Standards

1. The diversity and unity of life can be explained by the process of evolution.
2. Cells are a fundamental structural and functional unit of life.
3. Interdependent relationships characterize biological ecosystems.
4. Biological systems utilize energy and molecular building blocks to carry out life's essential functions.
5. Living systems have multiple mechanisms that are used to store, retrieve and transmit information.

Life Science

Organization and Structure of the Life Science Standards for College Success

The life science standards are intended to outline the knowledge, skills and abilities that students need in order to be prepared for success in an introductory college-level biology course, or in an Advanced Placement (AP) Biology course. Core ideas, or "big ideas" — identified by the NSF-funded AP committee members as being central to an introductory college-level biology course — were the foundation of the creation of the life science standards.

The life science standards are organized around core ideas of the discipline. While there are five standards, they are not meant to represent an equal division of material and **concepts**.* Each standard has two to five objectives that provide detailed descriptions of more specific life science core **principles** of which students should have knowledge. Similar to the enduring understandings that are the target concepts for the AP courses, the objectives are the focus of student mastery for college readiness and the key elements of the conceptual framework of the life science standards. An objective is often followed by a list of other objectives — within the discipline as well as from other disciplines — that are connected in some way to that objective. Both the standards and the objectives are preceded by key words and/or phrases that help articulate the content in a more concise manner. This is especially helpful when a standard or an objective is referenced either by another discipline or during curriculum or instructional planning.

The objectives are, in turn, supported by a set of performance expectations (PEs) and a set of essential knowledge (EK) statements. The PEs describe what students should know, understand and be able to do in order to apply, as well as build and reason with, the essential knowledge that is necessary to understand the content outlined in the objective. The PEs illustrate how students engage in science practices to develop a better understanding of the objective. Students should be able to successfully engage in, *at the very least,* the performance expectations listed for each objective in order to be considered college ready. These performance expectations, along with the essential knowledge statements, can provide guidance in the development of assessments and curriculum materials. The EK statements are an articulation of the conceptual targets for student learning, providing a more detailed description of the broader knowledge delineated in the objective. These statements should be approached from a holistic perspective, and they should not be viewed as a list of discrete, unrelated **facts** for students to memorize. The EK statements also provide the language and appropriate terminology that should be incorporated into students' completion of the performance expectations.

It should be noted that both the performance expectations and the essential knowledge statements were written based specifically on the objective-level statements. There is not a corresponding relationship between the PEs and the EK statements; the PEs are a representative (but certainly not all inclusive) set of applications of the essential knowledge. Therefore, when interpreting the depth and scope of each PE, the EK statements should be considered.

The number of objectives, as well as the number of performance expectations and essential knowledge statements, varies considerably from standard to standard. For example, Standard 5 contains the largest amount of material because DNA and its transmission lie at the heart of life science. It should also be made clear that these objectives, PEs and EK statements are not intended to show a linear progression through

* Boldfaced words and phrases are defined in the glossary.

the subject. Many of the topics and concepts in life science rely on more than one objective and on several PEs and EK statements, some of which may come from different standards. For example, the process of cell division (mitosis) has purposes associated with growth and development (Objective LS.2.3) as well as with the transmission of genetic information (Objective LS.5.2). In addition, the number of PEs for a given objective does not indicate any level of importance, and it is assumed that some PEs may require a greater amount of instructional time than others.

Goals of Life Science Education

Two current issues within life science education are the ongoing expansion of the breadth of the discipline and students' lack of the foundational knowledge needed to understand some of the current areas of research in the different life science fields. The life science standards are specifically designed to address these issues and, as a result, tough decisions have been made. First, in an effort to address the issue of the expanding breadth of the discipline, the Life Science Standards Advisory Committee decided to include certain objectives at just one of the grade bands. In other words, not all of the objectives for each standard cover both grade bands. For example, because of the concrete nature of the concepts related to ecosystem **interactions**, this area of life science is developed only in the 6–8 grade band. Students in the 9–12 grade band can use their understanding of these interactions and relationships in their study of natural selection.

Second, only one **model** of matter cycling is fully developed using the cycling of carbon. Teachers can expand this model to other elements, such as nitrogen, using the conceptual carbon model as a guide; however, the committee promotes the full development of the carbon cycle as a priority. Students in the 9–12 grade band focus on concepts that are more abstract and at the molecular level. This design narrows the breadth of information and also prepares students for an understanding of the current research in life science.

Finally, DNA (deoxyribonucleic acid) is used throughout the standards as the model for inheritance. The standards show how this model relates to chromosomes and **traits** that are typically used as models for inheritance. The committee believed that using a consistent model of DNA, rather than focusing on those of the past, would enhance students' understanding of the current model of inheritance as well as promote coherence in their understanding of the broader concept of inheritance.

All of these decisions were made with consideration of the following goals: to ensure grade band appropriateness (e.g., protein synthesis for students in grades 9–12 only); to provide adequate time for instructors to teach fewer concepts at each grade band; and to prevent unnecessary repetition of basic ideas (e.g., the annual instruction of the water [H_2O] cycle).

Definition of Rigor

The standards represent the shift in the College Board's view of rigor, from requiring that students know all of the facts, vocabulary and specific examples related to various topics, to ensuring students' understanding and application of core principles for the discipline and the integration of this knowledge with the skills essential for practicing science. The performance expectations were written to provide students with opportunities to make sense of the observed world in terms of the fundamental principles that explain these observations. As the committee members developed the standards, objectives, performance expectations and essential knowledge statements, they also looked for instances where connections could be made among the core principles and within each core principle, so that students' understanding would be more integrated and useful. For example, students should not memorize the details of each separate human body system, or the names and functions of each of the organs of these systems. Instead, students should focus on how the body systems (e.g., the digestive, circulatory and respiratory systems) are interdependent to carry out basic essential life functions such as extracting energy from **food** or eliminating wastes. In addition, in order for students to gain a true conceptual understanding of the principles of life science, they must be exposed to these concepts in multiple contexts that apply to different living systems and across different spatial scales. Rigor is no longer defined in terms of the facts and definitions students know, but in terms of how students can apply their knowledge and make connections among concepts.

The performance expectations also require that students become personally engaged in making sense of the ideas to which they are being introduced. Students are frequently asked to seek and gather information from "print and electronic resources" and to "give examples." The expectation is that students will be exposed to a wide variety of phenomena related to the ideas being taught. Students' experiences must go well beyond the few classic instances typically taught in the classroom or found in a textbook. The expectations regarding independent research of this kind should be appropriate for each grade band and related to the examples presented in the classroom, but they should also expand opportunities for each individual student to take personal initiative to explore the relevance of each idea in depth and in a wide range of new contexts.

Goal of Conceptual Understanding

The goal at both the 6–8 and 9–12 grade bands is conceptual understanding in the best sense of the word. Students are expected to understand the core principles of the life sciences, not only as abstract scientific generalizations but also in terms of how the ideas are related to phenomena that the students will encounter in the natural world. To reinforce the point that conceptual understanding is more important than the memorization of terminology, the standards highlight the optional technical terminology by placing the term in parentheses. Before a technical term is introduced in the classroom, the simpler term or phrase that summarizes the targeted concept should be developed. Whether or not the technical term in parentheses should be taught along with the fundamental idea is left up to the discretion of each individual teacher. These decisions should be based on the maturity and language sophistication of the students involved. In all cases, the most important thing is each student's conceptual understanding of the scientific principle, not the terminology.

Another aspect of rigor and conceptual understanding that is addressed is the extent to which students should know the specific mechanisms behind events and processes. The committee believes that students should be presented with underlying mechanisms as often as possible in order to enhance their understanding. However, there are times when a mechanism is too involved or too complex for most of the students at a certain grade band to comprehend without using excessive amounts of instructional time. There are times when it is more reasonable to "black box" a mechanism, while still providing students with an adequate conceptual understanding of the process. For example, students are expected to know that the sequence of nucleotide bases making up a strand of DNA determines the specific amino acid sequence in a protein molecule. The objective states: "Students understand that genetic information (DNA) is used to produce proteins that largely determine the traits of an organism." Essential knowledge statements that mention transcription and translation are included. However, additional details of the mechanism by which DNA is related to protein synthesis are left undefined. The committee takes the position that each teacher should determine how many of these details are accessible to and appropriate for the students, which details are needed to provide an adequate understanding of the basic concept, and how much should be "black boxed." The important point is that students know that there is a link between the structure of DNA and protein synthesis. This is the conceptual understanding that students need for college readiness. So although an awareness of underlying mechanisms may lead to increased understanding of the targeted concept, there are times when it may be unrealistic to include all of the details of these mechanisms.

