

Course Description:

AP Biology

Essential Knowledge

Demonstrated Evidence

Enduring Understanding

Big Idea

Illustrative Examples

Science Practices

Learning Objectives

About AP®

AP® enables students to pursue college-level studies while still in high school. Through more than 30 courses, each culminating in a rigorous exam, AP provides willing and academically prepared students with the opportunity to earn college credit and/or advanced placement. Taking AP courses also demonstrates to college admission officers that students have sought out the most rigorous course work available to them.

Each AP course is modeled upon a comparable college course, and college and university faculty play a vital role in ensuring that AP courses align with college-level standards. Talented and dedicated AP teachers help AP students in classrooms around the world develop and apply the content knowledge and skills they will need later in college.

Each AP course concludes with a college-level assessment developed and scored by college and university faculty as well as experienced AP teachers. AP Exams are an essential part of the AP experience, enabling students to demonstrate their mastery of college-level course work. More than percent of four-year colleges and universities in the United States grant students credit, placement, or both on the basis of successful AP Exam scores. Universities in more than 60 countries recognize AP Exam scores in the admission process and/or award credit and placement for qualifying scores.

Visit www.collegeboard.org/ap/creditpolicy to view AP credit and placement policies at more than 1,000 colleges and universities. Performing well on an AP Exam means more than just the successful completion of a course; it is a gateway to success in college. Research consistently shows that students who score a 3 or higher on AP Exams typically experience greater academic success in college and have higher graduation rates than otherwise comparable non-AP peers. Additional AP studies are available at www.collegeboard.org/research.

How AP Courses and Exams Are Developed

AP courses and exams are designed by committees of college faculty and expert AP teachers who ensure that each AP subject reflects and assesses college-level expectations. To find a list of each subject's current AP Development Committee members, please visit press.collegeboard.org/ap/committees. AP Development Committees define the scope and expectations of the course, articulating through a curriculum framework what students should know and be able to do upon completion of the AP course. Their work is informed by data collected from a range of colleges and universities to ensure that AP course work reflects current scholarship and advances in the discipline.

The AP Development Committees are also responsible for drawing clear and well-articulated connections between the AP course and AP Exam--work that includes designing and approving exam specifications and exam questions. The AP Exam development process is a multiyear endeavor; all AP Exams undergo extensive review, revision, piloting, and analysis to ensure that questions are high quality and fair and that there is an appropriate spread of difficulty across the questions.

Throughout AP course and exam development, the College Board gathers feedback from various stakeholders in both secondary schools and higher education institutions. This feedback is carefully considered to ensure that AP courses and exams are able to provide students with a college-level learning experience and the opportunity to demonstrate their qualifications for advanced placement upon college entrance.

How AP Exams Are Scored

The exam scoring process, like the course and exam development process, relies on the expertise of both AP teachers and college faculty. While multiple-choice questions are scored by machine, the free-response questions are scored by thousands of college faculty and expert AP teachers at the annual AP Reading. AP Exam Readers are thoroughly trained, and their work is monitored throughout the Reading for fairness and consistency. In each subject, a highly respected college faculty member fills the role of Chief Reader, who, with the help of AP readers in leadership positions, maintains the accuracy of the scoring standards. Scores on the free-response questions are weighted and combined with the results of the computer-scored multiple-choice questions, and this raw score is converted into a composite AP score of 5, 4, 3, 2, or 1.

The score-setting process is both precise and labor intensive, involving numerous psychometric analyses of the results of a specific AP Exam in a specific year and of the particular group of students who took that exam. Additionally, to ensure alignment with college-level standards, part of the score-setting process involves comparing the performance of AP students with the performance of students enrolled in comparable courses in colleges throughout the United States. In general, the AP composite score points are set so that the lowest raw score need to earn an AP score of 5 is equivalent to the average score among college students earning grades of A in the college course. Similarly, AP Exam scores of 4 are equivalent to college grades of B. AP Exam scores of 3 are equivalent to college grades of C.

Using and Interpreting AP Scores

The extensive work done by college faculty and AP teachers in the development of the course and the exam and throughout the scoring process ensures that AP Exam scores accurately represent students' achievement in the equivalent college course. While colleges and universities are responsible for setting their own credit and placement policies, AP scores signify how qualified students are to receive college credit or placement:

AP Score Recommendation

- 5: Extremely well qualified
- 4: Well qualified
- 3: Qualified
- 2: Possibly qualified
- 1: No recommendation

Additional Resources

Visit apcentral.collegeboard.org for more information about the AP Program.

AP Biology Curriculum Framework

Introduction

Given the speed with which scientific discoveries and research continuously expand scientific knowledge, we are faced with the challenge of balancing breadth of content coverage with depth of understanding. The revised AP[®] Biology course addresses this challenge by shifting from a traditional “content coverage” model of instruction to one that focuses on enduring, conceptual understandings and the content that supports them. This approach will enable us to spend less time on factual recall and more time on inquiry-based learning of essential concepts, and will help us develop the reasoning skills necessary to engage in the science practices used throughout the study of AP Biology.

To foster this deeper level of learning, the breadth of content coverage in AP Biology is defined in a way that distinguishes content essential to support the enduring understandings from the many examples or applications that can overburden the course. Illustrative examples are provided that offer a variety of optional instructional contexts to help achieve deeper understanding. Additionally, content that is outside the scope of the course and exam is also identified.

An AP Biology course designed using this curriculum framework as its foundation will also develop advanced inquiry and reasoning skills, such as designing a plan for collecting data, analyzing data, applying mathematical routines, and connecting concepts in and across domains. The result will be readiness for the study of advanced topics in subsequent college courses—a goal of every AP course.

The revised AP Biology course is equivalent to a two-semester college introductory biology course and has been endorsed enthusiastically by higher education officials. The prerequisites for AP Biology are high school courses in biology and chemistry.

The Emphasis on Science Practices

A practice is a way to coordinate knowledge and skills in order to accomplish a goal or task. The science practices establish lines of evidence and use them to develop and refine testable explanations and predictions of natural phenomena. Because content, inquiry and reasoning are equally important in AP Biology, each learning objective described in the concept outline combines content with inquiry and reasoning skills described in the science practices.

The science practices that follow the concept outline of this framework capture important aspects of the work that scientists engage in, at the level of competence expected in AP Biology coursework. Within the learning objectives, these practices are effectively integrated with the course content, and instruction is designed with these practices in mind.

Overview of the Concept Outline

The **key concepts** and related content that define the revised AP Biology course and exam are organized around a few underlying principles called the **big ideas**, which encompass the core scientific principles, theories and processes governing living organisms and biological systems. For each of the big ideas, enduring understandings, which incorporate the core concepts that should be retained from the learning experience, are also identified. Each **enduring understanding** is followed by statements of the **essential knowledge** necessary to support it. Unless otherwise specified, all of the details in the outline are required elements of the course and may be included in the AP Biology Exam. To help distinguish content that is essential to support the enduring understandings from the many possible examples and applications that can overburden a course—and to see where important connections exist among the different content areas—particular content components are emphasized as follows:

Underlying content that must also be taught in order to achieve an understanding of a particular required concept is specified in detail. These additional underlying content components are listed numerically under the required concept and are labeled “Demonstrated Evidence.”

Illustrative examples are suggested contexts for instructional purposes and are not required content components of the course. Knowledge of these contexts will not be assessed on the AP Biology Exam. Nevertheless, the illustrative examples provide suggestions that will support understanding of a particular

required concept. Illustrative examples can also lend themselves to case studies or project-based lessons. We are free to use our own examples and not be limited by solely those listed. The choice of which illustrative example to use (from those that are listed or elsewhere) should be selected according to the availability of data, regional relevance, interests, and expertise. Illustrative examples are designated as bulleted statements and are always labeled: “Illustrative Examples.”

Exclusion statements define content, or specific details about the content that do not need to be included in the course because this level of detail does not foster conceptual understanding. These details will not be assessed on the AP Biology Exam. Exclusion statements are denoted as shown in this example: **X** *Memorization of the names, molecular structures and specific effects of all plant hormones are beyond the scope of the course and the AP Exam.* Note: While illustrative examples and excluded content will not be assessed on the AP Biology Exam, they may be provided in the body of exam questions as background information for the concept and science practice(s) being assessed.

Learning objectives provide clear and detailed articulation of what should be known and be done. Each learning objective is designed to help integrate science practices with specific content, and to provide clear information about expectations regarding the demonstration of knowledge and abilities. Learning objectives are numbered to correspond with each Big Idea (e.g., LO 1.1). Alignment of the learning objectives to the science practices is denoted in brackets.

Science Practices for AP Biology

Science Practice 1: Use representations and models to communicate scientific phenomena and solve scientific problems.

Visual representations and models are indispensable tools for learning and exploring scientific concepts and ideas. Create representations and models using verbal or written explanations that describe biological processes. Use representations and models to illustrate biological processes and concepts; communicate information; make predictions; and describe systems to promote and document understanding. Illustrate examples of representations and models are diagrams describing the relationship between photosynthesis and cellular respiration; the structure and functional relationships of membranes; and diagrams that illustrate chromosome movement in mitosis and meiosis. Using model kits, build three-dimensional representations of organic functional groups, carbohydrates, lipids, proteins and nucleic acids. Demonstrate how chemical structures, such as the Watson and Crick model for DNA, link structure to function at the molecular level and can relate key elements of a process or structure across multiple representations, such as a schematic two-dimensional diagram and a space-filling model of DNA. Refine and/or revise visual representations of biological processes, including energy flow through ecosystems; immunological processes; movement of molecules in and out of cells; and graphs or other visual data representations of experimental results. Use/apply representations and models to make predictions and address scientific questions as well as interpret and create graphs drawn from experimental data.

- 1.1 Create representations and models of natural or man-made phenomena and systems in the domain.
- 1.2 Describe representations and models of natural or man-made phenomena and systems in the domain.
- 1.3 Refine representations and models of natural or man-made phenomena and systems in the domain.
- 1.4 Use representations and models to analyze situations or solve problems qualitatively and quantitatively.
- 1.5 Re-express key elements of natural phenomena across multiple representations in the domain.

Science Practice 2: Use mathematics appropriately.

Routinely use mathematics to solve problems, analyze experimental data, describe natural phenomena, make predictions, and describe processes symbolically. Justify the selection of a particular mathematical routine and apply the routine to describe natural phenomena. Estimate the answers to quantitative questions using simplifying assumptions and use this information to help describe and understand natural phenomena. Examples of the use of mathematics in biology include, but are not limited to, the use of Chi-square in analyzing observed versus predicted inherited patterns; determination of mean and median; use of the Hardy-Weinberg equation to predict changes in gene frequencies in a population; measurements of concentration gradients and osmotic potential; and determination of the rates of chemical reactions, processes and solute concentrations. Measure and collect experimental data with respect to volume, size, mass, temperature, pH, etc. In addition, estimate energy procurement and utilization in biological systems, including ecosystems.

- 2.1 Justify the selection of a mathematical routine to solve problems.
- 2.2 Apply mathematical routines to quantities that describe natural phenomena.
- 2.3 Estimate numerically quantities that describe natural phenomena.

Science Practice 3: Engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

As scientists, how do we know what we know? Facts, concepts and theories fill biology textbooks, but how did scientists discover facts, concepts and theories that make up modern science, such as that cells produce carbon dioxide as a by-product of respiration or that the details for copying the two strands of DNA differ during replication? What historical experiments provided evidence that DNA, not protein, was the hereditary material for living organisms? What scientific evidence supports evolution by natural selection, and how is this different than alternative ideas with respect to evolution and origin of life? To provide deeper understanding of the

concepts, answer: “How do we know what we know?” with, “This is why we know what we know.” Pose, refine and evaluate scientific questions about natural phenomena and investigate answers through experimentation, research, and information gathering and discussion. For example, posing the question: “What happens to photosynthesis at very high, non-biological temperatures?” could result in: literature searches, fact finding and/or designing an experiment to investigate the effect of temperature on chloroplast function, including collecting data, making predictions, drawing conclusions and refining the original question or approaches. Formulate good scientific questions--ones that are amenable to experimental approaches and addressable through evidence-- and distinguish them from other questions that are ethical, social or teleological in nature. Pose and rationally discuss questions that address ethical and civic issues that surround the development and application of scientific knowledge, and controversial issues such as stem cells, cloning, genetically modified organisms, and who should decide what types of biological research are acceptable and which are not.

- 3.1 Pose scientific questions.
- 3.2 Refine scientific questions.
- 3.3 Evaluate scientific questions.

Science Practice 4: Plan and implement data collection strategies appropriate to a particular scientific question.

Experimentation and the collection and analysis of scientific evidence are at the heart of biology. Data can be collected from many different sources: experimental investigation, scientific observation, the findings of others, historic reconstruction and archival records. After posing a question about biology, investigate and arrive at answers through experimentation and reasoning. In this coupled process, justify the selection of the kind of data needed to answer a question. For example, if the question is about how temperature affects enzymatic activity, collect data about temperature while controlling other variables, such as pH and solute concentration. To test a hypothesis about an observation, design an experiment; identify needed controls; identify needed supplies and equipment from a given list of resources; develop or follow an experimental protocol to collect data; analyze data and draw conclusions from the results; and describe the limitations of the experiment and conclusions. In addition, draw conclusions from experimental results of other scientists, e.g., the historical experiments of Fredrick Griffith, Calvin and Krebs, Hershey and Chase, and Watson and Crick.

- 4.1 Justify the selection of the kind of data needed to answer a particular scientific question.
- 4.2 Design a plan for collecting data to answer a particular scientific question.
- 4.3 Collect data to answer a particular scientific question.
- 4.4 Evaluate sources of data to answer a particular scientific question.

Science Practice 5: Perform data analysis and evaluation of evidence.

Analyze data collected from an experimental procedure or from a given source to determine whether the data support or does not support a conclusion or hypothesis. For example, conduct an experiment to determine if light intensity affects the rate of photosynthesis, construct a graph based on the collected data and use the graph to formulate statements, conclusions, and possibly a hypothesis. Alternatively, draw conclusions from a provided data set. For example, given a graph depicting the percent change in the mass of potato cores after exposure to different concentrations of sucrose, estimate the concentration of sucrose within the potato core. Assess the validity of experimental evidence. Using the same example, if given hypothetical data showing that potato cores increase in mass when placed in solutions with lower water potential (a hypertonic solution), explain why the data (evidence) are likely invalid: Since potatoes contain sucrose, they should increase in mass only when placed in solutions with higher water potential (hypotonic). After identifying possible sources of error in an experimental procedure or data set, revise the protocol to obtain more valid results. When presented with a range of data, identify outliers and propose an explanation for them as well as a rationale for how they should be dealt with.

- 5.1 Analyze data to identify patterns or relationships.
- 5.2 Refine observations and measurements based on data analysis.
- 5.3 Evaluate the evidence provided by data sets in relation to a particular scientific question.

Science Practice 6: Work with scientific explanations and theories.

Work with scientific descriptions, explanations and theories that describe biological phenomena and processes. In efforts to answer, “How do we know what we know?” call upon current knowledge and historical experiments, and draw inferences from explorations to justify claims with evidence. For example, cite evidence drawn from the different scientific disciplines that supports natural selection and evolution, such as the geological record, antibiotic-resistance in bacteria, herbicide resistance in plants or how a population bottleneck changes Hardy-Weinberg Equilibrium. Articulate through narrative or annotated visual representation how scientific explanations are refined or revised with the acquisition of new information based on experimentation; for example, describe/explain how advances in molecular genetics made possible a deeper understanding of how genes are carried in DNA and of how genes are expressed to determine phenotypes. New scientific discoveries often depend on advances in technology; for example, only when microscopy was sufficiently advanced could the linkage between chromosomes and the transmission of genetic traits be clearly established. Likewise, the ability to sequence whole genomes allows comparisons between the entire genetic information in different species, and technology is revealing the existence of many previously unknown genes and evolutionary relationships. In addition, use existing knowledge and models to make predictions. For example, when provided a sequence of DNA containing a designated mutational change, predict the effect of the mutation on the encoded polypeptide and propose a possible resulting phenotype. Evaluate the merits of alternative scientific explanations or conclusions.

