

Appendix A:

Preparing Students for Success in AP Biology

In order to provide teachers with the information they need to incorporate the science practices and required course concepts into the AP Biology classroom, this section includes a description of **desired performance** (what students should know and be able to do) for high achievement in an introductory college-level biology course (which is comparable to an AP Biology course). This includes information on the following:

- How students should be able to appropriately demonstrate the concepts and skills.
- How students can develop the desired performance level, if they haven't already.

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

Students need to understand the central position that evolution plays in the discipline of biology and the enduring understandings that support big idea 1. Differences in performance levels are distinguished by the student's ability to demonstrate his or her depth of understanding of concepts related to evolution. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 1?

Students should be able to do the following:

- a) Apply mathematical methods to data from a real or simulated population and predict what will happen to the population in the future based on the Hardy-Weinberg equilibrium model (e.g., genetic drift, bottleneck, migration, chi-square statistical analysis) and justify the prediction.
- b) Evaluate and connect evidence provided by data sets from many scientific disciplines (e.g., morphology, biochemistry, geology, biogeography, physics) and explain how the data support the modern concept of biological evolution.

- c) Construct, refine, revise, and/or justify mathematical models, diagrams, or simulations that represent processes of biological evolution and use the representations to predict future trends of a population; representations include complex cladograms and phylogenetic trees based on morphological features, amino acid/genetic sequence data, and geological timelines.
- d) Explain and justify conserved core processes and features that support common ancestry within and across domains of life.
- e) Construct and/or use phylogenetic representations to pose or answer scientific questions about the relatedness of a group of organisms.
- f) Explain how the different lines of data (morphological, biochemical, genetic) support the concept of a common ancestry within a phylogenetic domain and for all life.
- g) Describe speciation in an isolated population and make a prediction about speciation based on changes in gene frequency, change in environment, natural selection, and/or genetic drift. Description may include comparison of environments of the original and isolated populations, speed of reproductive isolation, how new species arise, why Archaea and Bacteria challenge definition of species, and factors that change Hardy-Weinberg frequencies.
- h) Evaluate data from a real or simulated population to explain how types of selection (e.g., bottleneck effect, hybrid sterility, reproductive isolating mechanisms) might affect the population in the future.
- i) Evaluate and explain several examples of scientific evidence that support the claim that evolution is an ongoing process (e.g., antibiotic resistance, pesticide resistance, antiviral resistance).
- j) Pose scientific questions about the origin of life on Earth and describe the scientific evidence that supports the proposed key events in the origin of life, including the abiotic synthesis of small organic molecules; assembly of monomers into complex polymers; formation of protobionts; and the origin of self-replicating, catalytic molecules.
- k) Describe several models about the origins of life on Earth (e.g., Oparin-Haldane organic “soup” model, solid reactive surface model), explain reasons for revisions of hypotheses based on new scientific evidence from different disciplines (e.g., “RNA World,” early atmosphere neither reducing nor oxidizing, origin of life in deep-sea vents, submerged volcanoes), and explain limitations of the various models, such as laboratory conditions simulating conditions on primitive Earth.
- l) Evaluate data from a variety of sources (e.g., Internet, government, universities, public interest groups) with respect to objectivity and accuracy with response to questions about the origin of life on Earth.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