Performance expectations should be viewed as representative of the expectations for all students and reflective of the core knowledge all students should have. In life science courses that are based on these expectations, instruction should provide students with many opportunities to work toward meeting the expectations. These opportunities should include a wide range of contexts that encompass the variety of living systems that exist in nature. In addition to being provided opportunities to work toward meeting these particular performance expectations, students should also have opportunities to develop additional practices and knowledge that may not necessarily be highlighted in these standards but still contribute to becoming college ready in life science.

Foundational Knowledge

Even though these standards are focused on grades 6–12, the College Board recognizes the importance of students' having certain foundational knowledge in life science upon entering sixth grade. Middle school teachers need to determine whether their students already have this foundational knowledge before they attempt to address the ideas described in the standards document, and they should adjust their instruction in terms of what students already know and what students do not know. Some of the foundational knowledge that students are expected to have by the end of fifth grade is listed below. These statements, organized into five groups, are found in various elementary school benchmarks in *Benchmarks for Science Literacy* (BSL), developed by the American Association for the Advancement of Science (AAAS).

- Organisms interact with each other in many ways besides providing food. Organisms have a variety of sources of food. Some organisms are more successful in different types of environments. Changes to an organism's habitat are sometimes beneficial and sometimes harmful.

- For offspring to resemble their parents, there must be a reliable way to transfer information from one generation to the next. Some likenesses between children and their parents are inherited, and some are learned.

- Some living systems consist of a single cell that needs all of the necessary life resources. Some organisms are made of a collection of cells that benefit from cooperating. Some organisms' cells vary greatly and perform very different roles.

- People obtain from food the energy and materials needed for body repair and growth. Almost all kinds of animals' food can be traced back to plants.

- Individuals of the same kind differ in their characteristics, and sometimes the differences give individuals an advantage in surviving and reproducing.

Standard LS.1
Evolution

The diversity and unity of life can be explained by the process of evolution.

Students understand that organisms — both extant and extinct — may have significant differences, but they also have many similarities. A corollary of this idea is that present-day species have descended from earlier, distinctly different species. Because some characteristics of earlier organisms are retained, the degree of similarity and difference can be used as **evidence** to make inferences regarding the lines of descent tracing back to a common ancestor. Research in this area is done at both the molecular level and at the more descriptive trait level.

Objective LS.1.1
Evidence of Common Ancestry and Divergence

Students understand that an analysis over time of both the anatomical structures and the DNA compositions of organisms can be used to infer lines of descent back to a common ancestor.

> **Suggested Connections**
> *Within Life Science:* Genetic Information Transmission (LS.5.2); [Grades 9–12 only: Changing Model of Inheritance (LS.5.1); DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Between Life Science and Other Disciplines:* Rock-Forming Environment (ES.1.5); Relative and Absolute Dating (ES.3.1); Rock and Fossil Records (ES.3.2)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1C, 2D, 3A, 3C; AP Environmental Science 2A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.1.1.1 Construct a **representation** that reflects the appropriate time scale of Earth's history and includes the variation of organisms over time. Representation describes major evolutionary developments (e.g., the first organism, oxygen in the atmosphere, the first land plants, appearance of vertebrates, etc.).

LSM-PE.1.1.2 Construct a representation, using information from the fossil record, that describes the organisms present during several different time periods in Earth's history.

LSM-PE.1.1.3 Observe the anatomical structures of a variety of organisms, and describe the similarities and differences among them. Organize the organisms into groups based on their similarities and differences. Make a **claim** about how recently organisms among the groups shared a common ancestor, and justify that claim based on the degree of similarity of their characteristics.

LSM-PE.1.1.4 Construct a simple model (e.g., phylogenetic tree), based on anatomical similarities and differences, of the degree of relatedness of different species. If necessary, revise the model based on new or additional anatomical evidence.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Fossils are preserved remains or traces of organisms that provide evidence of past life. The collection of all fossils and their placement in chronological order (e.g., dating or location in sedimentary layers) is known as the fossil record. Because of the unique geological conditions that are required for preservation, not all organisms left fossils that can be retrieved. *[**BOUNDARY:** Students are not expected to know specific methods for dating fossils or understand how these methods work; however, it is appropriate for students to work with **data** generated using these methods.]*

- The fossil record documents the existence, diversity, extinction and change over time of many life forms throughout Earth's history.

ESSENTIAL KNOWLEDGE (6–8), ***continued***

- The existence of different life forms in different time periods led to the idea that newer life forms descended from older life forms.
- Anatomical similarities and differences among various organisms living today are compared to those of organisms in the fossil record in order to reconstruct evolutionary history and infer lines of evolutionary descent.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.1.1 Provide evidence — reported in print and electronic resources, and regarding similarities and differences between organisms from the fossil record and preserved DNA — that supports the idea of descent with modification. Explain how similarities and differences among organisms support the idea of descent with modification.

LSH-PE.1.1.2 Construct a simple model (e.g., phylogenetic tree), based on anatomical evidence (physical traits), of the degree of relatedness among various organisms. If necessary, revise the model based on the inclusion of new molecular (i.e., DNA and/or amino acid) evidence.

LSH-PE.1.1.3 Explain, in terms of preserved DNA sequences, why specific extinct or extant organisms within a line of descent are considered to be either closely or more distantly related (i.e., share a common ancestor).

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Organisms resemble their ancestors because genetic information (DNA) is transferred from ancestor to offspring during reproduction.
- The branching that characterizes lines of descent can be inferred from the DNA composition of organisms over time.
- The similarities and differences in DNA sequences, amino acid sequences, anatomical evidence and fossil evidence provide information about the branching sequence of lines of evolutionary descent.

Objective LS.1.2
Natural Selection

Students understand that when a trait is favorable to an organism, the number of organisms with that trait will increase over time; and that when a trait is unfavorable, the number of organisms with that trait will decrease over time. Students understand that as a result, there is an increase in the proportion of individuals with the advantageous trait in a population. Over time, the process of natural selection leads to both the extinction of existing species and the evolution of new species.

> **Suggested Connections**
> *Within Life Science:* Living Systems and the Physical Environment (LS.3.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Between Life Science and Other Disciplines:* Climate (ES.2.4); Humans and Natural Hazards (ES.5.2); Humans and the Environment (ES.5.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1C, 2D, 3C, 4C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.1.2.1 Create an appropriately scaled representation that illustrates and traces two or more significant environmental changes (e.g., temperature, amount of carbon dioxide [CO_2] in the environment, presence of water) that have occurred throughout geologic time.

LSM-PE.1.2.2 Give examples, using information gathered from print and electronic resources, of natural environmental changes that have occurred in the recent past. Collect and organize data about the number, kind and/or geographical distribution of organisms before and after these changes occurred. Make a claim about how these environmental changes have affected the number, kind and/or distribution of specific organisms living in these environments. Using these examples of environmental changes and the data on number, kind and/or geographical distribution of organisms, make and justify a claim about the effects of changes in environmental conditions on the survival of some organisms compared to the effects of these changes on the survival of other organisms.

*[**BOUNDARY:** The focus is on the effects of changes in the environment on the survival of organisms. The examples should not only describe the effects on the survival rates of various species but also describe the effects of individual variation on survival within one species.]*

LSM-PE.1.2.3 Give examples, using information gathered from print and electronic resources, of environmental changes that have occurred in the recent past as a result of human actions. Collect and organize data about the number, kind and/or geographical distribution of organisms before and after these changes occurred. Make a claim about how these environmental changes have affected the number, kind and/or distribution of specific organisms living in these environments. Using these examples of environmental changes and the data on number, kind and/or geographical distribution of organisms, make and justify a claim about the effects of changes in environmental conditions on the survival of some organisms compared to the effects of these changes on the survival of other organisms.

