellular and intracellular signal transmissions mediate gene expression.
- 3.C: The processing of genetic information is imperfect and is a source of genetic variation.
  - 3.C.1: Changes in genotype can result in changes in phenotype.
  - 3.C.2: Biological systems have multiple processes that increase genetic variation.
  - 3.C.3: Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.
- 3.D: Cells communicate by generating, transmitting and receiving chemical signals.
  - 3.D.1: Cell communication processes share common features that reflect a shared evolutionary history.
  - 3.D.2: Cells communicate with each other through direct contact with other cells or from a distance via chemical signaling.
  - 3.D.3: Signal transduction pathways link signal reception with cellular response.
  - 3.D.4: Changes in signal transduction pathways can alter cellular response.
- 3.E: Transmission of information results in changes within and between biological systems.
  - 3.E.1: Individuals can act on information and communicate it to others.
  - 3.E.2: Animals have nervous systems that detect external and internal signals, transmit and integrate information, and produce responses.

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.
- 4.A: Interactions within biological systems lead to complex properties.
  - 4.A.1: The subcomponents of biological molecules and their sequence determine the properties of that molecule.
  - 4.A.2: The structure and function of subcellular components, and their interactions, provide essential cellular processes.
  - 4.A.3: Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues and organs.
  - 4.A.4: Organisms exhibit complex properties due to interactions between their constituent parts.
  - 4.A.5: Communities are composed of populations of organisms that interact in complex ways.
  - 4.A.6: Interactions among living systems and with their environment result in the movement of matter and energy.
- 4.B: Competition and cooperation are important aspects of biological systems.
  - 4.B.1: Interactions between molecules affect their structure and function.
  - 4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.
  - 4.B.3: Interactions between and within populations influence patterns of species distribution and abundance.
  - 4.B.4: Distribution of local and global ecosystems changes over time.

Big Idea 1: The process of evolution drives the diversity and unity of life.

1.A: Change in the genetic makeup of a population over time is evolution.

1.A.1: Natural selection is a major mechanism of evolution.

- ❑ According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations.
- ❑ Evolutionary fitness is measured by reproductive success.
- ❑ Genetic variation and mutation play roles in natural selection. A diverse gene pool is important for the survival of a species in a changing environment.
- ❑ Environments can be more or less stable or fluctuating, and this affects evolutionary rate and direction; different genetic variations can be selected in each generation.
- ❑ An adaptation is a genetic variation that is favored by selection and is manifested as a trait that provides an advantage to an organism in a particular environment.
- ❑ In addition to natural selection, chance and random events can influence the evolutionary process, especially for small populations.
- ❑ Conditions for a population or an allele to be in Hardy-Weinberg equilibrium are: (1) a large population size, (2) absence of migration, (3) no net mutations, (4) random mating and (5) absence of selection. These conditions are seldom met.
- ❑ Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.

1.A.2: Natural selection acts on phenotypic variations in populations.

- ❑ Environments change and act as selective mechanism on populations.
  - ❑ Peppered moth
- ❑ Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.
- ❑ Some phenotypic variations significantly increase or decrease fitness of the organism and the population.
  - ❑ Sickle cell
  - ❑ Peppered moth
  - ❑ DDT resistance in insects
- ❑ Humans impact variation in other species.
  - ❑ Artificial selection
  - ❑ Use of antibiotics

1.A.3: Evolutionary change is also driven by random processes.

- ❑ Genetic drift is a nonselective process occurring in small populations.
- ❑ Reduction of genetic variation within a given population can increase the differences between populations of the same species.

1.A.4: Biological evolution is supported by scientific evidence from many disciplines, including mathematics.

- Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical and mathematical applications.
- Molecular, morphological and genetic information of existing and extinct organisms add to our understanding of evolution.
    - Radiometric dating
    - Phylogenetic trees
    - Morphological and molecular homologies
    - Construction of phylogenetic trees

1.B: Organisms are linked by lines of descent from common ancestry.

1.B.1: Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.

- Structural and functional evidence supports the relatedness of all domains.
    - Organisms use DNA and RNA
    - Universal genetic code
    - Similarity of metabolic pathways
- Structural evidence supports the relatedness of all eukaryotes.
    - Mitochondria and chloroplasts
    - Linear chromosomes

1.B.2: Phylogenetic trees and cladograms are graphical representations (models) of evolutionary history that can be tested.

- Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.
    - Heart chambers
    - Legs in sea mammals
- Phylogenetic trees and cladograms illustrate speciation that has occurred, in that relatedness of any two groups on the tree is shown by how recently two groups had a common ancestor.
- Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species, and from DNA and protein sequence similarities, by employing computer programs that have sophisticated ways of measuring and representing relatedness among organisms.
- Phylogenetic trees and cladograms are dynamic (i.e., phylogenetic trees and cladograms are constantly being revised), based on the biological data used, new mathematical and computational ideas, and current and emerging knowledge.

1.C: Life continues to evolve within a changing environment.

1.C.1: Speciation and extinction have occurred throughout the Earth's history.

- Speciation rates can vary, especially when adaptive radiation occurs when new habitats become available.
- Species extinction rates are rapid at times of ecological stress.
    - Major extinctions
    - Human impact

1.C.2: Speciation may occur when two populations become reproductively isolated from each other.

- Speciation results in diversity of life forms. Species can be physically separated by a geographic barrier such as an ocean or a mountain range, or various pre-and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow.
- New species arise from reproductive isolation over time, which can involve scales of hundreds of thousands or even millions of years, or speciation can occur rapidly through mechanisms such as polyploidy in plants.

1.C.3: Populations of organisms continue to evolve.

- ❑ Scientific evidence supports the idea that evolution has occurred in all species.
- ❑ Scientific evidence supports the idea that evolution continues to occur.
    - ❑ Chemical resistance
    - ❑ Emergent diseases
    - ❑ Observed directional phenotypic change

1.D: The origin of living systems is explained by natural processes.

1.D.1: There are several hypotheses about the natural origin of life on Earth, each with supporting scientific evidence.

- ❑ Scientific evidence supports the various models.
    - ❑ Abiotic synthesis
    - ❑ RNA world hypothesis

1.D.2: Scientific evidence from many different disciplines supports models of the origin of life.

- ❑ Geological evidence provides support for models of the origin of life on Earth.
    - ❑ Earth age
    - ❑ Miller-Urey experiment
- ❑ Molecular and genetic evidence from extant and extinct organisms indicates that all organisms on Earth share a common ancestral origin of life.
    - ❑ Similar building blocks
    - ❑ Universal genetic code

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

2.A: Growth, reproduction and maintenance of the organization of living systems require free energy and matter.

2.A.1: All living systems require constant input of free energy.

- ❑ Life requires a highly ordered system.
    - ❑ Order maintained by free energy input.
    - ❑ Loss of order = death
    - ❑ Disorder/entropy offset by processes that maintain order
- ❑ Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.
    - ❑ Processes are coupled.
    - ❑ Input must exceed loss.
- ❑ Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway.
    - ❑ Krebs, glycolysis, Calvin, fermentation
- ❑ Organisms use free energy to maintain organization, grow and reproduce.
    - ❑ Various strategies to regulate body temperature
        - ❑ Endothermy
        - ❑ Ectothermy
    - ❑ Reproduction and rearing of offspring require free energy beyond that used for maintenance and growth. Different organisms use various reproductive strategies in response to energy availability.
        - ❑ Seasonal reproduction
        - ❑ Life-history
    - ❑ There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms — generally, the smaller the organism, the higher the metabolic rate.

        - ❑ Excess acquired free energy versus required free energy expenditure results in energy storage or growth.
        - ❑ Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.
- ❑ Changes in free energy availability can result in changes in population size.
- ❑ Changes in free energy availability can result in disruptions to an ecosystem.
    - ❑ Alter producer level

2.A.2: Organisms capture and store free energy for use in biological processes.

- ❑ Autotrophs capture free energy from physical sources in the environment.
    - ❑ Photoautotrophs
    - ❑ Chemoautotrophs
- ❑ Heterotrophs capture free energy present in carbon compounds produced by other organisms.
    - ❑ Hydrolysis of carbs, lipids and proteins
    - ❑ Fermentation
- ❑ Different energy-capturing processes use different types of electron acceptors.
    - ❑ $NADP^+$
    - ❑ O_2
- ❑ The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture free energy present in light to yield ATP and NADPH, which power the production of organic molecules.
    - ❑ Photosystems I and II
    - ❑ Chlorophylls
    - ❑ Chemiosmosis/Proton Gradient
    - ❑ ATP Synthase
- ❑ Photosynthesis first evolved in prokaryotic organisms; scientific evidence supports that prokaryotic (bacterial) photosynthesis was responsible for the production of an oxygenated atmosphere; prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis.
- ❑ Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.
    - ❑ Glycolysis
    - ❑ Redox
    - ❑ Pyruvate
    - ❑ Krebs cycle (substrate level phosphorylation)
    - ❑ NADH and $FADH_2$
- ❑ The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes.
    - ❑ Chemiosmosis/Proton Gradient
    - ❑ ATP Synthase
    - ❑ Compare mitochondria to prokaryotes
    - ❑ Decoupling oxidative phosphorylation from electron transport for thermoregulation
- ❑ Free energy becomes available for metabolism by the conversion of ADP → ATP, which is coupled to many steps in metabolic pathways.