- 6.1 Justify claims with evidence.
- 6.2 Construct explanations of phenomena based on evidence produced through scientific practices.
- 6.3 Articulate the reasons that scientific explanations and theories are refined or replaced.
- 6.4 Make claims and predictions about natural phenomena based on scientific theories and models.
- 6.5 Evaluate alternative scientific explanations.

Science Practice 7: Connect and relate knowledge across various scales, concepts and representations in and across domains.

Describe through narrative and/or annotated visual representation how biological processes are connected across various scales such as time, size and complexity. For example, DNA sequences, metabolic processes and morphological structures that arise through evolution connect the organisms that compose the tree of life, and use various types of phylogenetic trees/cladograms to show connections and ancestry, and describe how natural selection explains biodiversity. Examples of other connections are photosynthesis at the cellular level and environmental carbon cycling; biomass generation and climate change; molecular and macroevolution; the relation of genotype to phenotype and natural selection; cell signaling pathways and embryonic development; bioenergetics and microbial ecology; and competition and cooperation from molecules to populations. Describe how enduring understandings are connected to other enduring understandings, to a big idea, and how the big ideas in biology connect to one another and to other disciplines. Draw on information from other sciences to explain biological processes; examples include how the conservation of energy affects biological systems; why lipids are nonpolar and insoluble in water; why water exhibits cohesion and adhesion, and why molecules spontaneously move from high concentration to areas of lower concentration, but not vice versa.

- 7.1 Connect phenomena and models across spatial and temporal scales.
- 7.2 Connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas

BIG IDEA: The process of evolution drives the diversity and unity of life.

Evolution is a change in the genetic makeup of a population over time, with natural selection its major driving mechanism. Darwin's theory, which is supported by evidence from many scientific disciplines, states that inheritable variations occur in individuals in a population. Due to competition for limited resources, individuals with more favorable variations or phenotypes are more likely to survive and produce more offspring, thus passing traits to future generations.

In addition to the process of natural selection, naturally occurring catastrophic and human induced events as well as random environmental changes can result in alteration in the gene pools of populations. Small populations are especially sensitive to these forces. A diverse gene pool is vital for the survival of species because environmental conditions change. Mutations in DNA and recombinations during meiosis are sources of variation. Human-directed processes also result in new genes and combinations of alleles that confer new phenotypes. Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.

Scientific evidence supports the idea that both speciation and extinction have occurred throughout Earth's history and that life continues to evolve within a changing environment, thus explaining the diversity of life. New species arise when two populations diverge from a common ancestor and become reproductively isolated. Shared conserved core processes and genomic analysis support the idea that all organisms — Archaea, Bacteria, and Eukarya, both extant and extinct — are linked by lines of descent from common ancestry. Elements that are conserved across all three domains are DNA and RNA as carriers of genetic information, a universal genetic code and many metabolic pathways. Phylogenetic trees graphically model evolutionary history and "descent with modification." However, some organisms and viruses are able to transfer genetic information horizontally.

The process of evolution explains the diversity and unity of life, but an explanation about the *origin* of life is less clear. Experimental models support the idea that chemical and physical processes on primitive Earth could have produced complex molecules and very simple cells. Under laboratory conditions, complex polymers and self-replicating molecules can assemble spontaneously; thus, the first genetic material may not have been DNA, but short sequences of self-replicating RNA that may have served as templates for polypeptide synthesis. Protobiotic formation was most likely followed by the evolution of several primitive groups of bacteria that used various means of obtaining energy. Mutually beneficial associations among ancient bacteria are thought to have given rise to eukaryotic cells.

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

Natural selection is the major driving mechanism of evolution; the essential features of the mechanism contribute to the change in the genetic makeup of a population over time. Darwin's theory of natural selection states that inheritable variations occur in individuals in a population. Due to competition for resources that are often limited, individuals with more favorable variations or phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations. Fitness, the number of surviving offspring left to produce the next generation, is a measure of evolutionary success. Individuals do not evolve, but rather, populations evolve.

The environment is always changing, there is no "perfect" genome, and a diverse gene pool is important for the long-term survival of a species. Genetic variations within a population contribute to the diversity of the gene pool. Changes in genetic information may be silent (with no observable phenotypic effects) or result in a new phenotype, which can be positive, negative or neutral to the organism. The interaction of the environment and the phenotype determines the fitness of the phenotype; thus, the environment does not direct the changes in DNA, but acts upon phenotypes that occur through random changes in DNA. These changes can involve alterations in DNA sequences, changes in gene combinations and/or the formation of new gene combinations.

Although natural selection is usually the major mechanism for evolution, genetic variation in populations can occur through other processes, including mutation, genetic drift, sexual selection and artificial selection. Inbreeding, small population size, nonrandom mating, the absence of migration, and a net lack of mutations can lead to loss of genetic diversity. Human-directed processes such as genetic engineering can also result in new genes and combinations of alleles that confer new phenotypes.

Biological evolution driven by natural selection is supported by evidence from many scientific disciplines, including geology and physical science. In addition, biochemical, morphological, and genetic information from existing and extinct organisms support the concept of natural selection. Phylogenetic trees serve as dynamic models that show common ancestry, while geographical distribution and the fossil record link past and present organisms.

Enduring Understanding 1.A: Change in the genetic makeup of a population over time is evolution.*Illustrative Examples:**Graphical analysis of allele frequencies in a population (h)*

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

- a. According to Darwin's theory of natural selection, competition for limited resources results in differential survival.
- b. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations.
- c. Evolutionary fitness is measured by reproductive success.
- d. 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.
- e. 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.
- f. 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.
- g. In addition to natural selection, chance and random events can influence the evolutionary process, especially for small populations.
- h. 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.
- i. Mathematical approaches are used to calculate changes in allele frequency, providing evidence for the occurrence of evolution in a population.

LEARNING OBJECTIVES

1.1: Convert a data set from a table of numbers that reflect a change in the genetic makeup of a population over time and apply mathematical methods and conceptual understandings to investigate the causes and effects of this change.

[SP 1.5, 2.2]

1.2: Evaluate evidence provided by data to qualitatively and /or quantitatively investigate the role of natural selection in evolution.

[SP 2.2, 5.3]

1.3: Apply mathematical methods to data from a real or simulated population to predict what will happen to the population in the future.

[SP 2.2]

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

Illustrative Examples:

*Flowering time in relation to
global climate change (a)
Peppered moth (a, c)
Sickle cell anemia (c)
DDT resistance in insects (c)
Artificial selection (d)
Loss of genetic diversity within a
crop species (d)
Overuse of antibiotics (d)*

Essential Knowledge 1.A.2:

**Natural selection
acts on phenotypic
variations in
populations.**

- a. Environments change and act as selective mechanism on populations.
- b. Phenotypic variations are not directed by the environment but occur through random changes in the DNA and through new gene combinations.
- c. Some phenotypic variations significantly increase or decrease fitness of the organism and the population.
- d. Humans impact variation in other species.

LEARNING OBJECTIVES

1.4: Evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.
[SP 5.3]

1.5: Connect evolutionary changes in a population over time to a change in the environment.
[SP 7.1]

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

Illustrative Examples:

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

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

LEARNING OBJECTIVES

1.6: Use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and effects of selection in the evolution of specific populations.
[SP 1.4, 2.1]

1.7: Justify the selection of data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effects of selection in the evolution of specific populations.
[SP 2.1, 4.1]

1.8: Make predictions about the effects of genetic drift, migration, and artificial selection on the genetic makeup of a population.
[SP 6.4]

Enduring Understanding 1.A: Change in the genetic makeup of a population over time is evolution.*Illustrative Examples:*

Graphical analyses of allele frequencies in a population (b4)

Analyses of sequence data sets (b4)

Analyses of phylogenetic trees (b4)

Construction of phylogenetic trees based on sequence data (b4)

Essential Knowledge 1.A.4:

Biological evolution is supported by scientific evidence from many disciplines, including mathematics.

X The details of fossil dating methods are beyond the scope of this course and the AP Exam. (b1)

- a. Scientific evidence of biological evolution uses information from geographical, geological, physical, chemical, and mathematical applications.
- b. Molecular, morphological, and genetic information of existing and extinct organisms add to our understanding of evolution.
 - 1. Demonstrated Evidence--Fossils can be dated by a variety of methods that provide evidence for evolution. These include the age of the rocks where a fossil is found, the rate of decay of isotopes including carbon-14, the relationships within phylogenetic trees, and the mathematical calculations that take into account information from chemical properties and/or geographical data.
 - 2. Demonstrated Evidence--Morphological homologies represent features shared by common ancestry. Vestigial structures are remnants of functional structures, which can be compared to fossils and provide evidence for evolution.
 - 3. Demonstrated Evidence--Biochemical and genetic similarities, in particular DNA nucleotide and protein sequences, provide evidence for evolution and ancestry.
 - 4. Demonstrated Evidence--Mathematical models and simulations can be used to illustrate and support evolutionary concepts.

LEARNING OBJECTIVES

1.9: Evaluate evidence provided by data from many scientific disciplines that support biological evolution.
[SP 5.3]

1.10: Refine evidence based on data from many scientific disciplines that support biological evolution.
[SP 5.2]

1.11: Design a plan to answer scientific questions regarding how organisms have changed over time using information from morphology, biochemistry, and geology.
[SP 4.2]

1.12: Connect scientific evidence from many scientific disciplines to support the modern concept of evolution.
[SP 7.1]

1.13: Construct and/or justify mathematical models, diagrams, or simulations that represent processes of biological evolution.
[SP 1.1, 2.1]

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

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. Elements that are conserved across all domains of life are DNA and RNA as carriers of genetic information, a universal genetic code, and many metabolic pathways. 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. Phylogenetic trees graphically model evolutionary history and can represent both acquired traits and those lost during evolution.

In eukaryotes, conserved core elements provide evidence for evolution. These features include the presence of a cytoskeleton, a nucleus, membrane-bound organelles, linear chromosomes and endomembrane systems.

Enduring Understanding 1.B: Organisms are linked by lines of descent from common ancestry.*Illustrative Examples:*

Cytoskeleton--a network of structural proteins that facilitate cell movement, morphological integrity, and organelle transport (b)

Membrane-bound organelles -- mitochondria and/or chloroplasts (b)

Linear chromosomes (b)

Endomembrane systems, including the nuclear envelope (b)

Essential Knowledge 1.B.1:

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

- a. Structural and functional evidence supports the relatedness of all domains.
 - 1. Demonstrated Evidence--DNA and RNA are carriers of genetic information through transcription, translation, and replication.
 - 2. Demonstrated Evidence--Major features of the genetic code are shared by all modern living systems.
 - 3. Demonstrated Evidence--Metabolic pathways are conserved across all currently recognized domains.
- b. Structural evidence supports the relatedness of all eukaryotes.

LEARNING OBJECTIVES

1.14: Pose scientific questions that correctly identify essential properties of shared, core life processes that provide insights into the history of life on Earth.

[SP 3.1]

1.15: Describe specific examples of conserved core biological processes and features shared by all domains or within one domain of life, and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.

[SP 7.2]

1.16: Justify the scientific claim that organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.

[SP 6.1]

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

Illustrative Examples:
Number of heart chambers in
animals (a)
Opposable thumbs (a)
Absence of legs in some sea
mammals (a)

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

- a. Phylogenetic trees and cladograms can represent traits that are either derived or lost due to evolution.
- b. 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.
- c. 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.
- d. 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.

LEARNING OBJECTIVES

1.17: Pose scientific questions about a group of organisms whose relatedness is described by a phylogenetic tree or cladogram in order to (1) identify shared characteristics, (2) make inferences about the evolutionary history of the group, and (3) identify character data that could extend or improve the phylogenetic tree.
[SP 3.1]

1.18: Evaluate evidence provided by a data set in conjunction with a phylogenetic tree or a simple cladogram to determine evolutionary history and speciation.
[SP 5.3]

1.19: Create a phylogenetic tree or simple cladogram that correctly represents evolutionary history and speciation from a provided data set.
[SP 1.1]

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

Speciation and extinction have occurred throughout the Earth's history, and life continues to evolve within a changing environment. However, the rates of speciation and extinction vary. Speciation can be slow and gradual or, as described by punctuated equilibrium, can occur in "bursts" followed by relatively quiet periods. At times of ecological stress, extinction rates can be rapid, and mass extinctions are often followed by adaptive radiation, the rapid evolution of species when new habitats open. Scientific evidence, including emergent diseases, chemical resistance and genomic data, supports the idea that evolution occurs for all organisms and that evolution explains the diversity of life on the planet.

A species can be defined as a group of individuals capable of interbreeding and exchanging genetic information to produce viable, fertile offspring. New species arise when two populations diverge from a common ancestor and become reproductively isolated. Although speciation can occur by different processes, reproductive isolation must be maintained for a species to remain distinct. Evidence that speciation has occurred includes fossil records and genomic data.

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

*Illustrative Examples:
Five major extinctions (b)
Human impact on ecosystems
and species extinction rates
(b)*

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

*X The names and dates of
extinctions are beyond the scope
of this course and the AP Exam.*

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

LEARNING OBJECTIVES

1.20: Analyze data related to questions of speciation and extinction throughout the Earth's history.
[SP 5.1]

1.21: Design a plan for collecting data to investigate the scientific claim that speciation and extinction have occurred throughout the Earth's history.
[SP 4.2]

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

Illustrative Examples:

Essential Knowledge 1.C.2:

Speciation may occur when two populations become reproductively isolated from each other.

- a. 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.
- b. 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.

LEARNING OBJECTIVES

1.22: Use data from a real or simulated population(s), based on graphs or models of types of selection, to predict what will happen to the population in the future.
[SP 6.4]

1.23: Justify the selection of data that addresses questions related to reproductive isolation and speciation.
[SP 4.1]

1.24: Describe speciation in an isolated population and connect it to change in gene frequency, change in environment, natural selection, and/or genetic drift.
[SP 7.2]

Enduring Understanding 1.C: Life continues to evolve within a changing environment.**Essential Knowledge 1.C.3:**

**Populations of
organisms continue
to evolve.**

*Illustrative Examples:**Chemical resistance--*

*mutations for resistance
to antibiotics, pesticides,
herbicides, or chemotherapy
drugs occur in the absence of
a chemical (b)*

*Emergent diseases (b)**Observed directional phenotypic
change in a population--*

*Grant's observations of
Darwin's finches in the
Galapagos (b)*

*A eukaryotic example that
describes evolution of a
structure or process such as
heart chambers, limbs, the
brain, and the immune
system (b)*

- a. Scientific evidence supports the idea that evolution has occurred in all species.
- b. Scientific evidence supports the idea that evolution continues to occur.

LEARNING OBJECTIVES

1.25: Describe a model that represents evolution within a population.
[SP 1.2]

1.26: Evaluate given data sets that illustrate evolution as an ongoing process.
[SP 5.3]

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

The process of evolution explains the diversity and unity of life. A number of experimental investigations have provided evidence that the conditions early in the Earth's history provided an environment capable of generating complex organic molecules and simple cell-like structures. For example, in the "organic soup" model, the hypothesized primitive atmosphere contained inorganic precursors from which organic molecules could have been synthesized through natural chemical reactions catalyzed by the input of energy. In turn, these molecules served as monomers (building blocks) for the formation of more complex molecules, including amino acids and nucleotides. Some models suggest that primitive life developed on biogenic surfaces, such as clay, that served as templates and catalysts for assembly of macromolecules. Under laboratory conditions, complex polymers and self-replicating molecules can spontaneously assemble. It remains an open question whether the first genetic and self-replicating material was DNA or RNA.

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

Illustrative Examples:

Essential Knowledge 1.D.1:

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

a. Scientific evidence supports the various models.