LSM-PE.1.2.4 Give examples, using information gathered from print and electronic resources, of observations made by Charles Darwin of variation within species and of changes in environmental conditions that he used in the development of his **theory** of natural selection. For each example, describe the relationship between the variation within species and the changes in the environmental conditions.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Charles Darwin's theory of evolution had a dramatic effect on biology because of his use of clear and understandable argument and because of the inclusion of a massive array of evidence to support the argument.[3]
- Organisms that have certain traits are better suited than other organisms to survive and have offspring in a given environment. If these traits are heritable, the offspring of these organisms will likely have these traits as well; therefore, in that environment, the offspring will also be better suited to survive and reproduce in that environment.
- Changes in Earth's environment occur over both short and long time intervals. Small changes are relatively frequent, and large changes are relatively infrequent.
- Changes in environmental conditions can affect how beneficial a trait (phenotype) will be for the survival and reproductive success of an organism or an entire species.[4]
- Human activity (e.g., deforestation, urbanization, burning fossil fuels, overhunting or overfishing) can impact environmental conditions (e.g., temperature change, habitat and resource availability), which is currently leading to an increase in some populations of organisms but a decrease in many others. Overall, these changes in populations have led to a net extinction of species and thus have reduced biodiversity.
- Most species (approximately 99 percent) that have lived on Earth are now extinct. Throughout Earth's history, extinction of a species has occurred when the environment changes and the individual organisms of that species do not have the traits necessary to survive and reproduce in the changed environment.[5]

3. American Association for the Advancement of Science, *Atlas of Science Literacy Volume 2* (Washington, D.C.: Author, 2007), 85.
4. American Association for the Advancement of Science, *Benchmarks for Science Literacy* (New York: Oxford University Press, 1993), 124.
5. National Research Council, *National Science Education Standards* (Washington, D.C.: The National Academies Press, 1996), 158.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.2.1 Construct a model or run a simulation that represents natural selection in terms of how changes in environmental conditions can result in selective pressure on a population of organisms.

LSH-PE.1.2.1a Gather and record data from the model or simulation on the composition (e.g., distribution of traits, number of organisms, change in environmental conditions) of a population under varying environmental conditions. Complete multiple trials or use class data.

LSH-PE.1.2.1b Represent the data in a way that demonstrates the relationship, if any, between the environmental changes and the population.

LSH-PE.1.2.1c Calculate measures of central tendencies (i.e., mean, median, mode), represent spread of data (e.g., range), and determine error (e.g., number of **outliers**) of each variable in order to analyze the data and make a claim about the patterns observed.

LSH-PE.1.2.1d Explain how each part of the model or simulation is similar to, or different from, the process of natural selection.

LSH-PE.1.2.2 Predict and justify, based on ideas about natural selection, what might happen to a population of organisms after many generations if the population becomes geographically isolated from another population of the same species, and if the two groups experience different **biotic** and/or environmental conditions.

LSH-PE.1.2.3 Give examples, using information gathered from print and electronic resources, of observations made by Charles Darwin of variation within species and of changes in environmental conditions that he used in the development of his theory of natural selection. For each example, explain how the observations support the theory of natural selection.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Natural selection leads to a diversity of organisms that are anatomically, behaviorally and physiologically well suited to survive and reproduce in a specific environment.
- Over time, the differential survival and reproduction of organisms within a population that have an advantageous heritable trait lead to an increase in the proportion of individuals in future generations that have the trait and a decrease in the proportion of individuals that do not.
- Changes in the **abiotic** environment, including climatic and geological processes, have contributed to the decline of some species and the expansion of other species.
- When environmental change — naturally occurring or human induced — happens, extinction can occur. Species become extinct because they cannot survive and reproduce in their environments. If members cannot adjust — because change in the environment is too fast or too drastic — they die or become unable to reproduce, thus negating opportunity for evolution.
- Charles Darwin's theory of evolution had a dramatic effect on biology because of his use of clear and understandable argument and the inclusion of a massive array of evidence to support the argument.[6]

6. American Association for the Advancement of Science, *Atlas of Science Literacy Volume 2*, 85.

Objective LS.1.3
Genetic Variation Within Populations

Students understand that genetic variation within a population is essential for natural selection. Mutations, as well as random assortment of existing genes, can produce genetic variation in a population.

*[**BOUNDARY:** For this objective, genetic variation refers to the variation in the genetic makeup of organisms of the same species. Students are expected to make the connection and, when appropriate, articulate the connection between the variation of genetic information and the resulting variation in traits. The connection among DNA, protein and trait should not be considered a "black box" for the 9–12 grade band.]*

> **Suggested Connections**
> *Within Life Science:* Natural Selection (LS.1.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 3A, 3C, 4C

Note: For Objective LS.1.3, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.1.3.1 Give examples of how, following a change in environmental conditions, variation in traits within a specific population of organisms might affect the survival and reproductive ability of some of the organisms in that population, but not other organisms in the same population. Give examples of other environmental changes that may not affect the survival and reproduction of any of these organisms. Describe the type of data needed to determine whether the survival or reproductive success of individual organisms was due to the genetic variation within the population.

LSH-PE.1.3.2 Compare the effects of a significant environmental change on a population with great genetic diversity and the effects of such a change on a population with little genetic diversity. In each instance, indicate the environmental change, the organisms within the species that were affected, and the organisms that were not affected. Explain why genetic variation among organisms within the species affected the survival of the species.

LSH-PE.1.3.3 Explain similarities and differences between populations (e.g., dogs, horses, crops) undergoing artificial selection and populations undergoing natural selection. Describe the roles that humans play in artificial selection and how these roles are similar to the natural processes that take place in natural selection.

LSH-PE.1.3.4 Give examples, using information gathered from print and electronic resources, of different organisms whose classification as members of different "species" is questionable. After evaluating the two different proposed definitions of the term "species" that led to the controversial classification of the organisms, make and justify a claim about whether or not the organisms provided as examples should be considered members of different species or of the same species.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Natural selection can occur only if there is variation in the genetic information between organisms of the same species in a population and variation in the expression of that genetic information as a trait. Genetic variation within a population influences the likelihood that a population will survive and produce offspring.[7]

- Sexual reproduction not only allows the continuation of traits (phenotype) in a population but also provides a source of genetic variation among the individuals of a population.

7. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 125.

ESSENTIAL KNOWLEDGE (9–12), *continued*

- The expression of new anatomical, physiological and behavioral traits (phenotype) in organisms within a population can result from recombining existing genes and random sorting during sex cell production and fertilization. Variation within a population of organisms can also result from genetic mutations that create variation in the expression of traits (phenotype) between organisms of the same species.

- In artificial selection, humans have the capacity to influence certain characteristics of organisms by manipulating the transfer of genetic information from generation to generation.

Standard LS.2
Cells as a System

Cells are a fundamental structural and functional unit of life.

Students understand that all organisms consist of one or more cells, and that many of the basic functions (e.g., energy **transfer** and **transformation**, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment) of organisms take place within individual cells or within systems of cells. Although there are many types of cells — in terms of size, structure and specialized functions — all cells carry out the fundamental processes that are associated with life.

Objective LS.2.1
Cell Function

Students understand that cells perform the essential functions of life, such as energy transfer and transformation, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment.

*[**BOUNDARY:** The following cell components — nucleus, mitochondria, chloroplast, ribosome, plasma membrane, vacuole and lysosome — are appropriate for students in grades 6–8. Emphasis should be placed on the function and coordination of these components, as well as on their role in the overall cell function, before introducing and reinforcing the names of these components. For students in grades 9–12, the addition of cytoskeleton, Golgi complex and endoplasmic reticulum is appropriate.]*

> **Suggested Connections**
> *Within Life Science:* Cell Differentiation (LS.2.4); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); Nongenetic Information Transmission (LS.5.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1B, 2A, 2B, 2D, 3D, 4A, 4B; AP Environmental Science 3B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.1.1 Give examples of organisms that are made of one cell (both non-nucleated and nucleated) and organisms that are made of many cells. Compare and contrast the essential functions occurring in the single-cell organisms and in the cells of multicellular organisms.