2.A.3: Organisms must exchange matter with the environment to grow, reproduce and maintain organization.

- ❑ Molecules and atoms from the environment are necessary to build new molecules.
    - ❑ Carbon - all compounds
    - ❑ Nitrogen - proteins and nucleic acids
    - ❑ Phosphorus - nucleic acids and lipids
    - ❑ Water - properties

- ❑ Surface area-to-volume ratios affect a biological system’s ability to obtain necessary resources or eliminate waste products.
    - ❑ Demand for materials increase as ratio decreases
        - ❑ Root hairs
        - ❑ Alveoli
        - ❑ Villi and microvilli
    - ❑ Better to be smaller

2.B: Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.

2.B.1: Cell membranes are selectively permeable due to their structure.

- ❑ Cell membranes separate the internal environment of the cell from the external environment.
- ❑ Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.
    - ❑ Phospholipids
    - ❑ Proteins
    - ❑ Cholesterol
    - ❑ Glycolipids and glycoproteins
    - ❑ Small uncharged easier to pass across
- ❑ Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.
    - ❑ Cellulose in plants
    - ❑ Prokaryotes and fungi

2.B.2: Growth and dynamic homeostasis are maintained by the constant movement of molecules across membranes.

- ❑ Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.
    - ❑ Import resources, export wastes
    - ❑ Facilitated diffusion of charged and polar molecules
    - ❑ Hypertonic, hypotonic, isotonic
- ❑ Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration.
- ❑ The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.
    - ❑ Exocytosis
    - ❑ Endocytosis

2.B.3: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

- ❑ Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface area where reactions can occur.
- ❑ Membranes and membrane-bound organelles in eukaryotic cells localize (compartmentalize) intracellular metabolic processes and specific enzymatic reactions.
    - ❑ ER
    - ❑ Mitochondria
    - ❑ Chloroplasts
    - ❑ Golgi
    - ❑ Nuclear Envelope
- ❑ Archaea and Bacteria generally lack internal membranes and organelles and have a cell wall.

2.C: Organisms use feedback mechanisms to regulate growth and reproduction, and to maintain dynamic homeostasis.

2.C.1: Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

- ❑ Negative feedback mechanisms maintain dynamic homeostasis for a particular condition (variable) by regulating physiological processes, returning the changing condition back to its target set point.
  - ❑ Operons
  - ❑ Temperature regulation
- ❑ Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved farther away from the initial set-point. Amplification occurs when the stimulus is further activated which, in turn, initiates an additional response that produces system change.
  - ❑ Lactation
  - ❑ Labor
  - ❑ Ripening of fruit
- ❑ Alteration in the mechanisms of feedback often results in deleterious consequences.
  - ❑ Diabetes mellitus and insulin
  - ❑ Dehydration and ADH

2.C.2: Organisms respond to changes in their external environments.

- ❑ Organisms respond to changes in their environment through behavioral and physiological mechanisms.
  - ❑ Photoperiodism
  - ❑ Phototropism
  - ❑ Hibernation
  - ❑ Migration
  - ❑ Taxis and kinesis
  - ❑ Chemotaxis
  - ❑ Nocturnal/diurnal activity
  - ❑ Shivering and sweating

2.D: Growth and dynamic homeostasis of a biological system are influenced by changes in the system's environment.

2.D.1: All biological systems from cells and organisms to populations, communities and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.

- ❑ Cell activities are affected by interactions with biotic and abiotic factors.
  - ❑ Density
  - ❑ Temperature
  - ❑ Water
  - ❑ Sunlight
- ❑ Organism activities are affected by interactions with biotic and abiotic factors.
  - ❑ Symbiotic Relationships
  - ❑ Predator-Prey
  - ❑ Water, nutrients, temperature, salinity, pH
- ❑ The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.
  - ❑ Water and nutrients
  - ❑ Food chains/webs
  - ❑ Species diversity
  - ❑ Algal blooms

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

- ❑ Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions.
- ❑ Organisms have various mechanisms for obtaining nutrients and eliminating wastes.
  - ❑ Gas exchange in plants
  - ❑ Variations of digestive systems
  - ❑ Variations of respiratory systems
  - ❑ Nitrogenous waste production and elimination
- ❑ Homeostatic control systems in species of microbes, plants and animals support common ancestry.
  - ❑ Excretory systems
  - ❑ Osmoregulation
  - ❑ Circulatory systems
  - ❑ Countercurrent heat exchange

2.D.3: Biological systems are affected by disruptions to their dynamic homeostasis.