1. Demonstrated Evidence--Primitive Earth provided inorganic precursors from which organic molecules could have been synthesized due to the presence of available free energy and the absence of a significant quantity of oxygen.
2. Demonstrated Evidence--In turn, these molecules served as monomers or building blocks for the formation of more complex molecules, including amino acids and nucleotides.
3. Demonstrated Evidence--The joining of these monomers produced polymers with the ability to replicate, store and transfer information.
4. Demonstrated Evidence--These complex reaction sets could have occurred in solution (organic soup model) or as reactions on solid reactive surfaces.
5. Demonstrated Evidence--The RNA World hypothesis proposes that RNA could have been the earliest genetic material.

LEARNING OBJECTIVES

1.27: Describe a scientific hypothesis about the origin of life on Earth.
[SP 1.2]

1.28: Evaluate scientific questions based on hypotheses about the origin of life on Earth.
[SP 3.3]

1.29: Describe the reasons for revisions of scientific hypotheses of the origin of life on Earth.
[SP 6.3]

1.30: Evaluate scientific hypotheses about the origin of life on Earth.
[SP 6.5]

1.31: Evaluate the accuracy and legitimacy of data to answer scientific questions about the origin of life on Earth.
[SP 4.4]

Enduring Understanding 1.D: The origin of living systems is explained by natural processes.*Illustrative Examples:*

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

- a. Geological evidence provides support for models of the origin of life on Earth.
 - 1. Demonstrated Evidence--The Earth formed approximately 4.6 billion years ago (bya), and the environment was too hostile for life until 3.9 bya, while the earliest fossil evidence for life dates back to 3.5 bya. Taken together, this evidence provides a plausible range of dates when the origin of life could have occurred.
 - 2. Demonstrated Evidence--Chemical experiments have shown that it is plausible to form complex organic molecules from inorganic molecules in the absence of life.
- b. Molecular and genetic evidence from extant and extinct organisms indicates that all organisms on Earth share a common ancestral origin of life.
 - 1. Demonstrated Evidence--Scientific evidence includes molecular building blocks that are common to all life forms.
 - 2. Demonstrated Evidence--Scientific evidence includes a common genetic code.

LEARNING OBJECTIVES

1.32: Justify the selection of geological, physical, and chemical data that reveal early Earth conditions.
[SP 4.1]

BIG IDEA: Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.

Living systems require free energy and matter to maintain order, grow and reproduce. Organisms employ various strategies to capture, use and store free energy and other vital resources. Energy deficiencies are not only detrimental to individual organisms; they also can cause disruptions at the population and ecosystem levels.

Autotrophic cells capture free energy through photosynthesis and chemosynthesis. Photosynthesis traps free energy present in sunlight that, in turn, is used to produce carbohydrates from carbon dioxide. Chemosynthesis captures energy present in inorganic chemicals. Cellular respiration and fermentation harvest free energy from sugars to produce free energy carriers, including ATP. The free energy available in sugars drives metabolic pathways in cells. Photosynthesis and respiration are interdependent processes.

Cells and organisms must exchange matter with the environment. For example, water and nutrients are used in the synthesis of new molecules; carbon moves from the environment to organisms where it is incorporated into carbohydrates, proteins, nucleic acids or fats; and oxygen is necessary for more efficient free energy use in cellular respiration. Differences in surface-to-volume ratios affect the capacity of a biological system to obtain resources and eliminate wastes. Programmed cell death (apoptosis) plays a role in normal development and differentiation (e.g. morphogenesis).

Membranes allow cells to create and maintain internal environments that differ from external environments. The structure of cell membranes results in selective permeability; the movement of molecules across them via osmosis, diffusion and active transport maintains dynamic homeostasis. In eukaryotes, internal membranes partition the cell into specialized regions that allow cell processes to operate with optimal efficiency. Each compartment or membrane-bound organelle enables localization of chemical reactions.

Organisms also have feedback mechanisms that maintain dynamic homeostasis by allowing them to respond to changes in their internal and external environments. Negative feedback loops maintain optimal internal environments, and positive feedback mechanisms amplify responses. Changes in a biological system's environment, particularly the availability of resources, influence responses and activities, and organisms use various means to obtain nutrients and get rid of wastes. Homeostatic mechanisms across phyla reflect both continuity due to common ancestry and change due to evolution and natural selection; in plants and animals, defense mechanisms against disruptions of dynamic homeostasis have evolved. Additionally, the timing and coordination of developmental, physiological and behavioral events are regulated, increasing fitness of individuals and long-term survival of populations.

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

Living systems require energy to maintain order, grow and reproduce. In accordance with the laws of thermodynamics, to offset entropy, energy input must exceed energy lost from and used by an organism to maintain order. Organisms use various energy-related strategies to survive; strategies include different metabolic rates, physiological changes, and variations in reproductive and offspring-raising strategies. Not only can energy deficiencies be detrimental to individual organisms, but changes in free energy availability also can affect population size and cause disruptions at the ecosystem level.

Several means to capture, use and store free energy have evolved in organisms. Cells can capture free energy through photosynthesis and chemosynthesis. Autotrophs capture free energy from the environment, including energy present in sunlight and chemical sources, whereas heterotrophs harvest free energy from carbon compounds produced by other organisms. Through a series of coordinated reaction pathways, photosynthesis traps free energy in sunlight that, in turn, is used to produce carbohydrates from carbon dioxide and water. Cellular respiration and fermentation use free energy available from sugars and from interconnected, multistep pathways (i.e., glycolysis, the Krebs cycle and the electron transport chain) to phosphorylate ADP, producing the most common energy carrier, ATP. The free energy available in sugars can be used to drive metabolic pathways vital to cell processes. The processes of photosynthesis and cellular respiration are interdependent in their reactants and products.

Organisms must exchange matter with the environment to grow, reproduce and maintain organization. The cellular surface-to-volume ratio affects a biological system's ability to obtain resources and eliminate waste products. Water and nutrients are essential for building new molecules.

Carbon dioxide moves from the environment to photosynthetic organisms where it is metabolized and incorporated into carbohydrates, proteins, nucleic acids or lipids. Nitrogen is essential for building nucleic acids and proteins; phosphorus is incorporated into nucleic acids, phospholipids, ATP and ADP. In aerobic organisms, oxygen serves as an electron acceptor in energy transformations.

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

Illustrative Examples:

Krebs Cycle (c)
Glycolysis (c)
Calvin Cycle (c)
Fermentation (c)

Endothermy--the use of thermal energy generated by metabolism to maintain homeostatic body temperatures (d1)

Ectothermy--the use of external thermal energy to help regulate and maintain body temperature (d1)

Essential Knowledge 2.A.1:

**All living systems
require constant
input of free energy.**

Illustrative Examples:

Seasonal reproduction in animals and plants (d2)

Life-history strategy--biennial plants, reproductive diapause (d2)

Change in the producer level can affect the number and size of other trophic levels (f)

Change in energy resources levels such as sunlight can affect the number and size of the trophic levels (f)

- a. Life requires a highly ordered system.
 1. Demonstrated Evidence--Order is maintained by constant free energy input into the system.
 2. Demonstrated Evidence--Loss of order or free energy flow results in death.
 3. Demonstrated Evidence--Increased disorder and entropy are offset by biological processes that maintain or increase order.
- b. Living systems do not violate the second law of thermodynamics, which states that entropy increases over time.
 1. Demonstrated Evidence--Order is maintained by coupling cellular processes that increase entropy (and so have negative changes in free energy) with those that decrease entropy (and so have positive changes in free energy).
 2. Demonstrated Understanding—Energy input must exceed free energy lost to entropy to maintain order and power cellular processes.
 3. Demonstrated Understanding—Energetically favorable exergonic reactions, such as $\text{ATP} \rightarrow \text{ADP}$, that have a negative change in free energy can be used to maintain or increase order in a system by being coupled with reactions that have a positive free energy change.
- c. Energy-related pathways in biological systems are sequential and may be entered at multiple points in the pathway.
- d. Organisms use free energy to maintain organization, grow, and reproduce.
 1. Demonstrated Understanding—Organisms use various strategies to regulate body temperature and metabolism.
 2. Demonstrated Understanding—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.
 3. 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.
 4. Excess acquired free energy versus required free energy expenditure results in energy storage or growth.
 5. Insufficient acquired free energy versus required free energy expenditure results in loss of mass and, ultimately, the death of an organism.
- e. Changes in free energy availability can result in changes in population size.
- f. Changes in free energy availability can result in disruptions to an ecosystem.

LEARNING OBJECTIVES

2.1: Explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow, and to reproduce. [SP 6.2]

2.3: Predict how changes in free energy availability affect organisms, populations, and/or ecosystems. [SP 6.4]

2.2: Justify a scientific claim that free energy is required for living systems to maintain organization, to grow, or to reproduce, but that multiple strategies for obtaining and using energy exist in different living systems. [SP 6.1]

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

Illustrative Examples:

NADP⁺ in photosynthesis (c)

Oxygen in cellular respiration (c)

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

✗ Specific steps, names of enzymes and intermediates of the pathways for these processes are beyond the scope of the course and the AP Exam. (b)

✗ Memorization of the steps in the Calvin cycle, the structure of the molecules and the names of enzymes (with the exception of ATP synthase) are beyond the scope of the course and the AP Exam. (d)

✗ Memorization of the steps in glycolysis and the Krebs cycle, or of the structures of the molecules and the names of the enzymes involved, are beyond the scope of the course and the AP Exam. (f)

✗ The names of the specific electron carriers in the ETC are beyond the scope of the course and the AP Exam. (g)

- a. Autotrophs capture free energy from physical sources in the environment.
 1. Demonstrated Evidence--Photosynthetic organisms capture free energy present in sunlight.
 2. Demonstrated Evidence--Chemosynthetic organisms capture free energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen.
- b. Heterotrophs capture free energy present in carbon compounds produced by other organisms.
 1. Demonstrated Evidence--Heterotrophs may metabolize carbohydrates, lipids and proteins by hydrolysis as sources of free energy.
 2. Demonstrated Evidence--Fermentation produces organic molecules, including alcohol and lactic acid, and it occurs in the absence of oxygen.
- c. Different energy-capturing processes use different types of electron acceptors.
- d. 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.
 1. Demonstrated Evidence-- During photosynthesis, chlorophylls absorb free energy from light, boosting electrons to a higher energy level in Photosystems I and II.
 2. Demonstrated Evidence--Photosystems I and II are embedded in the internal membranes of chloroplasts (thylakoids) and are connected by the transfer of higher free energy electrons through an electron transport chain (ETC).
 3. Demonstrated Evidence--When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of hydrogen ions (protons) across the thylakoid membrane is established.
 4. Demonstrated Evidence--The formation of the proton gradient is a separate process, but it is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase.
 5. Demonstrated Evidence--The energy captured in the light reactions as ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle, which occurs in the stroma of the chloroplast.

- e. 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.
- f. Cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that harvest free energy from simple carbohydrates.
 - 1. Demonstrated Evidence--Glycolysis rearranges the bonds in glucose molecules, releasing free energy to form ATP from ADP and inorganic phosphate, and resulting in the production of pyruvate.
 - 2. Demonstrated Evidence--Pyruvate is transported from the cytoplasm to the mitochondrion, where further oxidation occurs.
 - 3. Demonstrated Evidence--In the Krebs cycle, carbon dioxide is released from organic intermediates ATP is synthesized from ADP and inorganic phosphate via substrate level phosphorylation and electrons are captured by coenzymes.
 - 4. Demonstrated Evidence--Electrons that are extracted in the series of Krebs cycle reactions are carried by NADH and FADH₂ to the electron transport chain.
- g. The electron transport chain captures free energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes.
 - 1. Demonstrated Evidence--Electron transport chain reactions occur in chloroplasts (photosynthesis), mitochondria (cellular respiration) and prokaryotic plasma membranes.
 - 2. Demonstrated Evidence--In cellular respiration, electrons delivered by NADH and FADH₂ are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. In photosynthesis, the terminal electron acceptor is NADP⁺.
 - 3. Demonstrated Evidence--The passage of electrons is accompanied by the formation of a proton gradient across the inner mitochondrial membrane or the thylakoid membrane of chloroplasts, with the membrane(s) separating a region of high proton concentration from a region of low proton concentration. In prokaryotes, the passage of electrons is accompanied by the outward movement of protons across the plasma membrane.
 - 4. Demonstrated Evidence--The flow of protons back through membrane-bound ATP synthase by chemiosmosis generates ATP from ADP and inorganic phosphate.
 - 5. Demonstrated Evidence--In cellular respiration, decoupling oxidative phosphorylation from electron transport is involved in thermoregulation.
- h. Free energy becomes available for metabolism by the conversion of ATP → ADP, which is coupled to many steps in metabolic pathways.

LEARNING OBJECTIVES

2.4: Use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store, and use free energy.
[SP 1.4, 3.1]

2.5: Construct explanations of the mechanisms and structural features of cells that allow organisms to capture, store, or use free energy.
[SP 6.2]

2.41: Evaluate data to show the relationship between photosynthesis and respiration in the flow of free energy through a system.
[SP 5.3, 71.]

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

Illustrative Examples:

Cohesion (a3)

Adhesion (a3)

High specific heat capacity (a3)

Universal solvent supports reactions (a3)

Heat of vaporization (a3)

Heat of fusion (a3)

Water's thermal conductivity (a3)

Root hairs (b1)

Cells of the alveoli (b1)

Cells of the villi (b1)

Microvilli (b1)

Essential Knowledge 2.A.3:

Organisms must exchange matter with the environment to grow, reproduce, and maintain organization.

- a. Molecules and atoms from the environment are necessary to build new molecules.
 - 1. Demonstrated Evidence--Carbon moves from the environment to organisms where it is used to build carbohydrates, proteins, lipids or nucleic acids. Carbon is used in storage compounds and cell formation in all organisms.
 - 2. Demonstrated Evidence--Nitrogen moves from the environment to organisms where it is used in building proteins and nucleic acids. Phosphorus moves from the environment to organisms where it is used in nucleic acids and certain lipids.
 - 3. Demonstrated Evidence--Living systems depend on properties of water that result from its polarity and hydrogen bonding.
- b. Surface area-to-volume ratios affect a biological system's ability to obtain necessary resources or eliminate waste products.
 - 1. Demonstrated Evidence--As cells increase in volume, the relative surface area decreases and demand for material resources increases; more cellular structures are necessary to adequately exchange materials and energy with the environment. These limitations restrict cell size.
 - 2. Demonstrated Evidence--The surface area of the plasma membrane must be large enough to adequately exchange materials; smaller cells have a more favorable surface area-to-volume ratio for exchange of materials with the environment.

LEARNING OBJECTIVES

2.6: Use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion.
[SP 2.2]

2.8: Justify the selection of data regarding the types of molecules that an animal, plant or bacterium will take up as necessary building blocks and excrete as waste products.
[SP 4.1]

2.7: Explain how cell size and shape affect the overall rate of nutrient intake and the rate of waste elimination.
[SP 6.2]

2.9: Represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth and reproduction.
[SP 1.1, 1.4]

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

Cell membranes separate the internal environment of the cell from the external environment. The specialized structure of the membrane described in the fluid mosaic model allows the cell to be selectively permeable, with dynamic homeostasis maintained by the constant movement of molecules across the membrane. Passive transport does not require the input of metabolic energy because spontaneous movement of molecules occurs from high to low concentrations; examples of passive transport are osmosis, diffusion, and facilitated diffusion. Active transport requires metabolic energy and transport proteins to move molecules from low to high concentrations across a membrane. Active transport establishes concentration gradients vital for dynamic homeostasis, including sodium/potassium pumps in nerve impulse conduction and proton gradients in electron transport chains in photosynthesis and cellular respiration. The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.

Eukaryotic cells also maintain internal membranes that partition the cell into specialized regions so that cell processes can operate with optimal efficiency by increasing beneficial interactions, decreasing conflicting interactions and increasing surface area for chemical reactions to occur. Each compartment or membrane-bound organelle localizes reactions, including energy transformation in mitochondria and production of proteins in rough endoplasmic reticulum.