LSM-PE.2.1.2 Gather data, based on observations of cell functions made using a microscope or on cell descriptions obtained from print material, that can be used as evidence to support the claim that there are a variety of cell types.

LSM-PE.2.1.3 Compare and contrast, using evidence of different cells and essential life functions, the various processes different cells (e.g., plant, fungi, protist, animal) use to accomplish the same life function (e.g., growing, obtaining energy).

LSM-PE.2.1.4 Construct a scaled model, based on measurements and estimates made using a microscope (when possible), that represents the relative sizes of a molecule, a bacterial cell, an animal cell and a virus.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- There are many types of cells. Organisms may consist of one cell or many different numbers and types of cells.
- Most cells are so small that the cells themselves and their details can be seen only with a microscope.
- The cell is the functional unit of all organisms. All essential life functions (e.g., energy transfer and transformation, exchange of gas, disposal of waste, growth, reproduction, and interaction with the environment) take place within a cell or within a system of cells.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.1.1 Describe the structure and function of at least one organ located in a plant and the analogous organ located in an animal (e.g., organs used for food storage, movement, reproduction, etc.). Description includes the types of cells, the structure of these cells, and the processes they perform to support the function of both the organ and the organism as a whole.

LSH-PE.2.1.2 Describe the function of at least one type of organ located in two different plants or in two different animals. Description includes the similarities and differences in the cells that make up the organ, and the similarities and differences in the processes that the cells perform to support the function of the organ in the two organisms.

LSH-PE.2.1.3 Describe, using information gathered from print and electronic resources, the structure and function of at least two organs that are part of a human body system (e.g., circulatory, digestive, gas exchange). Description includes how the two organs differ regarding the types of cells that make up each organ. Explain, using knowledge of systems of cells, how the cells and organs coordinate and contribute to the overall essential functions of the organism.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- In multicellular organisms, groups of one or more kinds of cells make up different systems of cells (i.e., tissues and organs) that are connected and that cooperate with each other in order to perform the essential functions of life within an organism.
- Different multicellular organisms use different systems of specialized cells to carry out the same basic life functions.
- The human body is made up of cells that are organized into tissues and organs. These tissues and organs make up complex systems that have specialized functions (e.g., circulatory, endocrine, etc.) that support essential life functions of the organism.

Objective LS.2.2
Cell Structure

Students understand that cells have internal structures that carry out specialized life functions, and that these internal structures vary depending on a cell's function.

*[**BOUNDARY:** The following cell components — nucleus, mitochondria, chloroplast, ribosome, plasma membrane, vacuole and lysosome — are appropriate for students in grades 6–8. Emphasis should be placed on the different structures in cells — and on how the number and types of structures vary in different cells that carry out different functions — before introducing and reinforcing the names of these components. For students in grades 9–12, the addition of cytoskeleton, cytosol, Golgi complex and endoplasmic reticulum is appropriate. There is a focus on the molecular level, so connections should be made, when appropriate, between the functions of the different cell subcomponents in terms of chemical reactions.]*

Suggested Connections
Within Life Science: Cell Function (LS.2.1); Cell Differentiation (LS.2.4); [Grades 9–12 only: Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); DNA to Trait (LS.5.3); Nongenetic Information Transmission (LS.5.5)]

Between Life Science and Other Disciplines: Structure–Property Relationships (C.2.2); Chemical Equilibrium (C.2.4); Chemical Kinetics (C.2.5)

Prepares students for the following AP Enduring Understandings: AP Biology 1B, 1D, 2A, 2B, 2D, 2E, 3D, 4A, 4B; AP Environmental Science 3B

Objective LS.2.2: Cell Structure

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.2.1 Describe, based on observations of cells made using a microscope and on information gathered from print and electronic resources, the internal structures (and the functions of these structures) of different cell types (e.g., amoeba, fungi, plant root, plant leaf, animal muscle, animal skin).

LSM-PE.2.2.2 Construct an analogical model (analogy) of the interaction of the internal components of a cell (e.g., working parts of a city, factory or automobile). Predict and justify, using the model, the impact on the cell or on the organism if one of the components fails to function properly.

LSM-PE.2.2.3 Observe patterns in the concentration of molecules of a solution (e.g., dye in water, tea) or across a membrane. Construct a model of the observed patterns.

LSM-PE.2.2.4 Predict **problems** that may arise when certain essential molecules cannot enter a cell. Justification is based on the function of the cell membrane and the role of these molecules in carrying out the essential life functions that take place within a cell.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The cell membrane forms the boundary that controls what enters the cell and what leaves the cell.
- All cells contain genetic information. Some cells (nucleated or eukaryotic) hold the genetic information in a nucleus. However, some cells (non-nucleated or prokaryotic) do not have a nucleus in which genetic information is held.
- Each cell has a specific internal organization of subcellular components that give a cell its shape and structure.
- The specialized subcomponents of nucleated cells perform essential functions such as transport of materials (cell membrane), repository of genetic information (nucleus), energy transfer (mitochondria and chloroplast), protein building (ribosomes), waste disposal (lysosomes), structure and support (cell wall, cytoskeleton), internal movement within the cell and, at times, external movement (cytoskeleton).
- Non-nucleated cells perform the same kinds of functions as nucleated cells, but many of these functions take place within the cytoplasm, not within specialized internal structures. For example, unlike nucleated cells, the genetic material of non-nucleated cells is located within the cytoplasm, not in a separate nucleus. Some of the essential functions of non-nucleated cells and these functions' locations include transport of material (cell membrane), protein building (ribosome), and structure and support (cell wall).

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.2.1 Observe the internal structures of at least three different types of cells (e.g., amoeba, fungi, plant root, plant leaf, animal muscle, animal skin). Describe, using information gathered from print and electronic resources, the functions of these structures. Construct a representation of each cell type, and compare — using gathered information and knowledge of cell structures and functions — the structures and functions across cell types. Explain why the representation is limited and simplified.

LSH-PE.2.2.2 Investigate the movement of molecules across a membrane.

LSH-PE.2.2.2a Formulate a **scientific question** about the movement of molecules across a membrane under differing conditions of temperature, starting concentration, pH, etc.

LSH-PE.2.2.2b Plan an investigation to address the variables that might affect the movement of molecules across a membrane.

PERFORMANCE EXPECTATIONS (9–12), *continued*

LSH-PE.2.2.2c Gather and record data on the movement of molecules across a membrane via passive transport under varying conditions of temperature, starting concentration, pH, etc., by completing multiple trials or by using class data. (Movement across the membrane can be measured as the percent change in the mass or volume of liquids on either side of the membrane, or by the degree of color change of liquids on either side of the membrane.)

LSH-PE.2.2.2d Calculate measures of central tendency (i.e., mean), spread of data (i.e., range) and error (i.e., number of outliers) of the concentration of the different molecules on either side of the membrane at different times.

LSH-PE.2.2.2e Make claims about the movement of the different molecules across the membrane and the factors that affect that movement.

LSH-PE.2.2.3 Explain why cells of organisms swell when placed in water and why they shrink when placed in a solution of salt water. Evaluate other student explanations of the same phenomenon. Construct a representation that generalizes the phenomenon to all organisms.

LSH-PE.2.2.4 Construct a representation of a cell membrane undergoing passive and active transport, in terms of difference in concentration, required energy and direction of molecule movement. Explain how the movement of molecules impacts the cell, and, as a result, impacts the organism as well.

LSH-PE.2.2.5 Collect data on the rates of reactions (synthesis and breakdown) via different enzymes and the rates of reactions that occur without each enzyme. Construct tables and graphs to represent the data for each enzyme. Compare the rates of reactions for the different enzymes.