- ❑ Disruptions at the molecular and cellular levels affect the health of the organism.
  - ❑ Toxic substances
  - ❑ Dehydration
  - ❑ Immunological responses to pathogens, toxins and allergens
- ❑ Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.
  - ❑ Invasive species
  - ❑ Human impact
  - ❑ Natural disturbances

2.D.4: Plants and animals have a variety of chemical defenses against infections that affect dynamic homeostasis.

- ❑ Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.
  - ❑ Plants - infection triggers chemical response
- ❑ Mammals use specific immune responses triggered by natural or artificial agents that disrupt dynamic homeostasis.
  - ❑ Cell mediated
  - ❑ Humoral
  - ❑ Second exposure

2.E: Many biological processes involved in growth, reproduction and dynamic homeostasis include temporal regulation and coordination.

2.E.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.

- ❑ Observable cell differentiation results from the expression of genes for tissue-specific proteins.
- ❑ Induction of transcription factors during development results in sequential gene expression.
  - ❑ Homeotic genes
  - ❑ Embryonic induction
  - ❑ Temp/water on seed germination
  - ❑ Genetic mutations and abnormal development
  - ❑ Genetic transplantation support the link between gene expression and normal development
  - ❑ microRNAs
- ❑ Programmed cell death (apoptosis) plays a role in the normal development and differentiation.
  - ❑ Fingers/toes
  - ❑ Immune function
  - ❑ *C. elegans* development

- Flower development

Essential knowledge 2.E.2: Timing and coordination of physiological events are regulated by multiple mechanisms.

- In plants, physiological events involve interactions between environmental stimuli and internal molecular signals.
  - Phototropism
  - Photoperiodism
- In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.
  - Circadian rhythms
  - Diurnal/nocturnal
  - Jet lag
  - Hibernation, estivation, migration
- In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.
  - Quorum sensing in bacteria

2.E.3: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.

- Individuals can act on information and communicate it to others.
  - Innate behaviors
  - Learning
- Responses to information and communication of information are vital to natural selection.
  - Phototropism
  - Photoperiodism
  - Hibernation, estivation, migration
  - Cooperative behavior (resource partitioning, mutualism, pollination)

Big Idea 3: Living systems store, retrieve, transmit and respond to information essential to life processes.

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

3.A.1: DNA, and in some cases RNA, is the primary source of heritable information.

- Genetic information is transmitted from one generation to the next through DNA or RNA.
  - Circular vs. linear chromosomes
  - Plasmids
  - Proof DNA was the genetic molecule (Watson, Crick, Wilkins, Franklin, Avery-MacLeod-McCarty, Hershey-Chase)
  - Semiconservative replication
  - Retroviruses
- DNA and RNA molecules have structural similarities and differences that define function.
  - Nucleotide structure
  - Overall structural differences
  - Base pairing
  - Purines and pyrimidines
  - RNA types (mRNA, tRNA, rRNA, RNAi)
- Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.
  - RNA polymerase
  - Transcript modifications (poly-A tail, GTP cap, introns)
  - Translation (initiation, elongation, termination)
- Phenotypes are determined through protein activities.

    - ❑ Enzymatic reactions
    - ❑ Transport
    - ❑ Synthesis
    - ❑ Degradation
- ❑ Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.
    - ❑ Electrophoresis
    - ❑ Plasmid-based transformation
    - ❑ Restriction enzyme analysis (creating RFLP)
    - ❑ PCR
- ❑ *Illustrative examples of products of genetic engineering include:*
    - ❑ GMO
    - ❑ Transgenic animals
    - ❑ Cloned animals
    - ❑ Pharmaceuticals

3.A.2: In eukaryotes, heritable information is passed to the next generation via processes that include the cell cycle and mitosis or meiosis plus fertilization.

- ❑ The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell.
    - ❑ Interphase
    - ❑ Checkpoints
    - ❑ Cyclins
    - ❑ Mitosis
    - ❑ G0
- ❑ Mitosis passes a complete genome from the parent cell to daughter cells.
    - ❑ Role in organisms
    - ❑ General process (names of phases not needed)
- ❑ Meiosis, a reduction division, followed by fertilization ensures genetic diversity in sexually reproducing organisms.
    - ❑ Importance
    - ❑ Chromosome movement
    - ❑ Crossing over
    - ❑ Fertilization

3.A.3: The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parent to offspring.