- a) Connecting evolutionary changes in a population over time to a change(s) in the environment by describing 2–3 examples (e.g., peppered moth, sickle cell anemia, DDT resistance in insects, introduction of nonnative species, introduction of predator, cataclysmic event).
- b) Describing several sources of evidence from multiple scientific disciplines that support biological evolution (e.g., fossil records, morphological features, DNA and/or protein sequences, radioactive dating, distribution, or extant and extinct species).
- c) Applying mathematical models (e.g., Hardy-Weinberg formula) to convert a data set from a table of numbers reflecting a change in the genetic makeup of a population over time and explaining the cause(s) and effect(s) of this change, such as natural selection, genetic drift, changes in population size, migration, mutations, and nonrandom mating.
- d) Describing a limited set of given conserved features and core processes shared within and between domains of life (e.g., DNA as the genetic material, a shared genetic code, common metabolic pathways, number of limbs, etc.) as evidence of common ancestry.
- e) Explaining how a phylogenetic representation reflects ancestral differences and similarities.
- f) Describing how given data support the concept of a common ancestry within and between phylogenetic domains and for all life.
- g) Analyzing data related to questions of speciation and extinction throughout Earth's history. Analysis may include (1) identifying patterns of speciation and/or extinction, (2) determining rates of speciation and/or extinction, and (3) connecting changes in gene frequency to speciation.
- h) Justifying the selection of data that address questions related to reproductive isolation and speciation (e.g., pre- and post-zygotic and allopatric and sympatric isolation).
- i) Describing a model that represents evolution within a population and providing evidence to support the description (e.g., evolution due to genetic variation, such as antibiotic resistance, structure, or process, such as the brain, immune system, or linkage of a given population to common ancestors, through genetic, physiological, and morphological data).

- j) Evaluating scientific hypotheses about the origin of life on Earth (e.g., organic “soup” model, solid surface, pangenetic) and predicting how a hypothesis would be revised in light of new evidence (e.g., “RNA World” hypothesis, new ideas about reducing atmosphere).
- k) Evaluating scientific questions based on hypotheses about the origin of life on Earth, such as what constitutes a scientific hypothesis versus other hypotheses or beliefs.

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

All organisms require free energy and matter to maintain order, grow, and reproduce. Different organisms employ various strategies to capture, use, and store free energy and exchange matter with the environment. Students need to understand the importance of matter exchange and free energy flow in maintaining life. Differences in achievement levels are distinguished by the student’s depth of understanding of the interrelatedness of the processes, structure-function relationships, and the roles these processes play within biological systems. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 2?

Students should be able to do the following:

- a) Calculate surface area-to-volume ratios for a variety of cell shapes (e.g., spherical, cuboidal, squamous, columnar) and predict, based on ratios, which cell(s) procures nutrients or eliminates wastes faster.
- b) Justify the selection of data to explain how cells absorb or eliminate molecules that various organisms acquire as necessary building blocks or eliminate as wastes.
- c) Create a visual representation (e.g., graph or diagram) to make predictions about the exchange of molecules between an organism and its environment, the use of these molecules (e.g., CHNOPS and incorporation into carbohydrates, proteins, lipids, nucleic acids, ATP for energy storage, enzymes, membrane structure, genetic information, etc.), and consequences to the organism if these molecules cannot be obtained.
- d) Pose scientific questions about how surface area-to-volume ratios influence the movement of nutrients and wastes into and out of cells.

- e) Pose scientific questions about what mechanisms and structural features allow organisms to capture, store, and use free energy (e.g., autotrophs versus heterotrophs, photosynthesis, chemosynthesis, anaerobic versus aerobic respiration).
- f) Create a visual representation to describe the structure of cell membranes and how membrane structure leads to the establishment of electrochemical gradients and the formation of ATP.
- g) Describe the interdependency of photosynthesis and cellular respiration (e.g., that the products of photosynthesis are the reactants for cellular respiration and vice versa).
- h) Use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure.
- i) Provided with electrochemical properties of several different molecules, make predictions about the permeability of the membrane to the molecule(s) and describe several methods of transport (e.g., diffusion, facilitated diffusion, osmosis, active transport, exocytosis, endocytosis) across the membrane.
- j) Explain how several internal membrane-bound organelles and other structural features (e.g., ER, ribosomes) work together to provide a specific function for the cell (e.g., synthesis of protein for export) and contribute to efficiency (e.g., increasing surface area for reactions, localization of processes).
- k) Evaluate data that describe the effect(s) of changes in concentrations of key molecules on negative or positive regulatory systems (e.g., operons in gene regulation, temperature regulation in animals, plant responses to water limitations, oxytocin levels in childbirth).
- l) Provided with a visual representation with multiple components, explain with justification or make predictions of how alterations of the components in a negative or positive regulatory system can result in deleterious consequences to the organism (e.g., change in blood glucose levels, decreased ADH level and diabetes insipidus, Graves' disease and hyperthyroidism).
- m) Justify the selection of the kind of data needed to pose scientific questions about the regulatory mechanism(s) that organisms use to respond to changes in their external environments (e.g., photoperiodism and phototropism in plants, hibernation in animals, circadian rhythms, shivering and sweating in humans).