LSH-PE.2.2.6 Give examples of several enzyme-catalyzed reactions that occur in living systems, and describe the importance of each reaction for the organism. Explain why an organism that has a deficiency of one of the enzymes is unable to perform a particular life function.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The essential functions of a cell involve chemical reactions that take place between many different types of molecules (e.g., water, carbohydrates, lipids, nucleic acids and proteins) and that are facilitated by enzymes. Water plays an important role both in reactions and as a major environmental component for all cells.

- Enzymes are proteins that enable chemical reactions to proceed at rates that support life functions. Environmental factors and modulators (inhibitors and activators) influence an enzyme's activity and its ability to regulate chemical reactions (i.e., life's essential functions).

  *[**BOUNDARY:** The targets of understanding are (1) changes in reaction rates due to enzymes, and (2) the factors that affect enzymes. Quantitative treatment of reaction rates is out of the scope of this objective. The molecular orientation of molecules (i.e., tertiary structure) and the specific enzyme mechanism (i.e., induced fit) are also not appropriate.]*

- Due to differences in concentration of molecules, molecules move in and out of a cell and among cells through specialized mechanisms called passive transport and active transport. The concentration of molecules and energy are factors in type and direction of transport.

Objective LS.2.3
Cell Growth and Repair

Students understand that cells of multicellular organisms repeatedly divide to make more cells for growth and repair.

> **Suggested Connections**
> *Within Life Science:* Cell Function (LS.2.1); Cell Differentiation (LS.2.4); Living Systems and the Physical Environment (LS.3.1); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: Nongenetic Information Transmission (LS.5.5)]
>
> *Between Life Science and Other Disciplines:* Conservation of Matter (C.2.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 2C, 2D, 2E, 3A, 3C, 4A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.3.1 Give examples of cell types that divide, cell types that do not divide at all, and cell types that divide only under very unusual circumstances.

LSM-PE.2.3.2 Organize and represent information gathered from print and electronic resources to compare the cell cycles of several cell types that undergo cell division. Representation(s) include the frequency of division, the typical duration of the cell cycle, the specialized function of the cell, and any special conditions that stimulate cell division and cell death. Make a claim about, and justify the relationship between, characteristics of cell cycles and the function of the cell.

*[**BOUNDARY:** Types of cells appropriate for grades 6–8 could include fungi, plant leaf, nerve, skin, muscle and plant root.]*

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- For growth and repair of multicellular organisms, each cell divides using a process (mitosis) that results in two new cells that carry the same genetic information (DNA) as the parent cell.

- Length of cell cycle and frequency of cell division typically vary among different cell types.
  *[**BOUNDARY:** Cell cycle at this level should be the time between the completion of cell divisions; the phases are not appropriate.]*

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.3.1 Make a claim about and justify, using ideas about conservation of matter, why new atoms and molecules must be added to cells in order for them to grow.

LSH-PE.2.3.2 Construct a representation of the changes that occur in a cell in terms of its size and internal components, and of the number of cells produced as a cell goes through a single cycle of cell growth and division. Predict, based on the representation, what might happen to a cell (e.g., increase in size, change in internal structure) that does not go through the entire cell cycle but still goes through division.

LSH-PE.2.3.3 Describe, using information gathered from print and electronic resources, examples of the following cell types from any multicellular organism: a cell type that divides, a cell type that does not divide at all, or a cell type that divides only under very unusual circumstances. Description includes information about the consequences and significance to an organism of having some cells that divide and some that do not.

LSH-PE.2.3.4 Identify, using information gathered from print and electronic resources, several specific parts of the cell cycle that are monitored by check point systems, and describe some of the problems that might occur if abnormal cells were allowed to continue cycling.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Cells typically undergo a continuous cycle of cell growth and division. Although most cells share the same cell cycle phases (e.g., cell growth, DNA replication, preparation for division, separation of chromosomes, cell membrane pinching off two daughters), the length of each cell cycle phase, and therefore the frequency of cell division, varies among different cell types.

  *[**BOUNDARY:** Detailed descriptions of the actions taking place during the different phases are not as important as the overall impact of these actions on the cell (changes that take place to the cell and its internal components) throughout the cycle.]*

- Normal progression through the cell cycle and readiness to initiate reproduction are constantly evaluated at check points throughout the cell cycle; abnormal or damaged cells are targeted for repair or for intentional destruction (apoptosis). Malfunctions in the check point feedback system may allow defective cells to continue cycling and the number of abnormal or damaged cells to proliferate, resulting in cancer.

Objective LS.2.4
Cell Differentiation

Students understand that in multicellular organisms, the single cell (zygote) ultimately divides and differentiates into specialized cells that form the various tissues and organs of the organism.

*[**BOUNDARY:** The purpose of this objective is to emphasize DNA's role in the process of cell differentiation. It is not intended to focus on the memorization of the stages of differentiation, the timing of a certain stage, or specific mechanisms of DNA activation or inactivation. The specifics of the process of differentiation are also not appropriate for students in grades 6–8.]*

Suggested Connections

Within Life Science: Cell Function (LS.2.1); Cell Structure (LS.2.2); Cell Growth and Repair (LS.2.3); Changing Model of Inheritance (LS.5.1); Genetic Information Transmission (LS.5.2); [Grades 9–12 only: DNA to Trait (LS.5.3); Nongenetic Information Transmission (LS.5.5)]

Prepares students for the following AP Enduring Understandings: AP Biology 2A, 2E, 3A, 3B, 3D, 4A

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.2.4.1 Observe and document the development of an organism (e.g., sea urchin). Construct a representation, using appropriate time scale, of the sequence of general stages of cell differentiation that begins immediately after fertilization and ends with the development of a simple multicellular organism. Representation includes major milestones of cell differentiation and growth.

*[**BOUNDARY:** Students do not need to know terms (e.g., cleavage, blastula, gastrula) that identify specific stages.]*

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- A single cell can develop into an entire organism with many types of cells.
- In multicellular organisms, the original cell (zygote) produced during fertilization goes through a series of cell divisions, leading to the formation of a cluster of cells. The cells in these cell clusters eventually differentiate into specialized cells that become the organism's tissues and organs.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.2.4.1 Construct a representation to demonstrate how gene activation and gene inactivation lead to cell differentiation. Representation includes the transmission of genetic information from DNA to protein to cell traits.

LSH-PE.2.4.2 Give examples, using information gathered from print and electronic resources, of situations in which errors that occur during gene activation or gene inactivation lead to errors in cell differentiation.

LSH-PE.2.4.3 Gather, from print and electronic resources, data that can be used as evidence to support or refute the claim that some kinds of stem cells have a greater potential than other kinds of stem cells to develop into a variety of different tissue types. Include comparisons between embryonic stem cells and adult or body stem cells, and comparisons among different types of adult stem cells.

LSH-PE.2.4.4 Identify current applications of plant and animal stem cells, and describe problems surrounding the use of these cells.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- During the successive division of an embryo's cells, activation or inactivation of different genes in these cells causes the cells to develop in different ways.
- The stem cells of plants and animals divide through mitosis. After the cells divide, at least one of the daughter cells remains undifferentiated. At specific times, some daughter cells will differentiate to become a specific type of cell with a specialized function, while others will continue as nonspecialized cells. There are stem cells at all stages of development (e.g., in embryos as well as in adults). Adult stem cells continue to divide, generating both a differentiated daughter cell of a specific tissue type and an undifferentiated daughter cell.

Standard LS.3
Interdependent Relationships

Interdependent relationships characterize biological ecosystems.

Students understand that biological systems are not isolated entities. The systems interact with other living and nonliving systems in interdependent relationships. Using a systems approach for ecosystems allows students to study the boundaries of an ecosystem, the components of an ecosystem, and the interactions between the living and nonliving components of an ecosystem. Data collected about the inputs and outputs of, and interactions within, an ecosystem are used to create models of the dynamic processes in an ecosystem that can be used to make **predictions** and evaluate the health or stability of an ecosystem. A stable system has various mechanisms that maintain a state of relative constancy in the system as these dynamic processes occur, but the interactions of living systems with each other and with nonliving components can also result in permanent changes to an ecosystem, both over long periods of time (e.g., evolution) and short periods of time (e.g., climate change, invasive species).