- ❑ Rules of probability can be applied to analyze passage of single gene traits from parent to offspring.
- ❑ Segregation and independent assortment of chromosomes result in genetic variation.
    - ❑ Applies to genes on different chromosomes
    - ❑ Linked genes and recombination
    - ❑ Patterns (mono-, di-, sex linked, linked genes) can be predicted based on data
- ❑ Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.
    - ❑ Sickle cell
    - ❑ Tay-Sachs
    - ❑ Huntington's
    - ❑ Color blindness
    - ❑ Trisomy 21
    - ❑ Klinefelter's
- ❑ Many ethical, social and medical issues surround human genetic disorders.
    - ❑ Reproduction issues
    - ❑ Ownership of genetic information, privacy

3.A.4: The inheritance pattern of many traits cannot be explained by simple Mendelian genetics.

- Many traits are the product of multiple genes and/or physiological processes.
  - Predicted ratios differ from observed ratios
- Some traits are determined by genes on sex chromosomes.
  - Y is small and carries few genes
  - XX and XY genotypes
  - Milk production and male pattern baldness
- Some traits result from non-nuclear inheritance.
  - Chloroplasts and mitochondria.
  - Maternal inheritance of mitochondria in animals

3.B: Expression of genetic information involves cellular and molecular mechanisms.

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.
  - Promoters
  - Terminators
  - Enhancers
  - Regulatory gene
- Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.
  - Operons
  - Inducer
  - Repressor
- In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.
  - Transcription factors
- Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.

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

- Signal transmission within and between cells mediates gene expression.
  - Cytokines and cellular division
  - SRY
  - Ethylene
- Signal transmission within and between cells mediates cell function.
  - HOX genes
  - p53 and cancer

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

3.C.1: Changes in genotype can result in changes in phenotype.

- Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.
  - Mutations can be positive, negative or neutral
- 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.
  - Effect of mutation on organism depends on the environment.
- Errors in mitosis or meiosis can result in changes in phenotype.
  - Plants - sterility or increased vigor of polyploids
  - Humans - developmental limitations

- ❑ Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected by environmental conditions.
    - ❑ Antibiotic, pesticide resistance
    - ❑ Sickle cell and heterozygote advantage

3.C.2: Biological systems have multiple processes that increase genetic variation.

- ❑ The imperfect nature of DNA replication and repair increases variation.
- ❑ 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.
- ❑ Sexual reproduction in eukaryotes involving gamete formation, including crossing-over during meiosis and the random assortment of chromosomes during meiosis, and fertilization serve to increase variation. Reproduction processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.

3.C.3: Viral replication results in genetic variation, and viral infection can introduce genetic variation into the hosts.

- ❑ Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms.
    - ❑ Rapid replication
    - ❑ Lytic cycle
    - ❑ High mutation rate
    - ❑ Related viruses can combine if in same host
    - ❑ HIV
- ❑ The reproductive cycles of viruses facilitate transfer of genetic information.
    - ❑ Transduction in bacteria
    - ❑ Transposons
    - ❑ Lysogenic cycle

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

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

- ❑ Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.
- ❑ Correct and appropriate signal transduction processes are generally under strong selective pressure.
- ❑ In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.
    - ❑ Quorum sensing
    - ❑ Pheromones to trigger reproduction and developmental pathways
- ❑ In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.
    - ❑ Epinephrine
    - ❑ Temperature determination of sex
    - ❑ DNA repair mechanisms

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

- ❑ Cells communicate by cell-to-cell contact.
    - ❑ Antigen presenting cells, helper T-cells and killer T-cells
    - ❑ Plasmodesmata
- ❑ Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.
    - ❑ Neurotransmitters

        - Plant immune response
        - Quorum sensing
    - Signals released by one cell type can travel long distances to target cells of another cell type.
        - Endocrine glands
        - Insulin
        - HGH
        - Thyroid hormones
        - Testosterone/estrogen

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

- Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein.
    - G-protein linked receptors
    - Ligand-gated ion channels
    - Receptor tyrosine kinases
- Signal transduction is the process by which a signal is converted to a cellular response.
    - Secondary messengers
    - Protein modifications
    - Phosphorylation

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

- Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.
    - Diabetes, autoimmune disease, cancer, cholera
    - Neurotoxins
    - Poisons
    - Pesticides
    - Drugs

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

3.E.1: Individuals can act on information and communicate it to others.

- Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.
    - Fight or flight response
    - Predator warnings
    - Protection of young
    - Plant-plant interactions due to herbivory
    - Avoidance responses
- Communication occurs through various mechanisms.
    - Living systems have a variety of signal behaviors or cues that produce changes in the behavior of other organisms and can result in differential reproductive success.
        - Herbivory responses, Territorial marking in mammals, Coloration in flowers
    - Animals use visual, audible, tactile, electrical and chemical signals to indicate dominance, find food, establish territory and ensure reproductive success.
        - Bee dances, Birds songs, Territorial marking in mammals, Pack behavior in animals, Herd, flock, and schooling behavior in animals, Predator warning, Colony and swarming behavior in insects, Coloration
- Responses to information and communication of information are vital to natural selection and evolution.
    - Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.
        - Parent and offspring interactions, Migration patterns, Courtship and mating behaviors, Foraging in bees and other animals, Avoidance behavior to electric fences, poisons, or traps
    - Cooperative behavior tends to increase the fitness of the individual and the survival of the population.

        - Pack behavior in animals, Herd, flock and schooling behavior in animals, Predator warning, Colony and swarming behavior in insects

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

- The neuron is the basic structure of the nervous system that reflects function.
    - A typical neuron has a cell body, axon and dendrites. Many axons have a myelin sheath that acts as an electrical insulator.
    - The structure of the neuron allows for the detection, generation, transmission and integration of signal information.
    - Schwann cells, which form the myelin sheath, are separated by gaps of unsheathed axon over which the impulse travels as the signal propagates along the neuron.
- Action potentials propagate impulses along neurons.
    - Membranes of neurons are polarized by the establishment of electrical potentials across the membranes.
    - In response to a stimulus, Na+ and K+ gated channels sequentially open and cause the membrane to become locally depolarized.
    - Na+ /K+ pumps, powered by ATP, work to maintain membrane potential.
- Transmission of information between neurons occurs across synapses.
    - In most animals, transmission across synapses involves chemical messengers called neurotransmitters.
        - Acetylcholine, Epinephrine, Norepinephrine, Dopamine, Serotonin, GABA
    - Transmission of information along neurons and synapses results in a response.
    - The response can be stimulatory or inhibitory.
- Different regions of the vertebrate brain have different functions.
    - Vision, Hearing, Muscle movement, Abstract thought and emotions, Neuro-hormone production, Forebrain (cerebrum), midbrain (brainstem) and hindbrain (cerebellum), Right and left cerebral hemispheres in humans

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

4.A: Interactions within biological systems lead to complex properties.

4.A.1: The subcomponents of biological molecules and their sequence determine the properties of that molecule.

- Structure and function of polymers are derived from the way their monomers are assembled.
    - In nucleic acids, biological information is encoded in sequences of nucleotide monomers. Each nucleotide has structural components: a five-carbon sugar (deoxyribose or ribose), a phosphate and a nitrogen base (adenine, thymine, guanine, cytosine or uracil). DNA and RNA differ in function and differ slightly in structure, and these structural differences account for the differing functions.
    - In proteins, the specific order of amino acids in a polypeptide (primary structure) interacts with the environment to determine the overall shape of the protein, which also involves secondary tertiary and quaternary structure and, thus, its function. The R group of an amino acid can be categorized by chemical properties (hydrophobic, hydrophilic and ionic), and the interactions of these R groups determine structure and function of that region of the protein.
    - In general, lipids are nonpolar; however, phospholipids exhibit structural properties, with polar regions that interact with other polar molecules such as water, and with nonpolar regions where differences in saturation determine the structure and function of lipids.
    - Carbohydrates are composed of sugar monomers whose structures and bonding with each other by dehydration synthesis determine the properties and functions of the molecules. Illustrative examples include: cellulose versus starch.
- Directionality influences structure and function of the polymer.

    - Nucleic acids have ends, defined by the 3' and 5' carbons of the sugar in the nucleotide, that determine the direction in which complementary nucleotides are added during DNA synthesis and the direction in which transcription occurs (from 5' to 3').
    - Proteins have an amino end and a carboxyl end, and consist of a linear sequence of amino acids connected by the formation of peptide bonds by dehydration synthesis between the amino and carboxyl groups of adjacent monomers.
    - The nature of the bonding between carbohydrate subunits determines their relative orientation in the carbohydrate, which then determines the secondary structure of the carbohydrate.

4.A.2: The structure and function of subcellular components, and their interactions, provide essential cellular processes.