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

Essential Knowledge 2.B.1:

Illustrative Examples:

**Cell membranes are
selectively
permeable due to
their structure.**

- a. Cell membranes separate the internal environment of the cell from the external environment.
- b. Selective permeability is a direct consequence of membrane structure, as described by the fluid mosaic model.
 - 1. Demonstrated Evidence--Cell membranes consist of a structural framework of phospholipid molecules, embedded proteins, cholesterol, glycoproteins and glycolipids.
 - 2. Demonstrated Evidence--Phospholipids give the membrane both hydrophilic and hydrophobic properties. The hydrophilic phosphate portions of the phospholipids are oriented toward the aqueous external or internal environments, while the hydrophobic fatty acid portions face each other within the interior of the membrane itself.
 - 3. Demonstrated Evidence--Embedded proteins can be hydrophilic, with charged and polar side groups, or hydrophobic, with nonpolar side groups.
 - 4. Demonstrated Evidence--Small, uncharged polar molecules and small nonpolar molecules, such as N_2 , freely pass across the membrane. Hydrophilic substances such as large polar molecules and ions move across the membrane through embedded channel and transport proteins. Water moves across membranes and through channel proteins called aquaporins.
- c. Cell walls provide a structural boundary, as well as a permeability barrier for some substances to the internal environments.
 - 1. Demonstrated Evidence--Plant cell walls are made of cellulose and are external to the cell membrane.
 - 2. Demonstrated Evidence--Other examples are cells walls of prokaryotes and fungi.

LEARNING OBJECTIVES

2.10: Use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure.
[SP 1.4, 3.1]

2.11: Construct models that connect the movement of molecules across membranes with membrane structure and function.
[SP 1.1, 7.1, 7.2]

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

Essential Knowledge 2.B.2:

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

X There is no particular membrane protein that is required for teaching facilitated diffusion. (a2)

Illustrative Examples:

Glucose Transport (a2)

Na⁺ / K⁺ transport (a2)

- a. Passive transport does not require the input of metabolic energy; the net movement of molecules is from high concentration to low concentration.
 1. Demonstrated Evidence--Passive transport plays a primary role in the import of resources and the export of wastes.
 2. Demonstrated Evidence--Membrane proteins play a role in facilitated diffusion of charged and polar molecules through a membrane.
 3. Demonstrated Evidence--External environments can be hypotonic, hypertonic or isotonic to internal environments of cells.
- b. Active transport requires free energy to move molecules from regions of low concentration to regions of high concentration.
 1. Demonstrated Evidence--Active transport is a process where free energy (often provided by ATP) is used by proteins embedded in the membrane to “move” molecules and/or ions across the membrane and to establish and maintain concentration gradients.
 2. Demonstrated Evidence--Membrane proteins are necessary for active transport.
- c. The processes of endocytosis and exocytosis move large molecules from the external environment to the internal environment and vice versa, respectively.
 1. Demonstrated Evidence--In exocytosis, internal vesicles fuse with the plasma membrane to secrete large macromolecules out of the cell.
 2. Demonstrated Evidence--In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane.

LEARNING OBJECTIVES

2.12: Use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes.

[SP 1.4]

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

Essential Knowledge 2.B.3:

Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.

Illustrative Examples:

Endoplasmic reticulum (b)

Mitochondria (b)

Chloroplasts (b)

Golgi (b)

Nuclear envelope (b)

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

LEARNING OBJECTIVES

2.13: Explain how internal membranes and organelles contribute to cell functions.
[SP 6.2]

2.14: Use representations and models to describe differences in prokaryotic and eukaryotic cells.
[SP 1.2, 1.4]

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

Organisms respond to changes in their internal and external environments through behavioral and physiological mechanisms, such as photoperiodism in plants, hibernation and migration in animals, and shivering and sweating in humans. Organisms use negative feedback mechanisms to maintain their internal environments by returning the changing condition back to its target set point, while positive feedback mechanisms amplify responses. Examples of negative feedback responses include temperature regulation in animals and plant responses to drought; examples of positive feedback mechanisms are the onset of labor in childbirth and ripening of fruit. Alterations in feedback mechanisms can have deleterious effects, including diabetes and Graves' disease in humans and the inability of plants to tolerate water stress during drought.

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

Essential Knowledge 2.C.1:

Organisms use feedback mechanisms to maintain their internal environments and respond to external environmental changes.

Illustrative Examples:

Operons in gene regulation (a)

Temperature regulation in animals (a)

Plant responses to water limitations (a)

Lactation in mammals (b)

Onset of labor in childbirth (b)

Ripening of fruit (b)

Illustrative Examples:

Diabetes mellitus in response to decreased insulin ©

Dehydration in response to decreased antidiuretic hormone (ADH) (c)

Graves' disease (hyperthyroidism) (c)

Blood clotting (c)

- a. 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.
- b. 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.
- c. Alteration in the mechanisms of feedback often results in deleterious consequences.

LEARNING OBJECTIVES

2.15: Justify a claim made about the effect(s) on a biological system at the molecular, physiological or organismal level when given a scenario in which one or more components within a negative regulatory system is altered.
[SP 6.1]

2.19: Make predictions about how positive feedback mechanisms amplify activities and processes in organisms based on scientific theories and models.
[SP 6.4]

2.16: Connect how organisms use negative feedback to maintain their internal environments.
[SP 7.2]

2.18: Make predictions about how organisms use negative feedback mechanisms to maintain their internal environments.
[SP 6.4]

2.17: Evaluate data that show the effect(s) of changes in concentrations of key molecules on negative feedback mechanisms.
[SP 5.3]

2.20: Justify that positive feedback mechanisms amplify responses in organisms.
[SP 6.1]

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

Essential Knowledge 2.C.2:

Illustrative Examples:

Photoperiodism and phototropism in plants (a)
Hibernation and migration in animals (a)
Taxis and kinesis in animals (a)
Chemotaxis in bacteria, sexual reproduction in fungi (a)
Nocturnal and diurnal activity: circadian rhythms (a)
Shivering and sweating in humans (a)

Organisms respond to changes in their external environments.

X No specific behavioral or physiological mechanism is required for organism response to changes in external environment. Choose the mechanism that best fosters understanding.

- a. Organisms respond to changes in their environment through behavioral and physiological mechanisms.

LEARNING OBJECTIVES

2.21: Justify the selection of the kind of data needed to answer scientific questions about the relevant mechanism that organisms use to respond to changes in their external environment.

[SP 4.1]

2.42: Pose a scientific question concerning the behavioral or physiological response of an organism to a change in its environment.
[SP 3.1]

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

All biological systems, from cells to ecosystems, are influenced by complex biotic and abiotic interactions. The availability of resources influences activities in cells and organisms; examples include responses to cell density, biofilm(s) formation, temperature responses, and responses to nutrient and water availability. The availability of resources affects a population's stability in size and its genetic composition; examples include birth rates versus death rates from bacteria to mammals and global distribution of food for humans.

Homeostatic mechanisms reflect both continuity due to common ancestry and change due to evolution in different environments. Supporting evidence includes a sampling of homeostatic control systems that are conserved across biological domains. Organisms have evolved various mechanisms for obtaining nutrients and getting rid of wastes, including gas exchange, osmoregulation and nitrogenous waste production. Disturbances to dynamic homeostasis effect biological processes, and plants and animals have evolved a variety of defenses against infections and other disruptions to homeostasis including immune responses. At the ecosystem level, disruptions impact the balance of the ecosystem and the interactions between specific organisms therein.

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

Illustrative Examples:

Cell density (a)
Biofilms (a)
Temperature (a)
Water availability (a)
Sunlight (a)
Symbiosis--mutualism, commensalism, parasitism (b)
Predator-prey relationships (b)
Water and nutrient availability, temperature, salinity, pH (b)
Water and nutrient availability (c)
Availability of nesting materials and sites (c)
Food chains and food webs (c)
Species diversity (c)
Population density (c)
Algal blooms (c)

Essential Knowledge 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.

X No specific example is required for the effect of biotic and abiotic interactions. Choose an example that best fosters understanding.

- a. Cell activities are affected by interactions with biotic and abiotic factors.
- b. Organism activities are affected by interactions with biotic and abiotic factors.
- c. The stability of populations, communities and ecosystems is affected by interactions with biotic and abiotic factors.

LEARNING OBJECTIVES

2.22: Refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems, from cells and organisms to populations, communities and ecosystems.

[SP 1.3, 3.2]

2.24: Analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities or ecosystems). [SP 5.1]

2.23: Design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities and ecosystems) are affected by complex biotic and abiotic interactions.

[SP 4.2, 7.2]

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

Essential Knowledge 2.D.2:

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

Illustrative Examples:

Gas exchange in aquatic and terrestrial plants (b)
Digestive mechanisms in animals such as food vacuoles, gastrovascular cavities, one-way digestive systems (b)
Respiratory systems of aquatic and terrestrial animals (b)
Nitrogenous waste production and elimination in aquatic and terrestrial animals (b)

Illustrative Examples:

Excretory systems in flatworms, earthworms and vertebrates (c)
Osmoregulation in bacteria, fish and protists (c)
Osmoregulation in aquatic and terrestrial plants (c)
Circulatory systems in fish, amphibians and mammals (c)
Thermoregulation in aquatic and terrestrial animals--countercurrent exchange mechanisms (c)

- a. Continuity of homeostatic mechanisms reflects common ancestry, while changes may occur in response to different environmental conditions.
- b. Organisms have various mechanisms for obtaining nutrients and eliminating wastes.
- c. Homeostatic control systems in species of microbes, plants and animals support common ancestry.

LEARNING OBJECTIVES

2.25: Construct explanations based on scientific evidence that homeostatic mechanisms reflect continuity due to common ancestry and/or divergence due to adaptation in different environments.

[SP 6.2]

2.27: Connect differences in the environment with the evolution of homeostatic mechanisms.

[SP 7.1]

2.26: Analyze data to identify phylogenetic patterns or relationships, showing that homeostatic mechanisms reflect both continuity due to common ancestry and change due to evolution in different environments.

[SP 5.1]

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

Illustrative Examples:

Physiological responses to toxic substances (a)

Dehydration (a)

Immunological responses to pathogens, toxins and allergens (a)

Invasive and/or eruptive species (b)

Human impact (b)

Hurricanes, floods, earthquakes, volcanoes, fires (b)

Water limitation (b)

Salination (b)

Essential Knowledge 2.D.3:

**Biological systems
are affected by
disruptions to their
dynamic
homeostasis.**

X No specific example is required for effect of disruption on dynamic homeostasis. Choose an example that best fosters understanding.

- a. Disruptions at the molecular and cellular levels affect the health of the organism.
- b. Disruptions to ecosystems impact the dynamic homeostasis or balance of the ecosystem.

LEARNING OBJECTIVES

2.28: Use representations or models to analyze quantitatively and qualitatively the effects of disruptions to dynamic homeostasis in biological systems.

[SP 1.4]

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

Essential Knowledge 2.D.4:

Illustrative Examples:

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

Study of the nervous and immune systems is required for concepts detailed in 2.D.4.

- a. Plants, invertebrates and vertebrates have multiple, nonspecific immune responses.
 - 1. Demonstrated Evidence--Invertebrate immune systems have nonspecific response mechanisms and may possess pathogen-specific defense responses.
 - 2. Demonstrated Evidence--Plant defenses against pathogens include molecular recognition systems with systemic responses; infection triggers chemical responses that destroy infected and adjacent cells, thus localizing the effects.
 - 3. Demonstrated Evidence--Vertebrate immune systems have nonspecific defense mechanisms against pathogens
- b. Mammals use specific immune responses triggered by natural or artificial agents that disrupt dynamic homeostasis.
 - 1. Demonstrated Evidence--The mammalian immune system includes two types of specific responses: cell mediated and humoral.
 - 2. Demonstrated Evidence--In the cell-mediated response, cytotoxic T cells, a type of lymphocytic white blood cell, "target" intracellular pathogens when antigens are displayed on the outside of the cells.
 - 3. Demonstrated Evidence--In the humoral response, B cells, a type of lymphocytic white blood cell, produce antibodies against specific antigens.
 - 4. Demonstrated Evidence--Antigens are recognized by antibodies to the antigen.
 - 5. Demonstrated Evidence--Antibodies are proteins produced by B cells, and each antibody is specific to a particular antigen.
 - 6. Demonstrated Evidence--A second exposure to an antigen results in a more rapid and enhanced immune response.

LEARNING OBJECTIVES

2.29: Create representations and models to describe immune responses.
[SP 1.1, 1.2]

2.29: Connect the concept of cell communication to the functioning of the immune system.
[SP 7.2]

2.30: Create representations or models to describe nonspecific immune defenses in plants and animals. [SP 1.1, 1.2]

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

Multiple mechanisms regulate the timing and coordination of molecular, physiological and behavioral events that are necessary for an organism's development and survival. Cell differentiation results from the expression of genes for tissue-specific proteins, and the induction of transcription factors during development results in sequential gene expression. Cell differentiation also results from specific silencing of gene expression. For example, homeotic genes determine developmental patterns and sequences, and temperature and water availability determine seed germination in most plants. Genetic transplantation experiments support the link between gene expression, mutations and development. Programmed cell death (apoptosis) plays a role in normal development and differentiation (e.g., morphogenesis).

Physiological events in organisms can involve interactions between environmental stimuli and internal molecular signals; phototropism and photoperiodism in plants and circadian rhythms and seasonal responses in animals are examples.

Timing and coordination of behavior are also regulated by several means; individuals can act on information and communicate it to others, and responses to information are vital to natural selection. Examples include behaviors in animals triggered by environmental cues (hibernation, migration and estivation), courtship rituals and other visual displays, and photoperiodism in plants due to changes in critical night length.

Communication and cooperative behavior within or between populations contributes to the survival of individuals and the population. For example, changes in resource availability can lead to fruiting body formation in certain bacteria and fungi and niche partitioning.

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

Illustrative Examples:

Morphogenesis of fingers and toes (c)
Immune function (c)
C. elegans development (c)
Flower development (c)

Essential Knowledge 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.

X Names of the specific stages of embryonic development are beyond the scope of the course and the AP Exam.

- a. Observable cell differentiation results from the expression of genes for tissue-specific proteins.
- b. Induction of transcription factors during development results in sequential gene expression.
 - 1. Demonstrated Evidence--Homeotic genes are involved in developmental patterns and sequences.
 - 2. Demonstrated Evidence--Embryonic induction in development results in the correct timing of events.
 - 3. Demonstrated Evidence--Temperature and the availability of water determine seed germination in most plants.
 - 4. Demonstrated Evidence--Genetic mutations can result in abnormal development.
 - 5. Demonstrated Evidence--Genetic transplantation experiments support the link between gene expression and normal development.
 - 6. Demonstrated Evidence--Genetic regulation by microRNAs plays an important role in the development of organisms and the control of cellular functions.
- c. Programmed cell death (apoptosis) plays a role in the normal development and differentiation.

LEARNING OBJECTIVES

2.31: Connect concepts in and across domains to show that timing and coordination of specific events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms.
[SP 7.2]

2.33: Justify scientific claims with scientific evidence to show that timing and coordination of several events are necessary for normal development in an organism and that these events are regulated by multiple mechanisms.
[SP 6.1]

2.32: Use a graph or diagram to analyze situations or solve problems (quantitatively or qualitatively) that involve timing and coordination of events necessary for normal development in an organism.
[SP 1.4]

2.34 Describe the role of programmed cell death in development and differentiation, the reuse of molecules, and the maintenance of dynamic homeostasis.
[SP 7.1]

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

Essential Knowledge 2.E.2:

Timing and coordination of physiological events are regulated by multiple mechanisms.