Objective LS.3.1
Living Systems and the Physical Environment

Students understand that in all ecosystems, living organisms interact with and depend on the physical (abiotic) conditions of their environment for survival.

Suggested Connections
Within Life Science: Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2); [Grades 9–12 only: Nongenetic Information Transmission (LS.5.5)]

Between Life Science and Other Disciplines: Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Climate (ES.2.4); Relative and Absolute Dating (ES.3.1); Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3)

Note: For Objective LS.3.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.1.1 Give examples of physical (abiotic) conditions (e.g., light, temperature, water, soil type, sites for shelter and reproduction) that affect a specific organism's survival, and describe how the physical (abiotic) conditions affect the organism's survival.

LSM-PE.3.1.2 Give examples of instances when specific organisms impact their local environment, and describe how other organisms are affected by the environmental change.

LSM-PE.3.1.3 Give examples of physical (abiotic) conditions that affect the survival of specific kinds or groups of organisms (e.g., fish that live in salt water versus those that live in fresh water; algae that can survive only within a certain range of light; fungi and plants that require a certain amount of water to survive). Use these examples to make and justify a claim about the effect of physical (abiotic) conditions on a specific organism's survival.

LSM-PE.3.1.4 Use data as evidence to make and justify a claim concerning whether or not a population of organisms is affected by varying environmental conditions in an ecosystem. Data show information regarding the number of organisms of each species in an ecosystem under varying environmental conditions (e.g., what happens to the number of a particular species — including organisms that can survive significant changes and those that cannot — when temperature, soil, moisture or sunlight varies over time). Using these data, predict the survival of a particular species in a specific ecosystem when certain changes occur to the physical (abiotic) environment.

LSM-PE.3.1.5 Make a general claim about the relationship between organisms' traits and their chances of survival. Justification for the claim is based on data from several populations of organisms with varying traits and under a variety of environmental conditions.

*[**BOUNDARY:** The traits presented in the data table should be appropriate for students in grades 6–8 in that the students are able to identify the connection between each trait and the environmental factors.]*

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.3.1.6 Investigate the relationship(s) between a population of organisms and the physical (abiotic) factors of an environment.

*[**BOUNDARY:** The preferred method of conducting an investigation for this concept is participation in a field experience; however, a lab-based experience is appropriate when investigating certain organisms (e.g., algae, duckweed, fruit flies, insects, fungi, bacteria). The physical (abiotic) factors used in the lab can be those that are introduced into the environment as a result of human activity. Any investigation conducted should not purposely intend to harm or kill the organisms.]*

LSM-PE.3.1.6a Formulate a scientific question that addresses the relationship between the number of organisms in a population and the physical (abiotic) factors of their environment.

LSM-PE.3.1.6b Plan an investigation of the relationship between the number of organisms in a population and a single variable of their environment. Investigation could include random sampling (e.g., measurements at different times or locations) of the population size within the ecosystem and, when possible, controlling other relevant variables (e.g., time of day, time of year).

LSM-PE.3.1.6c Gather and record data on the number of organisms, the environmental variable that is being investigated and other variables that could impact the conclusion about the relationship between environmental factors and population size.

LSM-PE.3.1.6d Organize the data (e.g., using a data table) in order to demonstrate the relationship, if any, between environmental factors and population size.

LSM-PE.3.1.6e Calculate the mean size of the population at different locations in the ecosystem or at different times, and rate of change of population size. Make a claim about the relationship between population size and each environmental factor investigated.

LSM-PE.3.1.7 Construct representations, using data and information gathered from print and electronic resources, of the different physical (abiotic) conditions that exist on Earth and the diverse environments (biomes) that arise from these varying physical (abiotic) conditions. Collect and organize data on the number and types of organisms (plant and animal) that exist in these diverse environments, and find patterns between the number and types of organisms based on physical (abiotic) conditions.

LSM-PE.3.1.8 Analyze the characteristics of different species (both plant and animal) within the same environment. Based on this analysis, identify the characteristics that allow them to successfully survive in that environment.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- An organism's survival depends on physical (abiotic) factors such as light, temperature, water, soil and the availability of sites for shelter and reproduction.
- Organisms have traits that enable them to be more successful in some physical (abiotic) environments than in others. Changes in environmental conditions result in changes to the number and types of organisms that survive in these environments.
- The variety of physical (abiotic) conditions that exists on Earth gives rise to diverse environments (e.g., deserts, rain forests, coral reefs, swamps) and allows for the existence of a wide variety of organisms (biodiversity).
- Organisms impact their local environment as they interact with other organisms and with their physical (abiotic) environment (e.g., building shelter, depositing waste, foraging, and using water and dissolved oxygen).

Objective LS.3.2
Interactions of Living Systems

Students understand that organisms in all ecosystems interact with and depend on each other, and that organisms with similar needs compete for limited resources.

> **Suggested Connections**
> *Within Life Science:* Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2)
>
> *Between Life Science and Other Disciplines:* Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3)

<u>Note</u>: For Objective LS.3.2, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.2.1 Give examples and distinguishing features of different ecosystems.

LSM-PE.3.2.2 Give examples of organisms that depend on other particular organisms for food, shelter or reproduction, and describe these interdependent relationships.

LSM-PE.3.2.3 Give examples, based on empirical observations, of competition between specific organisms in an ecosystem, including competition for food, shelter and nesting sites (e.g., plants may compete for light, water or nutrients; animals may compete for food or shelter). Examples include competition within a species, as well as competition among different species. Make and justify a claim, using knowledge of the behaviors and characteristics of specific organisms, concerning whether the organisms in the examples are in fact competing, and identify the resource that is the basis of the potential competition.

LSM-PE.3.2.4 Construct a food web diagram, based on observations of or information on feeding relationships among specific organisms, to describe the feeding relationships among organisms. Identify assumptions made about the feeding relationships, and identify ways in which the food web diagram differs from the actual ecosystem interrelationships.

LSM-PE.3.2.5 Analyze data (e.g., construct a graph or calculate rate of change) that show changes — increases or decreases — in the number of organisms within a population in an ecosystem relative to particular resource information. Explain, in terms of resources that may or may not be available to the organisms and potential limits to these resources, the pattern and rates of growth of the population. Make and justify a claim, based on these data, concerning whether or not a population of organisms in a given area can grow to be infinitely large.

LSM-PE.3.2.6 Predict, based on a food web representation, the effects that a change — increase or decrease — in the number of organisms of one species will have on the numbers of organisms of other species within the ecosystem. Prediction includes effects involving two organisms that are in a direct feeding relationship with each other, and effects involving two organisms whose relationship is mediated by one or more organisms.

LSM-PE.3.2.7 Give examples, using information gathered from print and electronic resources, of invasive species in a particular environment. Explain, using information about the needs and behaviors of the invasive species, why invasive species are often able to increase rapidly and why the numbers of other organisms either increase or decrease when invasive species enter an ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The network of organisms, the relationships among these organisms, and the nonliving environment in which these organisms live is called an ecosystem.
- The relationships (e.g., mutualism, commensalism, parasitism, predator–prey, herbivore–autotroph) within an ecosystem vary. Some organisms depend so much on a particular organism for food and shelter that they cannot survive without this other organism.
- There are limits to the number and types of organisms and populations an ecosystem can support (carrying capacity), depending in part on how the particular organisms involved interact with each other. These limits are determined by factors such as disease, predation, competition, and availability of biological (biotic) resources and physical (abiotic) factors.[8]
- All organisms interact with each other to obtain food. This type of interdependent relationship among organisms can be represented in a food web diagram.
- All resources are finite. Therefore, if a resource is used up by one organism, it is unavailable to another organism. Competition for these limited resources may occur among members of the same species, or among members of different species. Competition may involve one organism obtaining the resource before another organism can get to it. This may involve direct contact or fighting between the organisms, or it may involve one organism obtaining the resource before another organism can get to it, in which case there is no confrontation between the organisms.