- Ribosomes are small, universal structures comprised of two interacting parts: ribosomal RNA and protein. In a sequential manner, these cellular components interact to become the site of protein synthesis where the translation of the genetic instructions yields specific polypeptides.
- Endoplasmic reticulum occurs in two forms: smooth and rough.
    - Rough endoplasmic reticulum functions to compartmentalize the cell, serves as mechanical support, provides site-specific protein synthesis with membrane-bound ribosomes and plays a role in intracellular transport.
    - In most cases, smooth ER synthesizes lipids.
- The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs (cisternae).
    - Functions of the Golgi include synthesis and packaging of materials (small molecules) for transport (in vesicles), and production of lysosomes.
- Mitochondria specialize in energy capture and transformation.
    - Mitochondria have a double membrane that allows compartmentalization within the mitochondria and is important to its function.
    - The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds called cristae.
    - Cristae contain enzymes important to ATP production; cristae also increase the surface area for ATP production.
- Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials and programmed cell death (apoptosis). Lysosomes carry out intracellular digestion in a variety of ways.
- A vacuole is a membrane-bound sac that plays roles in intracellular digestion and the release of cellular waste products. In plants, a large vacuole serves many functions, from storage of pigments or poisonous substances to a role in cell growth. In addition, a large central vacuole allows for a large surface area to volume ratio.
- Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis.
    - The structure and function relationship in the chloroplast allows cells to capture the energy available in sunlight and convert it to chemical bond energy via photosynthesis.
    - Chloroplasts contain chlorophylls, which are responsible for the green color of a plant and are the key light-trapping molecules in photosynthesis. There are several types of chlorophyll, but the predominant form in plants is chlorophyll *a*.
    - Chloroplasts have a double outer membrane that creates a compartmentalized structure, which supports its function. Within the chloroplasts are membrane-bound structures called thylakoids. Energy-capturing reactions housed in the thylakoids are organized in stacks, called "grana," to produce ATP and, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO2 are converted to carbohydrates.

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.

4.A.4: Organisms exhibit complex properties due to interactions between their constituent parts.

- ❑ Interactions and coordination between organs provide essential biological activities.
    - ❑ Stomach and small intestines, Kidney and bladder, Root, stem and leaf
- ❑ Interactions and coordination between systems provide essential biological activities.
    - ❑ Respiratory and circulatory, Nervous and muscular, Plant vascular and leaf

4.A.5: Communities are composed of populations of organisms that interact in complex ways.

- ❑ The structure of a community is measured and described in terms of species composition and species diversity.
- ❑ Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community.
    - ❑ Predator/prey relationships spreadsheet model, Symbiotic relationship, Graphical representation of field data, Introduction of species, Global climate change models
- ❑ Mathematical models and graphical representations are used to illustrate population growth patterns and interactions.
    - ❑ Reproduction without constraints results in the exponential growth of a population.
    - ❑ A population can produce a density of individuals that exceeds the system's resource availability.
    - ❑ As limits to growth due to density-dependent and density- independent factors are imposed, a logistic growth model generally ensues.
    - ❑ Demographics data with respect to age distributions and fecundity can be used to study human populations.

4.A.6: Interactions among living systems and with their environment result in the movement of matter and energy.

- ❑ Energy flows, but matter is recycled.
- ❑ Changes in regional and global climates and in atmospheric composition influence patterns of primary productivity.
- ❑ Organisms within food webs and food chains interact.
- ❑ Food webs and food chains are dependent on primary productivity.
- ❑ Models allow the prediction of the impact of change in biotic and abiotic factors.
    - ❑ Competition for resources and other factors limits growth and can be described by the logistic model.
    - ❑ Competition for resources, territoriality, health, predation, accumulation of wastes and other factors contribute to density- dependent population regulation.
- ❑ Human activities impact ecosystems on local, regional and global scales.
    - ❑ As human populations have increased in numbers, their impact on habitats for other species have been magnified.
    - ❑ In turn, this has often reduced the population size of the affected species and resulted in habitat destruction and, in some cases, the extinction of species.
- ❑ Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.

4.B: Competition and cooperation are important aspects of biological systems.

4.B.1: Interactions between molecules affect their structure and function.