Illustrative Examples:

Circadian rhythms, or the physiological cycle of about 24 hours that is present in all eukaryotes and persists even in the absence of external cues (b)

Diurnal/nocturnal and sleep/awake cycles (b)

Jet lag in humans (b)

Seasonal responses, such as hibernation, estivation and migration (b)

Release and reaction to pheromones (b)

Visual displays in the reproductive cycle (b)

Fruiting body formation in fungi, slime molds and certain types of bacteria (c)

Quorum sensing in bacteria (c)

Illustrative Examples:

X Memorization of the names, molecular structures and specific effects of all plant hormones are beyond the scope of the course and the AP Exam. (a2)

X Memorization of the names, molecular structures and specific effects of hormones or features of the brain responsible for these physiological phenomena is beyond the scope of the course and the AP Exam. (c)

- a. In plants, physiological events involve interactions between environmental stimuli and internal molecular signals.
 1. Demonstrated Evidence--Phototropism, or the response to the presence of light.
 2. Demonstrated Evidence--Photoperiodism, or the response to change in length of the night, that results in flowering in long-day and short-day plants.
- b. In animals, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.
- c. In fungi, protists and bacteria, internal and external signals regulate a variety of physiological responses that synchronize with environmental cycles and cues.

LEARNING OBJECTIVES

2.35: Design a plan for collecting data to support the scientific claim that the timing and coordination of physiological events involve regulation. [SP 4.2]

2.36: Justify scientific claims with evidence to show how timing and coordination of physiological events involve regulation. [SP 6.1]

2.34 Connect concepts that describe mechanisms that regulate the timing and coordination of physiological events. [SP 7.2]

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

Essential Knowledge 2.E.3:

Illustrative Examples:

Hibernation (b3)

Estivation (b3)

Migration (b3)

Courtship (b3)

Availability of resources leading to fruiting body formation in fungi and certain types of bacteria (b4)

Niche and resource partitioning (b4)

Mutualistic relationships-- lichens; bacteria in digestive tracts of animals; mycorrhizae (b4)

Biology of pollination (b4)

Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.

- a. Individuals can act on information and communicate it to others.
 - 1. Demonstrated Evidence--Innate behaviors are behaviors that are inherited.
 - 2. Demonstrated Evidence--Learning occurs through interactions with the environment and other organisms.
- b. Responses to information and communication of information are vital to natural selection.
 - 1. Demonstrated Evidence--In phototropism in plants, changes in the light source lead to differential growth, resulting in maximum exposure of leaves to light for photosynthesis.
 - 2. Demonstrated Evidence--In photoperiodism in plants, changes in the length of night regulate flowering and preparation for winter.
 - 3. Demonstrated Evidence--Behaviors in animals are triggered by environmental cues and are vital to reproduction, natural selection and survival.
 - 4. Demonstrated Evidence--Cooperative behavior within or between populations contributes to the survival of the populations.

LEARNING OBJECTIVES

2.38: Analyze data to support the claim that responses to information and communication of information affect natural selection.
[SP 5.1]

2.39: Justify scientific claims, using evidence, to describe how timing and coordination of behavioral events in organisms are regulated by several mechanisms.
[SP 6.1]

2.40 Connect concepts in and across domain(s) to predict how environmental factors affect responses to information and change behavior.
[SP 7.2]

Note: Learning objectives 2.41, 2.42, and 2.43 are located after learning objectives 2.5, 2.21, and 2.30, respectively

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

Genetic information provides for continuity of life and, in most cases, this information is passed from parent to offspring via DNA. The double-stranded structure of DNA provides a simple and elegant solution for the transmission of heritable information to the next generation; by using each strand as a template, existing information can be preserved and duplicated with high fidelity within the replication process. However, the process of replication is imperfect, and errors occur through chemical instability and environmental impacts. Random changes in DNA nucleotide sequences lead to heritable mutations if they are not repaired. To protect against changes in the original sequence, cells have multiple mechanisms to correct errors. Despite the action of repair enzymes, some mutations are not corrected and are passed to subsequent generations. Changes in a nucleotide sequence, if present in a protein-coding region, can change the amino acid sequence of the polypeptide. In other cases, mutations can alter levels of gene expression or simply be silent. In order for information in DNA to direct cellular processes, information must be transcribed (DNA → RNA) and, in many cases, translated (RNA → protein). The products of transcription and translation play an important role in determining metabolism, i.e., cellular activities and phenotypes. Biotechnology makes it possible to directly engineer heritable changes in cells to yield novel protein products.

In eukaryotic organisms, heritable information is packaged into chromosomes that are passed to daughter cells. Alternating with

interphase in the cell cycle, mitosis followed by cytokinesis provides a mechanism in which each daughter cell receives an identical and a complete complement of chromosomes. Mitosis ensures fidelity in the transmission of heritable information, and production of identical progeny allows organisms to grow, replace cells, and reproduce asexually.

Sexual reproduction, however, involves the recombination of heritable information from both parents through fusion of gametes during fertilization. Meiosis followed by fertilization provides a spectrum of possible phenotypes in offspring and on which natural selection operates.

Mendel was able to describe a model of inheritance of traits, and his work represents an application of mathematical reasoning to a biological problem. However, most traits result from interactions of many genes and do not follow Mendelian patterns of inheritance. Understanding the genetic basis of specific phenotypes and their transmission in humans can raise social and ethical issues.

The expression of genetic material controls cell products, and these products determine the metabolism and nature of the cell. Gene

expression is regulated by both environmental signals and developmental cascades or stages. Cell signaling mechanisms can also modulate and control gene expression. Thus, structure and function in biology involve two interacting aspects: the presence of necessary genetic information and the correct and timely expression of this information.

Genetic information is a repository of instructions necessary for the survival, growth and reproduction of the organism.

Changes in

information can often be observed in the organism due to changes in phenotypes. At the molecular level, these changes may result from mutations in the genetic material whereupon effects can often be seen when the information is processed to yield a polypeptide; the changes may be positive, negative or neutral to the organism. At the cellular level, errors in the transfer of genetic information through mitosis and meiosis can result in adverse changes to cellular composition. Additionally, environmental factors can influence gene expression.

Genetic variation is almost always advantageous for the long-term survival and evolution of a species. In sexually reproducing organisms, meiosis produces haploid gametes, and random fertilization produces diploid zygotes. In asexually reproducing organisms, variation can be introduced through mistakes in DNA replication or repair and through recombination; additionally, bacteria can transmit and/or exchange genetic information horizontally (between individuals in the same generation). Viruses have a unique mechanism of replication that is dependent on the host metabolic machinery. Viruses can introduce variation in the host genetic material through lysogeny or latent infection.

To function in a biological system, cells communicate with other cells and respond to the external environment. Cell signaling pathways are determined by interacting signal and receptor molecules, and signaling cascades direct complex behaviors that affect physiological responses in the organism by altering gene expression or protein activity. Nonheritable

information transmission influences behavior within and between cells, organisms and populations; these behaviors are directed by underlying genetic information, and responses to information are vital to natural selection and evolution. Animals have evolved sensory organs that detect and process external information. Nervous systems interface with these sensory and internal body systems, coordinating response and behavior; and this coordination occurs through the transmission and processing of signal information. Behavior in the individual serves to increase its fitness in the population while contributing to the overall survival of the population.

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

The organizational basis of all living systems is heritable information. The proper storage and transfer of this information are critical for life to continue at the cell, organism and species levels. Reproduction occurs at the cellular and organismal levels. In order for daughter cells to continue subsequent generational cycles of reproduction or replication, each progeny needs to receive heritable genetic instructions from the parental source. This information is stored and passed to the subsequent generation via DNA. Viruses, as exceptional entities, can contain either DNA or RNA as heritable genetic information. The chemical structures of both DNA and RNA provide mechanisms that ensure information is preserved and passed to subsequent generations. There are important chemical and structural differences between DNA and RNA that result in different stabilities and modes of replication. In order for information stored in DNA to direct cellular processes, the information needs to be transcribed (DNA $\rightarrow$ RNA) and in many cases, translated (RNA $\rightarrow$ protein). The products of these processes determine metabolism and cellular activities and, thus, the phenotypes upon which evolution operates.

In eukaryotic organisms, genetic information is packaged into chromosomes, which carry essential heritable information that must be passed to daughter cells. Mitosis provides a mechanism that ensures each daughter cell receives an identical and complete set of chromosomes and that ensures fidelity in the transmission of heritable information. Mitosis allows for asexual reproduction of organisms in which daughter cells are genetically identical to the parental cell and allows for genetic information transfer to subsequent generations. Both unicellular and multicellular organisms have various mechanisms that increase genetic variation.

Sexual reproduction of diploid organisms involves the recombination of heritable information from both parents through fusion of gametes during fertilization. The two gametes that fuse to form a new progeny zygote each contain a single set (1n) of chromosomes. Meiosis reduces the number of chromosomes from diploid (2n) to haploid (1n) by following a single replication with two divisions. The random assortment of maternal and paternal chromosomes in meiosis and exchanges between sister chromosomes increase genetic variation; thus, the four gametes, while carrying the same number of chromosomes, are genetically unique with respect to individual alleles and allele combinations. The combination of these gametes at fertilization reestablishes the diploid nature of the organism and provides an additional mechanism for generating genetic variation, with every zygote being genetically different. Natural selection operates on populations through the phenotypic differences (traits) that individuals display; meiosis followed by fertilization provides a spectrum of possible phenotypes on which natural selection acts, and variation contributes to the long-term continuation of species.

Some phenotypes are products of action from single genes. These single gene traits provided the experimental system through which Mendel was able to describe a model of inheritance. The processes that chromosomes undergo during meiosis provide a mechanism that accounts for the random distribution of traits, the independence of traits, and the fact that some traits tend to stay together as they are transmitted from parent to offspring. Mendelian genetics can be applied to many phenotypes, including some human genetic disorders. Ethical, social and medical issues can surround such genetic disorders.

Whereas some traits are determined by the actions of single genes, most traits result from the interactions of multiple genes products or interactions between gene products and the environment. These traits often exhibit a spectrum of phenotypic properties that results in a wider range of observable traits, including weight, height and coat color in animals.

Enduring Understanding 3.A: Heritable information provides for continuity of life.**Essential Knowledge 3.A.1:**

DNA, and in some cases, RNA, is the primary source of heritable information.

Illustrative Examples:

Addition of a poly-A tail (c2)
Addition of a GTP cap (c2)
Excision of introns (c2)
Enzymatic reactions (d)
Transport by proteins (d)
Synthesis (d)
Degradation (d)
Electrophoresis (e)
Plasmid-based transformation (e)
Restriction enzyme analysis of DNA (e)
Polymerase Chain Reaction (PCR) (e)
Genetically modified foods (f)
Transgenic animals (f)
Cloned animals (f)
Pharmaceuticals, such as human insulin or factor X (f)

X The names of the steps and particular enzymes involved, beyond DNA polymerase, ligase, RNA polymerase, helicase and topoisomerase, are outside the scope of the course for the purposes of the AP Exam. (a6)
X The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the course and the AP® Exam. (c4)
X Memorization of the genetic code is beyond the scope of the course and the AP Exam. (c4)

- a. Genetic information is transmitted from one generation to the next through DNA or RNA.
 1. Demonstrated Evidence--Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
 2. Demonstrated Evidence--Noneukaryotic organisms have circular chromosomes, while eukaryotic organisms have multiple linear chromosomes, although in biology there are exceptions to this rule.
 3. Demonstrated Evidence--Prokaryotes, viruses and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded circular DNA molecules.
 4. Demonstrated Evidence--The proof that DNA is the carrier of genetic information involved a number of important historical experiments. These include:
 - Contributions of Watson, Crick, Wilkins, and Franklin on the structure of DNA
 - Avery-MacLeod-McCarty experiments
 - Hershey-Chase experiment
 5. Demonstrated Evidence--DNA replication ensures continuity of hereditary information.
 - Replication is a semiconservative process; that is, one strand serves as the template for a new, complementary strand.
 - Replication requires DNA polymerase plus many other essential cellular enzymes, occurs bidirectionally, and differs in the production of the leading and lagging strands.
 6. Demonstrated Evidence--Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny.
- b. DNA and RNA molecules have structural similarities and differences that define function.
 1. Demonstrated Evidence--Both have three components — sugar, phosphate and a nitrogenous base — which form nucleotide units that are connected by covalent bonds to form a linear molecule with and ends, with the nitrogenous bases perpendicular to the sugar-phosphate backbone.
 2. Demonstrated Evidence--The basic structural differences include:
 - DNA contains deoxyribose (RNA contains ribose).
 - RNA contains uracil in lieu of thymine in DNA.
 - DNA is usually double stranded, RNA is usually single stranded.
 - The two DNA strands in double-stranded DNA are antiparallel in directionality.
 3. Demonstrated Evidence--Both DNA and RNA exhibit specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G).
 - Purines (G and A) have a double ring structure.

- Pyrimidines (C, T and U) have a single ring structure.
4. Demonstrated Evidence--The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.
 - mRNA carries information from the DNA to the ribosome.
 - tRNA molecules bind specific amino acids and allow information in the mRNA to be translated to a linear peptide sequence.
 - rRNA molecules are functional building blocks of ribosomes.
 - The role of RNAi includes regulation of gene expression at the level of mRNA transcription.
- c. Genetic information flows from a sequence of nucleotides in a gene to a sequence of amino acids in a protein.
1. Demonstrated Evidence--The enzyme RNA-polymerase reads the DNA molecule in the 3' to 5' direction and synthesizes complementary mRNA molecules that determine the order of amino acids in the polypeptide.
 2. Demonstrated Evidence--In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications.
 3. Demonstrated Evidence--Translation of the mRNA occurs in the cytoplasm on the ribosome.
 4. Demonstrated Evidence--In prokaryotic organisms, transcription is coupled to translation of the message. Translation involves energy and many steps, including initiation, elongation and termination. The salient features include:
 - The mRNA interacts with the rRNA of the ribosome to initiate translation at the (start) codon.
 - The sequence of nucleotides on the mRNA is read in triplets called codons.
 - Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids have more than one codon.
 - tRNA brings the correct amino acid to the correct place on the mRNA.
 - The amino acid is transferred to the growing peptide chain.
 - The process continues along the mRNA until a "stop" codon is reached.
 - The process terminates by release of the newly synthesized peptide/protein.
- d. Phenotypes are determined through protein activities.
- e. Genetic engineering techniques can manipulate the heritable information of DNA and, in special cases, RNA.

LEARNING OBJECTIVES

3.1: Construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and in some cases, RNA are the primary sources of heritable information.
[SP 6.2, 6.5]

3.4: Describe representations and models that illustrate how genetic information is translated into polypeptides.
[SP 1.2]

3.2: Justify the selection of data from historical investigations that support the claim that NA is the source of heritable information.
[SP 4.1]

3.5 Explain how heritable information can be manipulated using common technologies.
[SP 6.2, 6.4]

3.3: Describe representations and models that illustrate how genetic information is copied for transmission between generations.
[SP 1.2]

3.6 Predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.
[SP 6.4]

Enduring Understanding 3.A: Heritable information provides for continuity of life.*Illustrative Examples:*

Mitosis-promoting factor (MPF) (a2)

Action of platelet-derived growth factor (PDGF) (a2)
Cancer results from disruptions in cell cycle control (a2)

Essential Knowledge 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.