Objective LS.3.3
Ecosystem Stability

Students understand that a complex set of interactions within an ecosystem can maintain the number and types of organisms in an ecosystem that is relatively constant over long periods of time.

Suggested Connections
Within Life Science: Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Matter Cycling (LS.4.1); Energy Transfer (LS.4.2)

Between Life Science and Other Disciplines: Climate (ES.2.4); Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Humans and Natural Resources (ES.5.1); Humans and the Environment (ES.5.3); Conservation of Matter (C.2.3)

Prepares students for the following AP Enduring Understandings: AP Biology 1C, 2A, 2D, 4A, 4B, 4C; AP Environmental Science 2A, 2B, 5A, 5B, 5C, 5E

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.3.3.1 Investigate the biodiversity of two or more ecosystems and/or two or more areas of an ecosystem.

LSM-PE.3.3.1a Make observations and gather data on the number of different kinds of organisms and the total number of organisms in the different ecosystems or in the areas of the ecosystem.

LSM-PE.3.3.1b Re-express and organize data in a graph that represents the number and kinds of species.

8. WestEd and the Council of Chief State School Officers, *Science Assessment and Item Specifications for the 2009 National Assessment of Educational Progress (Prepublication Edition)* (Washington, D.C.: National Assessment Governing Board), 58.

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.3.3.1c Calculate measures of central tendencies (i.e., mean, mode), spread of data (i.e., range) and sampling error for the number of different kinds of organisms and the total number of organisms in the different ecosystems or in the areas of the ecosystem. Analyze data, and make a claim, based on the data collected, as to which area of the ecosystem is more biodiverse.

LSM-PE.3.3.2 Predict and justify, based on knowledge of interaction between organisms and their physical (abiotic) environment, what might happen to the number of organisms of a given species in an ecosystem following a temporary biological (biotic) or physical (abiotic) change in that ecosystem (e.g., a very cold winter or a disease that kills large numbers of one of the species in the ecosystem).

LSM-PE.3.3.3 Give examples, using information gathered from print and electronic resources, of human-induced disruptions to an ecosystem that can affect the composition of that ecosystem. Explain, using evidence of the relationships among different organisms and using knowledge of the interaction of organisms with the physical (abiotic) environment, why one disruption can impact the composition of the ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Ecosystems are dynamic in nature; the number and types of species fluctuate over time. Disruptions, deliberate or inadvertent, to the physical (abiotic) or biological (biotic) components of an ecosystem impact the composition of an ecosystem.
- Biodiversity is often used as a measure of the health of an ecosystem.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.3.3.1 Describe the abiotic characteristics of an ecosystem: its boundaries, its components, its inputs and outputs, and its interactions, as well as the boundaries and other characteristics of overlapping ecosystems.

LSH-PE.3.3.2 Analyze data (e.g., mean, mode, spread of data, sampling error) that show the number of different species and the number of organisms within a species in two or more ecosystems over time (one of the ecosystems has more fluctuations than the other). Make a claim about the relative stability of each ecosystem. Devise a measure of relative stability, taking into account whether the stability is simply a lack of fluctuation of organism numbers, or if the stability should be measured based on a regular recurrence of a cyclical pattern of variation in an ecosystem.

*[**BOUNDARY:** There is no standard measure of relative stability for biodiversity. The measure of relative stability is generated by the student to give him or her an appreciation of the complexity of the factors involved.]*

LSH-PE.3.3.3 Gather information — and, when appropriate, numerical data — from print and electronic resources about the stability of various ecosystems, in terms of changes in the biotic and abiotic components of those ecosystems over time. Make a claim, based on this information and/or data, about whether the ecosystem is stable or unstable, and describe which conditions/factors indicate stability or instability.

LSH-PE.3.3.4 Analyze data that depict changes in the abiotic components of an ecosystem and changes in the biotic components of an ecosystem over time (e.g., percent change, average change, correlation and proportionality). Evaluate claims of possible relationships between the changes in the abiotic components and the biotic components of the environment.

LSH-PE.3.3.5 Predict what will happen to the number of organisms of a given species in an ecosystem following a temporary biotic or abiotic change in that ecosystem (e.g., a very cold winter or a disease that kills large numbers of one of the species in the ecosystem) and what will happen after conditions return to what they were before the disruption. Justification for the prediction is based on knowledge of how ecosystems typically respond to temporary changes in environmental conditions, how this particular ecosystem has responded to such changes in the past, and the scale of these particular changes.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- The number of organisms in ecosystems fluctuates over time as a result of mechanisms such as migration, birth and death. These fluctuations are essential for ecosystem stability and characterize the dynamic nature of ecosystems. Extreme fluctuations in the size of populations offset the stability of ecosystems in terms of habitat and resource availability.

- Ecosystems can be reasonably stable over hundreds or thousands of years.[9] If a disturbance to the biotic or abiotic components of an ecosystem occurs, the affected ecosystem may return to a system similar to the original one, or it may take a new direction and become a very different type of ecosystem.

- Ecosystems are not always stable over short periods of time. Changes in climate, migration by an invading species into an ecosystem, and human activity can impact the stability of an ecosystem.

9. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 117.

Standard LS.4
Matter and Energy

Biological systems utilize energy and molecular building blocks to carry out life's essential functions.

Students recognize that the interactions between organisms and their environment are dynamic in nature. The processes that define "being alive" involve chemical reactions that require the input of energy and that result in the rearrangement of atoms. Energy, which is ultimately derived from the Sun and transformed into chemical energy, is needed to maintain the activity of an organism. The matter that is involved in these dynamic processes is constantly **recycled** between the organisms and their environment.

Objective LS.4.1
Matter Cycling

Students understand that matter is continuously recycled within the biological system and between the biological (biotic) and physical (abiotic) components of an ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, matter is treated as being made of atoms and molecules. Chemical reactions are presented as the rearrangement of atoms in molecules. Chemical reactions in terms of subatomic structures of atoms are not appropriate.]*

> **Suggested Connections**
> *Within Life Science:* Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3)
>
> *Between Life Science and Other Disciplines:* Atmosphere as a System (ES.2.1); Oceans as a System (ES.2.2); Lithosphere as a System (ES.2.3); Water Cycle (ES.4.1); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Properties of Matter (PS.2.1); Particulate Nature of Matter (PS.2.3); Conservation of Matter (PS.3.1); Physical and Chemical Changes of Matter (PS.3.2); Electric Circuit Interactions (PS.4.2)

LIFE SCIENCE

Note: For Objective LS.4.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.1.1 Create a representation to describe the cycling of a carbon atom from the physical (abiotic) environment through the molecules of the biological (biotic) components of an ecosystem back to the physical (abiotic) environment.

*[**BOUNDARY:** The chemical structure of any of the molecules is not appropriate.]*

LSM-PE.4.1.2 Make and justify a claim concerning whether a particular molecule of oxygen inhaled today could be made of the same atoms of oxygen inhaled by someone a hundred years ago. Make and justify a claim concerning whether a particular molecule of water consumed today could be made of the same atoms of hydrogen and oxygen consumed by someone a hundred years ago.

LSM-PE.4.1.3 Predict and justify what might happen to an ecosystem if there were no bacteria or fungi present. Prediction and justification are based on ideas about matter recycling between the biological (biotic) and physical (abiotic) parts of an ecosystem.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Matter is transferred among organisms in an ecosystem when organisms eat, or when they are eaten by others for food. Molecules from food react with oxygen to provide energy that is needed to carry out essential life functions, become incorporated into the body structures of organisms, or are stored for later use. Although matter is transformed in these processes as the atoms of molecules are rearranged, the matter is neither created nor destroyed.

- Matter moves within individual organisms through a series of chemical reactions in which molecules are rearranged to form new molecules. These chemical reactions enable organisms to carry out essential life processes and to build body structures.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- All the molecules that make up the food in an ecosystem once existed as other molecules in the physical (abiotic) environment and were transformed and incorporated into the biological (biotic) components of the ecosystem primarily via photosynthesis. Organisms that "produce" this food from molecules in the physical (abiotic) environment (through the process of photosynthesis) are called producers.