- n) Analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system, identify and explain any anomalies in the pattern or relationship, and predict consequences of a change in a biotic or abiotic factor(s) to the system.
- o) Connect differences in the environment with the evolution of homeostatic mechanisms and describe how these mechanisms reflect both common ancestry and divergence due to adaptations.
- p) Create representations and models to describe essential aspects of nonspecific and specific immune response systems in plants, invertebrates, and vertebrates (e.g., chemical responses in plants, cell-mediated and humoral responses in mammals).
- q) Connect concepts in and across domains to describe how timing and coordination of specific events are necessary for normal development in an organism, describe how these events are regulated by multiple mechanisms (e.g., homeotic genes, environmental factors, embryonic induction, role of microRNAs), and predict consequences in alterations in mechanisms necessary for normal development (e.g., genetic mutation, mutations of transcription factors).
- r) Justify claims with 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 (e.g., homeotic genes in developmental patterns and sequences, embryonic induction in timing of developmental events).
- s) Analyze data to support the claim that responses to information and communication of information can affect natural selection (e.g., changes in light source and phototropism, seasonal behavior in animals and reproduction, visual and auditory signals and species recognition, mutualistic relationships).

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

- a) Calculating simple surface area-to-volume ratios for cubic and round cells and explaining how this impacts procurement of nutrients and elimination of wastes.
- b) Identifying several (more than 4) chemical elements and molecules that function as key building blocks (e.g., C, N, H₂O, sugars, lipids, proteins) or are eliminated as wastes.

- c) Predicting 1–2 consequences to organisms, populations, and ecosystems if sufficient free energy is not available (e.g., death, changes in population size, changes to number and size of trophic levels in ecosystems).
- d) Describing 2–3 different strategies that organisms employ to obtain free energy for cell processes (e.g., different metabolic rates, physiological changes, variations in reproductive and offspring-rearing strategies).
- e) Refining or revising a visual representation to more accurately depict the light-dependent and light-independent (i.e., Calvin cycle) reactions of photosynthesis and the dependency of the processes in the capture and storage of free energy.
- f) Provided with a visual representation of the fluid mosaic model of the cell membrane, identifying the molecular components and describing how each component is directly related to the selective permeability of that membrane (e.g., transport proteins, lipid bilayer).
- g) Explaining how the phospholipid bilayer of the cell membrane is a barrier to the diffusion of polar molecules across it.
- h) Using representations and models to describe how eukaryotic cells use internal membranes that partition the cell into several specialized regions (e.g., mitochondria, Golgi, ER), and how cell structure of eukaryotes differs from cell structure of prokaryotes.
- i) Provided with an example of a simple positive feedback loop, making predictions about how the mechanism amplifies activities and processes in organisms based on scientific models (e.g., lactation in mammals, progression of labor in childbirth, ripening of fruit, blood clotting).
- j) Describing an example of a simple negative regulatory system and how an organism uses the mechanism to respond to an environmental change (e.g., temperature regulation in animals, plant responses to water limitation, blood glucose level).
- k) Connecting the use of negative feedback and maintaining the internal environment in response to changing external conditions and consequences if dynamic homeostasis is not maintained.
- l) Justifying, based on scientific evidence, the statement that homeostatic mechanisms reflect continuity due to common ancestry and/or divergence due to adaptation in different environments (e.g., mechanisms for obtaining nutrients and eliminating wastes) in several different phyla or species, using appropriate examples.
- m) Refining representations and models to describe an example of a nonspecific immune defense system in plants and animals (e.g., chemical responses, cellular responses).