- Change in the structure of a molecular system may result in a change of the function of the system.
- The shape of enzymes, active sites and interaction with specific molecules are essential for basic functioning of the enzyme.
    - For an enzyme-mediated chemical reaction to occur, the substrate must be complementary to the surface properties (shape and charge) of the active site. In other words, the substrate must fit into the enzyme's active site.
    - Cofactors and coenzymes affect enzyme function; this interaction relates to a structural change that alters the activity rate of the enzyme. The enzyme may only become active when all the appropriate cofactors or coenzymes are present and bind to the appropriate sites on the enzyme.
- Other molecules and the environment in which the enzyme acts can enhance or inhibit enzyme activity. Molecules can bind reversibly or irreversibly to the active or allosteric sites, changing the activity of the enzyme.
- The change in function of an enzyme can be interpreted from data regarding the concentrations of product or substrate as a function of time. These representations demonstrate the relationship between an enzyme's activity, the disappearance of substrate, and/ or presence of a competitive inhibitor.

4.B.2: Cooperative interactions within organisms promote efficiency in the use of energy and matter.

- Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole.
    - At the cellular level, the plasma membrane, cytoplasm and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell.
    - Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.
        - Exchange of gases, Circulation of fluids, Digestion of food, Excretion of wastes
    - Interactions among cells of a population of unicellular organisms can be similar to those of multicellular organisms, and these interactions lead to increased efficiency and utilization of energy and matter.
        - Bacterial community in the rumen of animals, Bacterial community in and around deep sea vents

4.B.3: Interactions between and within populations influence patterns of species distribution and abundance.

- Interactions between populations affect the distributions and abundance of populations.
    - Competition, parasitism, predation, mutualism and commensalism can affect population dynamics.
    - Relationships among interacting populations can be characterized by positive and negative effects, and can be modeled mathematically (predator/prey, epidemiological models, invasive species).
    - Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.
- A population of organisms has properties that are different from those of the individuals that make up the population. The cooperation and competition between individuals contributes to these different properties.
- Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance.
    - Loss of keystone species, Kudzu, Dutch elm disease

4.B.4: Distribution of local and global ecosystems changes over time.

- Human impact accelerates change at local and global levels.
    - Logging, slash and burn agriculture, urbanization, monocropping, infrastructure development (dams, transmission lines, roads), and global climate change threaten ecosystems and life on Earth.
    - An introduced species can exploit a new niche free of predators or competitors, thus exploiting new resources.

        - Dutch elm disease, Potato blight, Small pox [historic example for Native Americans]
- Geological and meteorological events impact ecosystem distribution.
    - Biogeographical studies illustrate these changes.
        - El Niño, Continental drift, Meteor impact on dinosaurs

4.C: Naturally occurring diversity among and between components within biological systems affects interactions with the environment.

4.C.1: Variation in molecular units provides cells with a wider range of functions.
- Variations within molecular classes provide cells and organisms with a wider range of functions.
    - Different types of phospholipids in cell membranes
    - Different types of hemoglobin
    - MHC proteins
    - Chlorophylls
    - Molecular diversity of antibodies in response to an antigen
- Multiple copies of alleles or genes (gene duplication) may provide new phenotypes.
    - 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.
    - Gene duplication creates a situation in which one copy of the gene maintains its original function, while the duplicate may evolve a new function.
        - The antifreeze gene in fish

4.C.2: Environmental factors influence the expression of the genotype in an organism.
- Environmental factors influence many traits both directly and indirectly.
    - Height and weight in humans
    - Flower color based on soil pH
    - Seasonal fur color in arctic animals
    - Sex determination in reptiles
    - Density of plant hairs as a function of herbivory
    - Effect of adding lactose to a Lac+ bacterial culture
    - Effect of increased UV on melanin production in animals
    - Presence of the opposite mating type on pheromones production in yeast and other fungi
- An organism's adaptation to the local environment reflects a flexible response of its genome.
    - Darker fur in cooler regions of the body in certain mammal species
    - Alterations in timing of flowering due to climate changes

4.C.3: The level of variation in a population affects population dynamics.
- Population ability to respond to changes in the environment is affected by genetic diversity. Species and populations with little genetic diversity are at risk for extinction.
    - California condors
    - Black-footed ferrets
    - Prairie chickens
    - Potato blight causing the potato famine
    - Corn rust affects on agricultural crops
    - Tasmanian devils and infectious cancer
- Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions.
    - Not all animals in a population stampede.
    - Not all individuals in a population in a disease outbreak are equally affected; some may not show symptoms, some may have mild symptoms, or some may be naturally immune and resistant to the disease.

- ❑ Allelic variation within a population can be modeled by the Hardy- Weinberg equation(s).

4.C.4: The diversity of species within an ecosystem may influence the stability of the ecosystem.

- ❑ Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.
- ❑ Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem. The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem, and when they are removed from the ecosystem, the ecosystem often collapses.