X Knowledge of any one cyclin-Cdk pair or growth factor is beyond the scope of this AP Exam. (a3)

X Memorization of the names of the phases of mitosis is beyond the scope of the course and the AP Exam. (b4)

- a. The cell cycle is a complex set of stages that is highly regulated with checkpoints, which determine the ultimate fate of the cell.
 1. Demonstrated Evidence--Interphase consists of three phases: growth, synthesis of DNA, preparation for mitosis.
 2. Demonstrated Evidence--The cell cycle is directed by internal controls or checkpoints. Internal and external signals provide stop-and-go signs at the checkpoints.
 3. Demonstrated Evidence--Cyclins and cyclin-dependent kinases control the cell cycle.
 4. Demonstrated Evidence--Mitosis alternates with interphase in the cell cycle.
 5. Demonstrated Evidence--When a cell specializes, it often enters into a stage where it no longer divides, but it can reenter the cell cycle when given appropriate cues. Nondividing cells may exit the cell cycle; or hold at a particular stage in the cell cycle.
- b. Mitosis passes a complete genome from the parent cell to daughter cells.
 1. Demonstrated Evidence--Mitosis occurs after DNA replication.
 2. Demonstrated Evidence--Mitosis followed by cytokinesis produces two genetically identical daughter cells.
 3. Demonstrated Evidence--Mitosis plays a role in growth, repair, and asexual reproduction.
 4. Demonstrated Evidence--Mitosis is a continuous process with observable structural features along the mitotic process. Replication, alignment, and separation are the order of processes.
- c. Meiosis, a reduction division, followed by fertilization, ensures genetic diversity in sexually reproducing organisms.
 1. Demonstrated Evidence--Meiosis ensures that each gamete receives one complete haploid (1n) set of chromosomes.
 2. Demonstrated Evidence--During meiosis, homologous chromosomes are paired, with one homologue originating from the maternal parent and the other from the paternal parent. Orientation of the chromosome pairs is random with respect to the cell poles.
 3. Demonstrated Evidence--Separation of the homologous chromosomes ensures that each gamete receives a haploid (1n) set of chromosomes composed of both maternal and paternal chromosomes.
 4. Demonstrated Evidence--During meiosis, homologous chromatids exchange genetic material via a process called "crossing over," which increases genetic variation in the resultant gametes.
 5. Demonstrated Evidence--Fertilization involves the fusion of two gametes, increases genetic variation in populations by providing for new combinations of genetic information in the zygote, and restores the diploid number of chromosomes.

LEARNING OBJECTIVES

3.7: Make predictions about natural phenomena occurring during the cell cycle.
[SP 6.2, 6.5]

3.8: Describe the events that occur in the cell cycle.
[SP 1.2]

3.9: Construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization.
[SP 6.2]

3.10: Represent the connection between meiosis and increased genetic diversity necessary for evolution.
[SP 7.1]

3.11 Evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization.
[SP 5.3]

Enduring Understanding 3.A: Heritable information provides for continuity of life.**Essential Knowledge 3.A.3:****Illustrative Examples:**

Sickle cell anemia (c)
Tay-Sachs disease (c)
Huntington's disease (c)
X-linked color blindness (c)
Trisomy 21/Down syndrome (c)
Klinefelter's syndrome (c)
Reproduction issues (d)
Civic issues such as ownership of genetic information, privacy, historical contexts, etc. (d)

The chromosomal basis of inheritance provides an understanding of the pattern of passage (transmission) of genes from parents to offspring.

- a. Rules of probability can be applied to analyze passage of single gene traits from parent to offspring.
- b. Segregation and independent assortment of chromosomes result in genetic variation.
 - 1. Demonstrated Evidence--Segregation and independent assortment can be applied to genes that are on different chromosomes.
 - 2. Demonstrated Evidence--Genes that are adjacent and close to each other on the same chromosome tend to move as a unit; the probability that they will segregate as a unit is a function of the distance between them.
 - 3. Demonstrated Evidence--The pattern of inheritance (monohybrid, dihybrid, sex-linked, and genes linked on the same homologous chromosome) can often be predicted from the data that gives the parent genotype/phenotype and/or the offspring genotypes/phenotypes.
- c. Certain human genetic disorders can be attributed to the inheritance of single gene traits or specific chromosomal changes, such as nondisjunction.
- d. Many ethical, social, and medical issues surround human genetic disorders.

LEARNING OBJECTIVES

3.12: Construct a representation that connects the process of meiosis to the passage of traits from parent to offspring.

[SP 1.1, 7.2]

3.13: Pose questions about ethical, social, and medical issues surrounding human genetic disorders.

[SP 3.1]

3.14: Apply mathematical routines to determine Mendelian patterns of inheritance provided by data set.

[SP 2.2]

Enduring Understanding 3.A: Heritable information provides for continuity of life.*Illustrative Examples:*

Sex-linked genes reside on sex chromosomes (X in humans) (b)

In mammals and flies, the Y chromosome is very small and carries few genes (b)

In mammals and flies, females are XX and males are XY; as such, X-linked recessive traits are always expressed in males (b)

Some traits are sex limited, and expression depends on the sex of the individual, such as milk production in female mammals and pattern baldness in males (b)

Essential Knowledge 3.A.4:

The inheritance pattern of many traits cannot be explained by simple Mendelian genetics.

X Epistasis and pleiotropy are beyond the scope of the course and the AP Exam. (c2)

- a. Many traits are the product of multiple genes and/or physiological processes.
 - 1. Demonstrated Evidence--Patterns of inheritance of many traits do not follow ratios predicted by Mendel's laws and can be identified by quantitative analysis, where observed phenotypic ratios statistically differ from the predicted ratios.
- b. Some traits are determined by genes on sex chromosomes.
- c. Some traits result from nonnuclear inheritance.
 - 1. Demonstrated Evidence--Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules.
 - 2. Demonstrated Evidence--In animals, mitochondrial DNA is transmitted by the egg and not by sperm; as such, mitochondrial-determined traits are maternally inherited.

LEARNING OBJECTIVES

3.15: Explain deviations from Mendel's model of the inheritance of traits.
[SP 6.2, 6.5]

3.16: Explain how the inheritance patterns of many traits cannot be accounted for by Mendelian genetics.
[SP 6.3]

3.17: Describe representations of an appropriate example of inheritance patterns that cannot be explained by Mendel's model of the inheritance of traits.
[SP 1.2]

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

Structure and function in biology result from the presence of genetic information and the correct expression of this information. The expression of the genetic material controls cell products, and these products determine the metabolism and nature of the cell. Most cells within an organism contain the same set of genetic instructions, but the differential expression of specific genes determines the specialization of cells. Some genes are continually expressed, while the expression of most is regulated; regulation allows more efficient energy utilization, resulting in increased metabolic fitness. Gene expression is controlled by environmental signals and developmental cascades that involve both regulatory and structural genes. A variety of different gene regulatory systems are found in nature. Two of the best studied are the inducible and the repressible regulatory systems (i.e., operons) in bacteria, and several regulatory pathways that are conserved across phyla use a combination of positive and negative regulatory motifs. In eukaryotes, gene regulation and expression are more complex and involve many factors, including a suite of regulatory molecules.

Multicellular organisms have developmental pathways from zygote to adult, yet all cells in the organism start with the same complement of DNA. The developmental sequences are predominately determined and programmed by differential gene expression. Which gene gets expressed and the level of expression are determined by both internal and external signals. In multicellular organisms, cell-to-cell interactions and cell-to-cell signaling via small molecules modulate and control gene expression and cell function. For example, morphogens help to determine spatial development, and hormones can influence cell metabolism.

Developmental gene sequences have an evolutionary origin and are conserved across species; for example, HOX genes are present in genome sequences from *Drosophila* to humans. Errors or changes in regulation of genes involved in development often lead to severe, detrimental and even bizarre consequences.

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

Essential Knowledge 3.B.1:

Illustrative Examples:

Promoters (a1)
Terminators (a1)
Enhancers (a1)

**Gene regulation results
in differential gene
expression, leading to
cell specialization.**

- a. Both DNA regulatory sequences, regulatory genes, and small regulatory RNAs are involved in gene expression.
 - 1. Demonstrated Evidence--Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription.
 - 2. Demonstrated Evidence--A regulatory gene is a sequence of DNA encoding a regulatory protein or RNA.
- b. Both positive and negative control mechanisms regulate gene expression in bacteria and viruses.
 - 1. Demonstrated Evidence--The expression of specific genes can be turned on by the presence of an inducer.
 - 2. Demonstrated Evidence--The expression of specific genes can be inhibited by the presence of a repressor.
 - 3. Demonstrated Evidence--Inducers and repressors are small molecules that interact with regulatory proteins and/or regulatory sequences.
 - 4. Demonstrated Evidence--Regulatory proteins inhibit gene expression by binding to DNA and blocking transcription (negative control).
 - 5. Demonstrated Evidence--Regulatory proteins stimulate gene expression by binding to DNA and stimulating transcription (positive control) or binding to repressors to inactivate repressor function.
 - 6. Demonstrated Evidence--Certain genes are continuously expressed; that is, they are always turned "on," e.g., the ribosomal genes.
- c. In eukaryotes, gene expression is complex and control involves regulatory genes, regulatory elements and transcription factors that act in concert.
 - 1. Demonstrated Evidence--Transcription factors bind to specific DNA sequences and/or other regulatory proteins.
 - 2. Demonstrated Evidence--Some of these transcription factors are activators (increase expression), while others are repressors (decrease expression).
 - 3. Demonstrated Evidence--The combination of transcription factors binding to the regulatory regions at any one time determines how much, if any, of the gene product will be produced.
- d. Gene regulation accounts for some of the phenotypic differences between organisms with similar genes.

LEARNING OBJECTIVES

3.18: Describe the connection between the regulation of gene expression and observed differences between different kinds of organisms.
[SP 7.1]

3.20: Explain how the regulation of gene expression is essential for the processes and structures that support efficient cell function.
[SP 6.2]

3.19: Describe the connection between the regulation of gene expression and observed differences between individuals in a population.
[SP 7.1]

3.21: Use representations to describe how gene regulation influences cell products and function.
[SP 1.4]

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

Essential Knowledge 3.B.2:

A variety of intercellular and intracellular signal transmissions mediate gene expression.

Illustrative Examples:

Cytokines regulate gene expression to allow for cell replication and division (a)
Mating pheromones in yeast trigger mating gene expression (a)
Levels of cAMP regulate metabolic gene expression in bacteria (a)
Expression of the SRY gene triggers the male sexual development pathway in animals (a)
Ethylene levels cause changes in the production of different enzymes, allowing fruits to ripen (a)
Seed germination and gibberellin (a)
Mating pheromones in yeast trigger mating genes expression and sexual reproduction (b)
Morphogens stimulate cell differentiation and development (b)
Changes in p53 activity can result in cancer (b)
HOX genes and their role in development (b)

- a. Signal transmission within and between cells mediates gene expression.
- b. Signal transmission within and between cells mediates cell function.

LEARNING OBJECTIVES

3.22: Explain how signal pathways mediate gene expression, including how this process can affect protein production.
[SP 6.2]

3.23: Use representations to describe mechanisms of the regulation of gene expression.
[SP 1.4]

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

Genetic information is a set of instructions necessary for the survival, growth and reproduction of an organism. In order for the information to be useful, it needs to be processed by the cell. Processing includes replication, decoding and transfer of the information. When genetic information changes, either through natural processes or genetic engineering, the results may be observable changes in the organism. At the molecular level, these changes may be the result of mutations in the genetic material, the effects of which may be seen when the information is processed to yield a nucleic acid or a polypeptide. The processes of transcription, mRNA processing and translation are imperfect, and errors can occur and may, in certain cases, alter phenotypes. However, these errors are random and are not heritable except in the case of RNA viruses where the random errors change the genetic information of the virus. External factors in the environment can affect the degree of, or the potential for increased probability for, errors in the information and processing. Cellular mechanisms that usually correct errors have evolved. Genetic variations at the genome level, when expressed as phenotypes, are subject to natural selection.

Since all organisms, as well as viruses, exist in a dynamic environment, mechanisms that increase genetic variation are vital for a species' ability to adapt to a changing environment. In a meiotic organism, the transfer process, whereby each gamete receives one set of chromosomes, ensures that this set is unique and different from that of the parent. Random processes such as the transposition of DNA regions ("jumping genes") occur in all biological domains. Bacteria divide by binary fission and do not have the random assortment processes that occur in eukaryotic organisms. Nonetheless, mechanisms have evolved in bacteria that ensure genetic variation beyond the variation that is introduced through normal DNA metabolism, e.g., replication, repair, and recombination. Bacterial genetic information can be transmitted or exchanged laterally through a variety of processes, including conjugation, transduction, and transformation. This type of exchange yields rapid dissemination of new phenotypes within and between bacterial populations, allowing for rapid evolution.

The basic structure of viruses includes a protein capsid that surrounds and protects the genetic information (genome) that can be either DNA or RNA. Viruses have a mechanism of replication that is dependent on the host metabolic machinery to produce necessary viral components and viral genetic material. Some classes of viruses use RNA without a DNA intermediate; however, retroviruses, such as HIV, use a DNA intermediate for replication of their genetic material. Some viruses introduce variation into the host genetic material. When the host is bacterial, it is referred to as lysogenesis; whereas in eukaryotic cells, this is referred to as transformation. Since viruses use the host metabolic pathways, they experience the same potential as the host for genetic variation that results from DNA metabolism.

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

Essential Knowledge 3.C.1:

Illustrative Examples:

Antibiotic resistance mutations (d)

Pesticide resistance mutations (d)

*Sickle cell disorder and
heterozygote advantage (d)*

**Changes in genotype
can result in changes in
phenotype.**

- a. Alterations in a DNA sequence can lead to changes in the type or amount of the protein produced and the consequent phenotype.
 - 1. Demonstrated Evidence--DNA mutations can be positive, negative or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein.
- b. 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.
 - 1. Demonstrated Evidence--Whether or not a mutation is detrimental, beneficial or neutral depends on the environmental context. Mutations are the primary source of genetic variation.
- c. Errors in mitosis or meiosis can result in changes in phenotype.
 - 1. Demonstrated Evidence--Changes in chromosome number often result in new phenotypes, including sterility caused by triploidy and increased vigor of other polyploids.
 - 2. Demonstrated Evidence--Changes in chromosome number often result in human disorders with developmental limitations, including Trisomy 21 (Down syndrome) and XO (Turner syndrome).
- d. 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.
 - 1. Demonstrated Evidence--Selection results in evolutionary change.

LEARNING OBJECTIVES

3.24: Predict how a change in genotype, when expressed as a phenotype, provides a variation that can be subject to natural selection. [SP 6.4, 7.2]

3.26: Explain the connection between genetic variation in organisms and phenotypic variation in populations. [SP 7.2]

3.25: Create a visual representation to illustrate how changes in a DNA nucleotide sequence can result in a change in the polypeptide produced. [SP 1.1]

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

Illustrative Examples:

Essential Knowledge 3.C.2:

Biological systems have multiple processes that increase genetic variation.

✗ Details and specifics about the acquisition of genetic information are beyond the scope of the course and the AP Exam. (b)
✗ The details of sexual reproduction cycles in various plants and animals are beyond the scope of the course and the AP Exam. However, the similarities of the processes that provide for genetic variation are relevant and should be the focus of instruction. (c)

- a. The imperfect nature of DNA replication and repair increases variation.
- b. 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.
- c. 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.

LEARNING OBJECTIVES

3.27: Compare and contrast processes by which genetic variation is produced and maintained in organisms from multiple domains.
[SP 7.2]

3.28: Construct an explanation of the multiple processes that increase variation within a population.
[SP 6.2]

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

Essential Knowledge 3.C.3:

Illustrative Examples:

Transduction in bacteria (b1)
Transposons present in incoming DNA (b1)

Viral replication results in genetic variation, and viral infection can introduce genetic variation into the host.

- a. Viral replication differs from other reproductive strategies and generates genetic variation via various mechanisms.
 - 1. Demonstrated Evidence--Viruses have highly efficient replicative capabilities that allow for rapid evolution and acquisition of new phenotypes.
 - 2. Demonstrated Evidence--Viruses replicate via a component assembly model allowing one virus to produce many progeny simultaneously via the lytic cycle.
 - 3. Demonstrated Evidence--Virus replication allows for mutations to occur through usual host pathways.
 - 4. Demonstrated Evidence--RNA viruses lack replication error-checking mechanisms, and thus have higher rates of mutation.
 - 5. Demonstrated Evidence--Related viruses can combine/recombine information if they infect the same host cell.
 - 6. Demonstrated Evidence--HIV is a well-studied system where the rapid evolution of a virus within the host contributes to the pathogenicity of viral infection.
- b. The reproductive cycles of viruses facilitate transfer of genetic information.
 - 1. Demonstrated Evidence--Viruses transmit DNA or RNA when they infect a host cell.
 - 2. Demonstrated Evidence--Some viruses are able to integrate into the host DNA and establish a latent (lysogenic) infection. These latent viral genomes can result in new properties for the host such as increased pathogenicity in bacteria.