- n) Using a visual representation (e.g., graph or diagram) to make predictions about the sequence of steps in the development of an organism.
- o) Designing a plan for collecting data to support the claim that the timing and coordination of physiological events in an organism of choice involve regulation (e.g., phototropism in plants, circadian rhythms, jet lag in humans).
- p) Describing 2–3 examples of how a cooperative behavior benefits both the individual and the population (e.g., mutualistic relationships, niche partitioning) that involves timing and coordination of activities/events.

Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes. Genetic information provides for continuity of life, and this information is passed from parent to offspring. Random changes in information allow for evolution, with natural selection acting upon the products of genetic information, i.e. phenotypes. Understanding how cells code, decode, and regulate expression of genetic information is essential to knowing how biological systems from cells to communities of organisms operate, communicate, respond to the environment, and evolve. Differences in achievement levels are distinguished by the student's depth of understanding of these concepts and processes. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 3?

Students should be able to do the following:

- a) Predict which features of DNA and RNA were necessary to allow the identification of DNA as the genetic material and justify how these features enable information to be replicated, stored, and expressed.
- b) Using at least two commonly used technologies, describe how humans manipulate heritable information and possible consequences.
- c) Justify the effects of a change in the cell cycle mitosis and/or meiosis will have on chromosome structure, gamete viability, genetic diversity, and evolution.
- d) Predict possible effects that alterations in the normal process of meiosis will have on the phenotypes of offspring compared to the normal situation and connect the outcomes to issues surrounding human genetic diseases.

- e) Apply mathematical routines to determine Mendelian patterns of inheritance provided by data sets, and, using appropriate examples, explain at the chromosome, cellular, and offspring (organism) levels why certain traits do or do not follow Mendel's model of inheritance.
- f) Justify how various modes of gene regulation (positive and negative) can explain the differences seen at the cellular, organismal, and population level. Predict how changes in regulation will affect cellular functions.
- g) Using appropriate examples, predict how changes in signal transduction pathways will affect specific cellular processes and responses for both bacteria and eukaryotes.
- h) Predict how various types of change in a DNA sequence can alter a phenotype, and describe several using real-world examples.
- i) Justify how various molecular, cellular, and organismal processes in bacteria and eukaryotes increase genetic variation in a population and allow for natural selection.
- j) Using specific examples, justify how the life cycles of DNA and RNA viruses can contribute to rapid evolution of both the virus and the host.
- k) Justify how the mechanics of cell-to-cell communication support common lines of evolutionary descent. Pose scientific questions that test the justification rationale.
- l) Using appropriate examples from plants, animals, and bacteria, justify how the features of cell-to-cell contact and the use of chemical signals allow communication over short and long distances.
- m) Construct a model that illustrates how chemical signals can alter cellular responses. Predict the effects of changes in the signal pathway on cellular responses using appropriate examples.
- n) Justify how changes in internal or external clues affect the behavior of individuals and their interactions within a population and between related individuals.
- o) Describe how the animal nervous system's biochemical, physiological, and structural components work together to respond to internal and/or external stimuli. Describe how changes within nerve cells and the nervous system produce responses to the stimuli.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

- a) Explaining how the structural features of DNA and RNA allow heritable information to be replicated, stored, expressed, and transmitted to future generations.
- b) Explaining how the steps in the cell cycle allow transmission of heritable information between generations and contribute to genetic diversity.
- c) Identifying mathematical evidence that supports the roles of chromosomes and fertilization in the passage of traits from parent to offspring.
- d) Justifying whether a given data set supports Mendelian inheritance.
- e) Using appropriate examples, explaining how gene regulation allows for cell specialization and efficient cell function.
- f) Using an appropriate example, describing a signal transduction pathway mechanism that affects protein expression.
- g) Describing the basic processes by which a change in a DNA sequence results in a change in a peptide sequence.
- h) Describing two processes that increase genetic variation and explaining how genetic variation allows for natural selection within a population.
- i) Describing several mechanisms that result in increased genetic variation and rapid evolution of viruses.
- j) Proposing scientific questions that address if there are shared mechanisms for cell-to-cell communication across evolutionary lines.
- k) Describing how both plants and animals use cell-to-cell communication for cellular processes using an appropriate example from each.
- l) Explaining key features of models that illustrate how changes in a signal pathway can alter cellular responses.
- m) Describing how behavior is modified in response to external and internal cues for both animals and plants using appropriate examples from each.
- n) Describing how the nervous system detects external and internal stimuli and transmits signals along and between nerve cells.