LEARNING OBJECTIVES

3.29: Construct an explanation of how viruses introduce genetic variation in host organisms.
[SP 6.2]

3.30: Use representations and appropriate models to describe how viral replication introduces genetic variation in the viral population.
[SP 1.4]

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

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

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

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

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

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

Essential Knowledge 3.D.1:

Illustrative Examples:

Use of chemical messengers by microbes to communicate with other nearby cells and to regulate specific pathways in response to population density (quorum sensing) (c)

Use of pheromones to trigger reproduction and developmental pathways (c)

Response to external signals by bacteria that influences cell movement (c)

Epinephrine stimulation of glycogen breakdown in mammals (d)

Temperature determination of sex in some vertebrate organisms (d)

DNA repair mechanisms (d)

Cell communication processes share common features that reflect a shared evolutionary history.

- a. Communication involves transduction of stimulatory or inhibitory signals from other cells, organisms or the environment.
- b. Correct and appropriate signal transduction processes are generally under strong selective pressure.
- c. In single-celled organisms, signal transduction pathways influence how the cell responds to its environment.
- d. In multicellular organisms, signal transduction pathways coordinate the activities within individual cells that support the function of the organism as a whole.

LEARNING OBJECTIVES

3.31: Describe basic chemical processes for cell communication shared across evolutionary lines of descent.
[SP 7.2]

3.32: Generate scientific questions involving cell communication as it relates to the process of evolution.
[SP 3.1]

3.33: Use representation(s) and appropriate models to describe features of a cell signaling pathway.
[SP 1.4]

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

Illustrative Examples:

Immune cells interact by cell-cell contact, antigen-presenting cells, helper T-cells and killer T-cells (a)

Plasmodesmata between plant cells that allow material to be transported from cell to cell (a)

Neurotransmitters (b)

Plant immune response (b)

Quorum sensing in bacteria (b)

Morphogens in embryonic development (b)

Insulin (c1)

Human growth hormone (c1)

Thyroid hormones (c1)

Testosterone (c1)

Estrogen (c1)

Essential Knowledge 3.D.2:

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

X No specific system, with the exception of the endocrine system, is required concepts in 3.D.2. Choose a system that best fosters understanding.

- a. Cells communicate by cell-to-cell contact.
- b. Cells communicate over short distances by using local regulators that target cells in the vicinity of the emitting cell.
- c. Signals released by one cell type can travel long distances to target cells of another cell type.
 - 1. Demonstrated Evidence--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.

LEARNING OBJECTIVES

3.34: Construct explanations of cell communication through cell-to-cell direct contact or through chemical signaling.
[SP 6.2]

3.35: Create representation(s) that depict how cell-to-cell communication occurs by direct contact or from a distance through chemical signaling.
[SP 1.1]

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

Essential Knowledge 3.D.3:

Signal transduction pathways link signal reception with cellular response.

X No particular system is required for signal transduction pathways. Choose a system that best fosters understanding.

Illustrative Examples:

*G-protein linked receptors ($\alpha 2$)
Ligand-gated ion channels ($\alpha 2$)
Receptor tyrosine kinases ($\alpha 2$)
Ligand-gated ion channels
Second messengers, such as cyclic GMP, cyclic AMP calcium ions, and inositol triphosphate*

- a. Signaling begins with the recognition of a chemical messenger, a ligand, by a receptor protein.
 - 1. Demonstrated Evidence--Different receptors recognize different chemical messengers, which can be peptides, small chemicals or proteins, in a specific one-to-one relationship.
 - 2. Demonstrated Evidence--A receptor protein recognizes signal molecules, causing the receptor protein's shape to change, which initiates transduction of the signal.
- b. Signal transduction is the process by which a signal is converted to a cellular response.
 - 1. Demonstrated Evidence--Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, with the result of appropriate responses by the cell.
 - 2. Demonstrated Evidence--Second messengers are often essential to the function of the cascade.
 - 3. Demonstrated Evidence--Many signal transduction pathways include:
 - Protein modifications (an illustrative example could be how methylation changes the signaling process)
 - Phosphorylation cascades in which a series of protein kinases add a phosphate group to the next protein in the cascade sequence

LEARNING OBJECTIVES

3.36: Describe a model that expresses the key elements of signal transduction pathways by which a signal is converted to a cellular response.
[SP 1.5]

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

Essential Knowledge 3.D.4:

Illustrative Examples:

*Diabetes, heart disease,
neurological disease,
autoimmune disease, cancer,
cholera (a)*

*Effects of neurotoxins, poisons,
pesticides (a)*

*Drugs (Hypertensives, Anesthetics,
Antihistamines and Birth Control
Drugs) (a)*

**Changes in signal
transduction pathways
can alter cellular
response.**

X Specific mechanisms of these diseases and action of drugs are beyond the scope of the course and the AP Exam.

- a. Conditions where signal transduction is blocked or defective can be deleterious, preventative or prophylactic.

LEARNING OBJECTIVES

3.37: Justify claims based on scientific evidence that changes in signal transduction pathways can alter cellular response.
[SP 6.1]

3.39: Construct an explanation of how certain drugs affect signal reception and, consequently, signal transduction pathways.
[SP 6.2]

3.38: Describe a model that expresses key elements to show how change in signal transduction can alter cellular response.
[SP 1.5]

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

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

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

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

Populations of organisms exist in communities. Individual behavior influences population behavior, and both are the products of information recognition, processing and transmission. Communication among individuals within a population may increase the long-term success of the population. Cooperative behavior within a population provides benefits to the population and to the individuals within the population. Examples of benefits include protection from predators, acquisition of prey and resources, sexual reproduction, recognition of offspring and genetic relatedness, and transmission of learned responses.

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

Illustrative Examples:

Fight or flight response (a)
Predator warnings (a)
Protection of young (a)
Plant-plant interactions due to herbivory (a)
Avoidance responses (a)
Herbivory responses (b1)
Territorial marking in mammals (b1)
Coloration in flowers (b1)
Bee dances (b2)
Birds songs (b2)
Territorial marking in mammals (b2)
Pack behavior in animals (b2)
Herd, flock, and schooling behavior in animals (b2)
Predator warning (b2)
Colony and swarming behavior in insects (b2)
Coloration (b2)
Parent and offspring interactions (c1)
Migration patterns (c1)
Courtship and mating behaviors (c1)
Foraging in bees and other animals (c1)
Avoidance behavior to electric fences, poisons, or traps (c1)
Pack behavior in animals (c2)
Herd, flock and schooling behavior in animals (c2)
Predator warning (c2)
Colony and swarming behavior in insects (c2)

Essential Knowledge 3.E.1:

Individuals can act on information and communicate it to others.

X The details of the various communications and community behavioral systems are beyond the scope of the course and the AP Exam. (c2)

- a. Organisms exchange information with each other in response to internal changes and external cues, which can change behavior.
- b. Communication occurs through various mechanisms.
 1. Demonstrated Evidence--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.
 2. Demonstrated Evidence--Animals use visual, audible, tactile, electrical and chemical signals to indicate dominance, find food, establish territory and ensure reproductive success.
- c. Responses to information and communication of information are vital to natural selection and evolution.
 1. Demonstrated Evidence--Natural selection favors innate and learned behaviors that increase survival and reproductive fitness.
 2. Demonstrated Evidence--Cooperative behavior tends to increase the fitness of the individual and the survival of the population.

LEARNING OBJECTIVES

3.40: Analyze data that indicate how organisms exchange information in response to internal changes and external cues, and which can change behavior.
[SP 5.1]

3.42: Describe how organisms exchange information in response to internal changes or environmental cues.
[SP 7.1]

3.41: Create a representation that describes how organisms exchange information in response to internal changes and external cues, and which can result in changes in behavior.
[SP 1.1]

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

Essential Knowledge 3.E.2:

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

Illustrative Examples:

Acetylcholine (c1)
Epinephrine (c1)
Norepinephrine (c1)
Dopamine (c1)
Serotonin (c1)
GABA (c1)
Vision (d)
Hearing (d)
Muscle movement (d)
Abstract thought and emotions (d)
Neuro-hormone production (d)
Forebrain (cerebrum), midbrain (brainstem) and hindbrain (cerebellum) (d)
Right and left cerebral hemispheres in humans (d)

X Study of the nervous and immune systems is required for concepts detailed in 3.E.2.

X The types of nervous systems, development of the human nervous system, details of the various structures and features of the brain parts, and details of specific neurologic processes are beyond the scope of the course and the AP Exam.

- a. The neuron is the basic structure of the nervous system that reflects function.
 1. Demonstrated Evidence--A typical neuron has a cell body, axon and dendrites. Many axons have a myelin sheath that acts as an electrical insulator.
 2. Demonstrated Evidence--The structure of the neuron allows for the detection, generation, transmission and integration of signal information.
 3. Demonstrated Evidence--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.
- b. Action potentials propagate impulses along neurons.
 1. Demonstrated Evidence--Membranes of neurons are polarized by the establishment of electrical potentials across the membranes.
 2. Demonstrated Evidence--In response to a stimulus, Na⁺ and K⁺ gated channels sequentially open and cause the membrane to become locally depolarized.
 3. Demonstrated Understanding—Na⁺ / K⁺ pumps, powered by ATP, work to maintain membrane potential.
- c. Transmission of information between neurons occurs across synapses.
 1. Demonstrated Evidence--In most animals, transmission across synapses involves chemical messengers called neurotransmitters.
 2. Demonstrated Evidence--Transmission of information along neurons and synapses results in a response.
 3. Demonstrated Evidence--The response can be stimulatory or inhibitory.
- d. Different regions of the vertebrate brain have different functions.

LEARNING OBJECTIVES

3.43: Construct an explanation, based on scientific theories and models, about how nervous systems detect external and internal signals, transmit and integrate information, and produce responses.

[SP 6.2, 7.1]

3.46: Describe how the vertebrate brain integrates information to produce a response.

[SP 1.2]

3.48: Create a visual representation to describe how nervous systems detect external and internal signals.

[SP 1.1]

3.44: Describe how nervous systems detect external and internal signals.

[SP 1.2]

3.49: Create a visual representation to describe how nervous systems transmit information.

[SP 1.1]

3.45: Describe how nervous systems transmit information.

[SP 1.2]

3.47: Create a visual representation of complex nervous systems to describe/explain how these systems detect external and internal signals, transmit and integrate information, and produce responses.

[SP 1.1]

3.50: Create a visual representation to describe how the vertebrate brain integrates information to produce a response.

[SP 1.1]

BIG IDEA: Enduring understanding 4.A: Interactions within biological systems lead to complex properties.

All biological systems, from cells to ecosystems, are composed of parts that interact with each other. When this happens, the resulting interactions enable characteristics not found in the individual parts alone. In other words, “the whole is greater than the sum of its parts,” a phenomenon sometimes referred to as “emergent properties.”

At the molecular level, the properties of a polymer are determined by its subcomponents and their interactions. For example, a DNA molecule is comprised of a series of nucleotides that can be linked together in various sequences; the resulting polymer carries hereditary material for the cell, including information that controls cellular activities. Other polymers important to life include carbohydrates, lipids and proteins. The interactions between the constituent parts of polymers, their order, their molecular orientation and their interactions with their environment define the structure and function of the polymer.

At the cellular level, organelles interact with each other and their environment as part of a coordinated system that allows cells to live, grow and reproduce. For example, chloroplasts produce trioses through the process of photosynthesis; however, once trioses are synthesized and exported from the chloroplast, they may be packaged by the Golgi body and distributed to the edge of the cell where they serve as a building block for cellulose fibers comprising the cell wall. Similarly, several organelles are involved in the manufacture and export of protein. The repertory of subcellular organelles determines cell structure and differentiation; for instance, the components of plant leaf cells are different from the components of plant root cells, and the components of human liver cells are different from those in the retina. Thus, myriad interactions of different parts at the subcellular level determine the functioning of the entire cell, which would not happen with the activities of individual organelles alone.

In development, interactions between regulated gene expression and external stimuli, such as temperature or nutrient levels or signal molecules, result in specialization of cells, organs and tissues. Differentiation of the germ layers during vertebrate gastrulation is an example of one such divergence. The progression of stem cells to terminal cells can also be explained by the interaction of stimuli and genes. Additionally, cells, organs and tissues may change due to changes in gene expression triggered by internal cues, including regulatory proteins and growth factors, which result in the structural and functional divergence of cells.

Organisms exhibit complex properties due to interactions of their constituent parts, and interactions and coordination between organs and organ systems provide essential biological activities for the organism as a whole. Examples include the vessels and hearts of animals and the roots and shoots of plants. Environmental factors such as temperature can trigger responses in individual organs that, in turn, affect the entire organism.

Interactions between populations within communities also lead to complex properties. As environmental conditions change in time and space, the structure of the community changes both physically and biologically, resulting in a mosaic in the landscape (variety or patterns) in a community. Communities are comprised of different populations of organisms that interact with each other in either negative or positive ways (e.g., competition, parasitism and mutualism); community ecology seeks to understand the manner in which groupings of species are distributed in nature, and how they are influenced by their abiotic environment and species interactions. The physical structure of a community is affected by abiotic factors, such as the depth and flow of water in a stream, and also by the spatial distribution of organisms, such as in the canopy of trees. The mix of species in terms of both the number of individuals and the diversity of species defines the structure of the community. Mathematical or computer models can be used to illustrate and investigate interactions of populations within a community and the effects of environmental impacts on a community. Community change resulting from disturbances sometimes follows a pattern (e.g., succession following a wildfire), and in other cases is random and unpredictable (e.g., founder effect).

At the ecosystem level, interactions among living organisms and with their environment result in the movement of matter and energy. Ecosystems include producers, consumers, decomposers and a pool of organic matter, plus the physiochemical environment that provides the living conditions for the biotic components. Matter, but not energy, can be recycled within an ecosystem via biogeochemical cycles. Energy flows through the system and can be converted from one type to another, e.g., energy available in sunlight is converted to chemical bond energy via photosynthesis. Understanding individual organisms in relation to the environment and the diverse interactions that populations have with one another (e.g., food

chains and webs) informs the development of ecosystem models; models allow us to identify the impact of changes in biotic and abiotic factors. Human activities affect ecosystems on local, regional and global scales.

Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.**Essential Knowledge 4.A.1:***Illustrative Examples:*

The subcomponents of biological molecules and their sequence determine the properties of that molecule.

✗ The molecular structure of specific nucleotides is beyond the scope of the course and the AP Exam. (a1)

✗ The molecular structure of specific amino acids is beyond the scope of the course and the AP Exam. (a2)

✗ The molecular structure of specific lipids is beyond the scope of the course and the AP Exam. (a3)

✗ The molecular structure of specific carbohydrate polymers is beyond the scope of the course and the AP Exam. (a4)

- a. Structure and function of polymers are derived from the way their monomers are assembled.
 1. Demonstrated Evidence--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.
 2. Demonstrated Evidence--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.
 3. Demonstrated Evidence--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.
 4. Demonstrated Evidence--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.
- b. Directionality influences structure and function of the polymer.
 1. Demonstrated Evidence--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'.
 2. Demonstrated Evidence--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.
 3. Demonstrated Evidence--The nature of the bonding between carbohydrate subunits determines their relative orientation in the carbohydrate, which then determines the secondary structure of the carbohydrate.

LEARNING OBJECTIVES

4.1: Explain the connection between the sequence and the subcomponents of a biological polymer and its properties.

[SP 7.1]

4.2: Refine representations and models to explain how the subcomponents of a biological polymer and their sequence determine the properties of that polymer.

[SP 1.3]

4.3: Use models to predict and justify that changes in the subcomponents of a biological polymer affect the functionality of the molecule.