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties. All biological systems are composed of parts that interact with one another and the environment, and these interactions result in characteristics not found in the individual parts alone. Interactions, including competition and cooperation, play important roles in the activities of biological systems. From the molecular level to the ecosystem level, biological systems exhibit properties of biocomplexity and diversity; these properties provide robustness that enables greater resiliency and flexibility to tolerate and respond to changes in the environment. Understanding biotic and abiotic interactions, including competition, and cooperation within and between biological components and systems, is necessary to comprehend the beauty and complexity of biology. Differences in achievement levels are distinguished by a student's depth of understanding of these interactions and their effects on individual organisms, populations, and ecosystems. The student also must demonstrate his or her ability to apply different science practices in articulating understanding of these concepts.

What should students be able to do to demonstrate high achievement with the concepts and skills related to big idea 4?

Students should be able to do the following:

- a) Justify how structure imparts function for key biological molecules (DNA, RNA, lipids, carbohydrates, proteins, ATP) and cell organelles (nucleus, Golgi, ER, mitochondria, plasma membrane chloroplasts, vacuoles) and describe how they interact in key biological processes.
- b) Predict how changes in internal and environmental stimuli will affect gene expression and the development of specialized cells, tissues, and organs based on a given developmental model or representation.
- c) Pose scientific questions that address how interactions between constituent parts of a biological system (cells, tissue, organs) provide essential biological activities.
- d) Pose scientific questions and apply mathematical routines to analyze interactions among community components.
- e) Predict the effect of a change in one of the components on the interactions within the community and matter and energy flow.
- f) Analyze data showing how changes in enzyme structure, substrate concentration, and environmental conditions (pH, temperature, salinity, etc.) affect enzymatic activity. Predict the effects when one of the parameters is further changed.

- g) Use representations and models to describe and analyze how cooperative interactions at the cellular, organismal, or system level increase efficiency and fitness of the organism.
- h) Analyze data to develop and refine qualitative and quantitative models for species and population, abundance, densities, distribution, and interactions and predict the effect(s) of human activity on the biological system.
- i) Using appropriate examples, justify why molecular variation in genes, basic cellular building blocks, and macromolecules provides a wider range of metabolic and cellular functions and explain how these variations affect fitness and evolution.
- j) Use evidence to justify the claim that phenotype is a product of both genetics and environment, explain the mechanism(s) that operates to affect the change, and predict how a change in environment can alter a phenotype.
- k) Analyze evidence to develop models and predictions as to the effect that changes in the level of variation within populations and species diversity will have on fitness and system stability.

How can students develop this level of performance if they haven't already?

Students can begin by doing the following:

- a) Describing the basic structure and functions of key biological polymers (DNA, RNA, lipids, carbohydrates, proteins) and cell organelles (nucleus, Golgi, ER, mitochondria, chloroplast, vacuoles, plasma membrane).
- b) Describing in general terms how cells specialize and become tissue and organs.
- c) Explaining how interactions between constituent parts of a biological system (cells, tissues, organs) provide essential biological activities.
- d) Refining models showing organism interaction and matter and energy flow in a biological system and predicting the effects of a change in one of the components.
- e) Analyzing data showing how changes in structure and concentrations affect enzymatic activity
- g) Identifying patterns that show cooperative interactions at the cellular, organismal, or system level that increase efficiency and fitness of the organism.

- g) Analyzing data to identify patterns depicting species and population abundance distribution and interactions such as predator-prey, competition, and human activity effects.
- h) Using appropriate examples, explaining how molecular variation in genes, basic cellular building blocks, and macromolecules provide a wider range of functions.
- i) Using appropriate examples from both plants and animals, explaining how environment can influence the expression of a phenotype.
- j) Justifying the claim that variation within populations and increased species diversity account for increased population fitness and system stability.