[SP 6.1, 6.4]

Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.*Illustrative Examples:***Essential Knowledge 4.A.2:**

The structure and function of subcellular components, and their interactions, provide essential cellular processes.

X Specific functions of smooth ER in specialized cells are beyond the scope of the course and the AP Exam. (b2)
X Specific examples of how lysosomes carry out intracellular digestion are beyond the scope of the course and the AP Exam. (e)
X The molecular structure of chlorophyll a is beyond the scope of the course and the AP Exam. (g2)

- a. 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.
- b. Endoplasmic reticulum occurs in two forms: smooth and rough.
 1. Demonstrated Evidence--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.
 2. Demonstrated Evidence--In most cases, smooth ER synthesizes lipids.
- c. The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs (cisternae). [See also]
 1. Demonstrated Evidence--Functions of the Golgi include synthesis and packaging of materials (small molecules) for transport (in vesicles), and production of lysosomes.
- d. Mitochondria specialize in energy capture and transformation.
 1. Demonstrated Evidence--Mitochondria have a double membrane that allows compartmentalization within the mitochondria and is important to its function.
 2. Demonstrated Evidence--The outer membrane is smooth, but the inner membrane is highly convoluted, forming folds called cristae.
 3. Demonstrated Evidence--Cristae contain enzymes important to ATP production; cristae also increase the surface area for ATP production.
- e. 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.
- f. 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.
- g. Chloroplasts are specialized organelles found in algae and higher plants that capture energy through photosynthesis.
 1. Demonstrated Evidence--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.
 2. Demonstrated Evidence--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.
 3. Demonstrated Evidence--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 NADPH₂, which fuel carbon-fixing reactions in the Calvin-Benson cycle. Carbon fixation occurs in the stroma, where molecules of CO₂ are converted to carbohydrates.

LEARNING OBJECTIVES

4.4: Make a prediction about the interactions of subcellular organelles.
[SP 6.4]

4.5: Construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.
[SP 6.2]

4.6: Use representations and models to analyze situations qualitatively to describe how interactions of subcellular structures, which possess specialized functions, provide essential functions.
[SP 1.4]

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

Essential Knowledge 4.A.3:

Illustrative Examples:

Interactions between external stimuli and regulated gene expression result in specialization of cells, tissues, and organs.

- a. Differentiation in development is due to external and internal cues that trigger gene regulation by proteins that bind to DNA.
- b. Structural and functional divergence of cells in development is due to expression of genes specific to a particular tissue or organ type.
- c. Environmental stimuli can affect gene expression in a mature cell.

LEARNING OBJECTIVES

4.7: Refine representations to illustrate how interactions between external stimuli and gene expression result in specialization of cells, tissues and organs.

[SP 1.3]

Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.*Illustrative Examples:**Stomach and small intestines (a)**Kidney and bladder (a)**Root, stem and leaf (a)**Respiratory and circulatory (b)**Nervous and muscular (b)**Plant vascular and leaf (b)***Essential Knowledge 4.A.4:**

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

- a. Interactions and coordination between organs provide essential biological activities.
- b. Interactions and coordination between systems provide essential biological activities.

LEARNING OBJECTIVES

4.8: Evaluate scientific questions concerning organisms that exhibit complex properties due to the interaction of their constituent parts.
[SP 3.3]

4.9: Predict the effects of a change in a component(s) of a biological system on the functionality of an organism(s).
[SP 6.4]

4.10: Refine representations and models to illustrate biocomplexity due to interactions of the constituent parts.
[SP 1.3]

Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.**Essential Knowledge 4.A.5:***Illustrative Examples:**Predator/prey relationships**spreadsheet model (b)**Symbiotic relationship (b)**Graphical representation of field data (b)**Introduction of species (b)**Global climate change models (b)*

**Communities are
composed of
populations of
organisms that interact
in complex ways.**

- a. The structure of a community is measured and described in terms of species composition and species diversity.
- b. Mathematical or computer models are used to illustrate and investigate population interactions within and environmental impacts on a community.
- c. Mathematical models and graphical representations are used to illustrate population growth patterns and interactions.
 - 1. Demonstrated Evidence--Reproduction without constraints results in the exponential growth of a population.
 - 2. Demonstrated Evidence--A population can produce a density of individuals that exceeds the system's resource availability.
 - 3. Demonstrated Evidence--As limits to growth due to density-dependent and density-independent factors are imposed, a logistic growth model generally ensues.
 - 4. Demonstrated Evidence--Demographics data with respect to age distributions and fecundity can be used to study human populations.

LEARNING OBJECTIVES

4.11: Justify the selection of the kind of data needed to answer scientific questions about the interaction of populations within communities [SP 1.4, 4.1]

4.12: Apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways. [SP 2.2]

4.13: Predict the effects of a change in the community's populations on the community. [SP 6.4]

Enduring Understanding 4.A: Interactions within biological systems lead to complex properties.**Essential Knowledge 4.A.6:***Illustrative Examples:*

*Predator/prey relationships
spreadsheet model (b)
Symbiotic relationship (b)
Graphical representation of field
data (b)
Introduction of species (b)
Global climate change models (b)*

**Interactions among
living systems and with
their environment
result in the movement
of matter and energy.**

- a. Energy flows, but matter is recycled.
- b. Changes in regional and global climates and in atmospheric composition influence patterns of primary productivity.
- c. Organisms within food webs and food chains interact.
- d. Food webs and food chains are dependent on primary productivity.
- e. Models allow the prediction of the impact of change in biotic and abiotic factors.
 - 1. Demonstrated Evidence--Competition for resources and other factors limits growth and can be described by the logistic model.
 - 2. Demonstrated Evidence--Competition for resources, territoriality, health, predation, accumulation of wastes and other factors contribute to density-dependent population regulation.
- f. Human activities impact ecosystems on local, regional and global scales.
 - 1. Demonstrated Evidence--As human populations have increased in numbers, their impact on habitats for other species have been magnified.
 - 2. Demonstrated Evidence--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.
- g. Many adaptations of organisms are related to obtaining and using energy and matter in a particular environment.

LEARNING OBJECTIVES

4.14: Apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.
[SP 2.2]

4.16: Predict the effects of a change of matter or energy availability on communities.
[SP 6.4]

4.15: Use visual representations to analyze situations or solve problems qualitatively to illustrate how interactions among living systems and with their environment result in the movement of matter and energy.
[SP 1.4]

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

Competition and cooperation play important roles in the activities of biological systems at all levels of organization. Living systems require a myriad of chemical reactions on a constant basis, and each of these chemical reactions relies on the cooperation between a particular enzyme and specific substrates, coenzymes and cofactors. Chemical inhibitors may compete for the active sites of enzymes that, in turn, affect the ability of the enzyme to catalyze its chemical reactions. Thus, interactions between molecules affect their structure and function. Other examples of this phenomenon include receptor-ligand interactions and changes in protein structure due to amino acid sequence.

Similar cells may compete with each other when resources are limited; for example, organisms produce many more spores or seeds than will germinate. Competition for resources also determines which organisms are successful and produce offspring. In the vertebrate immune system, competition via antigen-binding sites determines which B-cell lineages are stimulated to reproduce.

The cooperation of parts extends to the organism that depends on the coordination of organs and organ systems, such as between the digestive and excretory systems of an animal or the roots and shoots of a plant. Cooperation within organisms increases efficiency in the use of matter and energy. For example, without the coordination and cooperation of its shoot and roots, a plant would be unable to survive if its root system was too small to absorb water to replace the water lost through transpiration by the shoot. Similarly, exchange of oxygen and carbon dioxide in an animal depends on the functioning of the respiratory and circulatory systems. Furthermore, population interactions influence patterns of species distribution and abundance, and global distribution of ecosystems changes substantially over time.

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

Illustrative Examples:

Essential Knowledge 4.B.1:

Interactions between molecules affect their structure and function.

X No specific cofactors or coenzymes are within the scope of the course and the AP Exam. (b2)

- a. Change in the structure of a molecular system may result in a change of the function of the system.
- b. The shape of enzymes, active sites and interaction with specific molecules are essential for basic functioning of the enzyme.
 - 1. Demonstrated Evidence--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.
 - 2. Demonstrated Evidence--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.
- c. 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.
- d. 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.

LEARNING OBJECTIVES

4.17: Analyze data to identify how molecular interactions affect structure and function.

[SP 5.1]

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

Essential Knowledge 4.B.2:

Cooperative interactions within organisms promote efficiency in the use of energy and matter.

Illustrative Examples:

Exchange of gases (a2)

Circulation of fluids (a2)

Digestion of food (a2)

Excretion of wastes (a2)

Bacterial community in the rumen of animals (a3)

Bacterial community in and around deep sea vents (a3)

- a. Organisms have areas or compartments that perform a subset of functions related to energy and matter, and these parts contribute to the whole.
 - 1. Demonstrated Evidence--At the cellular level, the plasma membrane, cytoplasm and, for eukaryotes, the organelles contribute to the overall specialization and functioning of the cell.
 - 2. Demonstrated Evidence--Within multicellular organisms, specialization of organs contributes to the overall functioning of the organism.
 - 3. Demonstrated Evidence--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.

LEARNING OBJECTIVES

4.18: Use representations and models to analyze how cooperative interactions within organisms promote efficiency in the use of energy and matter.

[SP 1.4]

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

Essential Knowledge 4.B.3:

Interactions between and within populations influence patterns of species distribution and abundance.

Illustrative Examples:

Loss of keystone species (c)

Kudzu (c)

Dutch elm disease (c)

✗ Specific symbiotic interactions are beyond the scope of the course and the AP Exam. (a3)

- a. Interactions between populations affect the distributions and abundance of populations.
 - 1. Demonstrated Evidence--Competition, parasitism, predation, mutualism and commensalism can affect population dynamics.
 - 2. Demonstrated Evidence--Relationships among interacting populations can be characterized by positive and negative effects, and can be modeled mathematically (predator/prey, epidemiological models, invasive species).
 - 3. Demonstrated Evidence--Many complex symbiotic relationships exist in an ecosystem, and feedback control systems play a role in the functioning of these ecosystems.
- b. 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.
- c. Species-specific and environmental catastrophes, geological events, the sudden influx/depletion of abiotic resources or increased human activities affect species distribution and abundance.

LEARNING OBJECTIVES

4.19: Use data analysis to refine observations and measurements regarding the effect of population interactions on patterns of species distribution and abundance.

[SP 1.4]

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

Essential Knowledge 4.B.4:

Distribution of local and global ecosystems changes over time.

Illustrative Examples:

Logging (a)
Slash and burn agriculture (a)
Urbanization (a)
Monocropping (a)
Infrastructure development--dams, transmission lines, roads (a)
Global climate change (a)
Dutch elm disease (c)
Potato blight (c)
Small pox [historic example for Native Americans] (c)
El Niño (d)
Continental drift (d)
Meteor impact on dinosaurs (d)

- a. Human impact accelerates change at local and global levels and threaten ecosystems and life on Earth.
- b. An introduced species can exploit a new niche free of predators or competitors, thus exploiting new resources.
- c. Introduction of new diseases can devastate native species.
- d. Geological and meteorological events impact ecosystem distribution.
 - 1. Demonstrated Evidence--Biogeographical studies illustrate these changes.

LEARNING OBJECTIVES

4.20: Explain how the distribution of ecosystems changes over time by identifying large-scale events that have resulted in these changes in the past.

[SP 6.2, 6.3]

4.21: Predict consequences of human actions on both local and global ecosystems.

[SP 6.4]

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

A biological system that possesses many different components often has greater flexibility to respond to changes in its environment. This phenomenon is sometimes referred to as “robustness.” Variation in molecular units provides cells with a wider range of functions; cells with multiple copies of genes or heterozygous genes possess a wider range of functions compared to cells with less genetic diversity, while cells with myriad enzymes can catalyze myriad chemical reactions.

Environmental factors influence the phenotypic expression of an organism’s genotype. In humans, weight and height are examples of complex traits that can be influenced by environmental conditions. However, even simple single gene traits can be influenced by the environment; for example, flower color in some species of plants is dependent upon the pH of the environment. Some organisms possess the ability to respond flexibly to environmental signals to yield phenotypes that allow them to adapt to changes in the environment in which they live. Environmental factors such as temperature or density can affect sex determination in some animals, while parthenogenesis can be triggered by reproductive isolation. Plant seed dormancy can increase the survival of a species, and some viruses possess both lysogenic and lytic life cycles.

The level of variation in a population affects its dynamics. The ability of a population to respond to a changing environment (fitness) is often measured in terms of genomic diversity. Species with little genetic diversity, such as a population of plants that reproduces asexually or a very small population exhibiting a genetic bottleneck effect, are at risk with regard to long-term success and survival.

Diversity of species within an ecosystem may influence the stability of the ecosystem. Ecosystems with little species diversity are often less resilient to changes in the environment. Keystone species, predators, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem. For example, the removal of sea otters or mollusks can drastically affect a marine ecosystem, and the introduction of an exotic plant or animal species can likewise affect the stability of a terrestrial ecosystem.

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

Essential Knowledge 4.C.1:

Variation in molecular units provides cells with a wider range of functions.

Illustrative Examples:

Different types of phospholipids in cell membranes (a)

Different types of hemoglobin (a)
MHC proteins (a)

Chlorophylls (a)

Molecular diversity of antibodies in response to an antigen (a)

The antifreeze gene in fish (b2)

- a. Variations within molecular classes provide cells and organisms with a wider range of functions.
- b. Multiple copies of alleles or genes (gene duplication) may provide new phenotypes.
 - 1. Demonstrated Evidence--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.
 - 2. Demonstrated Evidence--Gene duplication creates a situation in which one copy of the gene maintains its original function, while the duplicate may evolve a new function.

LEARNING OBJECTIVES

4.22: Construct explanations based on evidence of how variation in molecular units provides cells with a wider range of functions.

[SP 6.2]

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

Essential Knowledge 4.C.2:

Environmental factors influence the expression of the genotype in an organism.

Illustrative Examples:

Height and weight in humans (a)
Flower color based on soil pH (a)
Seasonal fur color in arctic animals (a)
Sex determination in reptiles (a)
Density of plant hairs as a function of herbivory (a)
Effect of adding lactose to a Lac⁺ bacterial culture (a)
Effect of increased UV on melanin production in animals (a)
Presence of the opposite mating type on pheromones production in yeast and other fungi (a)
Darker fur in cooler regions of the body in certain mammal species (b)
Alterations in timing of flowering due to climate changes (b)

- a. Environmental factors influence many traits both directly and indirectly.
- b. An organism's adaptation to the local environment reflects a flexible response of its genome.

LEARNING OBJECTIVES

4.23: Construct explanations of the influence of environmental factors on the phenotype of an organism.
[SP 6.2]

4.24: Predict the effects of a change in an environmental factor on gene expression and the resulting phenotype of an organism.
[SP 6.4]

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

Essential Knowledge 4.C.3:

The level of variation in a population affects population dynamics.

Illustrative Examples:

California condors (a)
Black-footed ferrets (a)
Prairie chickens (a)
Potato blight causing the potato famine (a)
Corn rust effects on agricultural crops (a)
Tasmanian devils and infectious cancer (a)
Not all animals in a population stampede (b)
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 (b)

- a. 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.
- b. Genetic diversity allows individuals in a population to respond differently to the same changes in environmental conditions.
- c. Allelic variation within a population can be modeled by the Hardy-Weinberg equation(s).

LEARNING OBJECTIVES

4.25: Use evidence to justify a claim that a variety of phenotypic responses to a single environmental factor can result from different genotypes within the population.
[SP 6.1]

4.26: Use theories and models to make scientific claims and/or predictions about the effects of variation within populations on survival and fitness.
[SP 6.4]

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

Essential Knowledge 4.C.4:

Illustrative Examples:

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

- a. Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.
- b. 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.

LEARNING OBJECTIVES

4.27: Make scientific claims and predictions about how species diversity within an ecosystem influences ecosystem stability.
[SP 6.4]