- Plants and other photosynthetic organisms take in other essential molecules (**minerals**) from their environment (e.g., soil or water). Although these substances are essential for plants and other photosynthetic organisms to incorporate into food, they are not a source of energy.

- During photosynthesis, carbon dioxide and water from the physical (abiotic) environment change (react) chemically to produce sugar molecules in plants and other photosynthetic organisms. The sugar molecules are used immediately by the organisms as an energy resource for life processes such as growth and reproduction, are incorporated into body structures, or are stored for later use.

- Matter is transferred from organisms to the physical (abiotic) environment when molecules from food react with oxygen to produce carbon dioxide and water in a process called cellular respiration. Cellular respiration takes place in most species.

- Matter is also transferred from the biological (biotic) environment to the physical (abiotic) environment by bacteria or fungi (decomposers). Decomposers consume the remains of organisms as food and break down the molecules into simpler molecules that can no longer be used as food. These simpler molecules are the source of essential molecules that plants and photosynthetic organisms absorb from the soil, and the source of molecules that are incorporated into food during photosynthesis.

Objective LS.4.2
Energy Transfer

Students understand that all of the processes that take place within organisms require energy. In most ecosystems, the energy is derived from the Sun and transferred into chemical energy in photosynthetic organisms of that ecosystem.

*[**BOUNDARY:** At the 6–8 grade band, energy transfer, conversion or transformation should be based on the concept of energy conservation. The total energy in any process can be transferred from one object to another across the system boundary and/or transformed within a system from one form to another, but it never disappears. Incorporating system language and boundaries when focusing on ecosystems and organisms is important for accurately understanding energy transfer and transformation.]*

Suggested Connections

Within Life Science: Cell Function (LS.2.1); Cell Structure (LS.2.2); Living Systems and the Physical Environment (LS.3.1); Interactions of Living Systems (LS.3.2); Ecosystem Stability (LS.3.3); Matter Cycling (LS.4.1)

Between Life Science and Other Disciplines: Planetary Evolution (ES.2.5); Carbon Cycle (ES.4.2); Humans and the Environment (ES.5.3); Physical and Chemical Changes of Matter (PS.3.2); Conservation of Energy (PS.4.4); Thermal Energy (PS.4.5); Periodic Table (C.2.1); Chemical Equilibrium (C.2.4); Chemical Kinetics (C.2.5); Conservation of Energy (C.3.1); Energy Transfers and Transformations (C.3.2); Chemical Energy (C.3.3); Contact Interactions and Energy (P.3.1)

Prepares students for the following AP Enduring Understandings: AP Biology 2A, 2D, 4A, 4B; AP Environmental Science 1A, 1C, 2B, 3A, 3B, 3C, 5E

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.4.2.1 Give examples and classify organisms as producers, consumers or decomposers based on their source of energy for growth and development.

PERFORMANCE EXPECTATIONS (6–8), *continued*

LSM-PE.4.2.2 Describe, using a representation, the transfer of energy through an ecosystem. Representation includes the Sun, producers, consumers, decomposers and the transformation of chemical energy to thermal energy at each trophic level of an ecosystem.

LSM-PE.4.2.3 Predict which trophic level, or levels, in any given ecosystem will have the greatest number of organisms, and which will have the least. Justifications are based on ideas about energy transfers in ecosystems.

LSM-PE.4.2.4 Investigate the relationship between energy from the Sun and plant growth and health.

LSM-PE.4.2.4a Formulate a scientific question about the relationship between energy from the Sun and plant growth and health (e.g., number of leaves, number of flowers, color of leaves).

LSM-PE.4.2.4b Gather and record data, using tools to improve **accuracy** and **precision** of measurements, and complete multiple trials or use class data, for plants grown in varying conditions (e.g., light intensity, duration).

LSM-PE.4.2.4c Construct graphs and/or tables of data for plants grown in the different variable conditions.

LSM-PE.4.2.4d Calculate average change, rate of change, spread of data (i.e., range) and measurement error in order to analyze data, and describe the data in terms of the accuracy and precision of the data.

LSM-PE.4.2.4e Make a claim about the relationship between plant growth and health and energy from the Sun. Justification is based on collected evidence and on the understanding of photosynthesis and the cycling of matter.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Light energy is an essential source of energy for most ecosystems. Some organisms utilize the energy transferred from the Sun to convert carbon dioxide and water into molecules in which carbon atoms are linked together (sugar) and oxygen is released. This process is called photosynthesis.

  *[**BOUNDARY:** Students are not expected to know that chemosynthesis is a process in which the energy needed for the synthesis of sugar molecules from carbon dioxide and water in an ecosystem comes from another chemical reaction, not from the Sun.]*

- All organisms require energy to live, and the energy that organisms need to perform essential life functions is chemical energy that is stored in a system of reacting molecules. Molecules from food, in which carbon atoms are linked to other carbon atoms and to hydrogen atoms, are the source of chemical energy for organisms as they react chemically with oxygen.

- Chemical energy is transferred from one organism in an ecosystem to another as the organisms interact with each other for food. Because an organism's entire body is not used as food by organisms at the next trophic level, and because much of the chemical energy is transferred to the environment as thermal energy (heat), only a fraction of the energy at any given trophic level is used for growth, reproduction and other body functions of organisms at the next trophic level.

- Photosynthetic organisms (producers) at the lowest trophic level transform energy from the Sun to chemical energy. At the next trophic level, the chemical energy in producers is transferred to organisms (consumers) that eat the producers. Consumers that use other consumers for food make up the next trophic level. Other organisms (decomposers) consume the remains of both producers and consumers as food. Decomposers transfer any remaining chemical energy to molecules that can no longer be used as food.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.4.2.1 Construct a graphical representation of the number of sugar molecules that are broken down into carbon dioxide and the amount of ATP (adenosine triphosphate) that is produced during fermentation (when oxygen is limited) and during cellular respiration (when oxygen is available). Explain, using the representation, common exercise phenomena (e.g., lactic acid buildup, changes in breathing during and after exercise, cool down after exercise).

LSH-PE.4.2.2 Investigate variables that affect the processes of fermentation and/or cellular respiration in living organisms.

*[**BOUNDARY:** The context of this investigation is purposely open so that experiences that best fit students' interest and level of understanding can be selected.]*

LSH-PE.4.2.2a Formulate a scientific question about the relationship between variables (e.g., type of food, temperature, process input, process output) that impact fermentation and/or cellular respiration.

LSH-PE.4.2.2b Gather and record data (e.g., color indicator change, pulse rate, amount and type of product or reactant), using tools to improve accuracy and precision of measurements, and complete multiple trials or use class data.

LSH-PE.4.2.2c Construct graphs and tables of data for changes in the different variable conditions.

LSH-PE.4.2.2d Calculate changes in rate, percent change, averages and measurement error in order to analyze data and discover patterns. Evaluate the data as it relates to the formulated scientific question.

LSH-PE.4.2.2e Coordinate the results of different investigations that have analyzed different variables that impact either fermentation or cellular respiration. Construct a representation of all of the evidence collected from the various studies.

LSH-PE.4.2.2f Make a claim, based on evidence collected from all investigations, about real-world phenomena (e.g., ethanol production, wine or bread making, exercise).

LSH-PE.4.2.3 Give examples of functions (e.g., removal of wastes, muscular activity, cell division) that are carried out by organisms and that involve the conversion of ATP to ADP (adenosine diphosphate) and an inorganic phosphate.

LSH-PE.4.2.4 Give examples of chemical reactions (e.g., synthesis of glycogen, oxidation of glucose) involved in basic functions of organisms in which the reactants and products of the reaction are paired with reactions involving ATP and ADP and an inorganic phosphate. Construct an illustration, in terms of reactants and products, of the chemical reactions of basic functions and ATP and ADP with an inorganic phosphate.

*[**BOUNDARY:** The molecular structure of molecules is not appropriate for this PE.]*

LSH-PE.4.2.5 Construct a representation of the transfer of energy through an ecosystem, starting with the Sun and ending with increased motion of molecules in the environment. Representation should reflect the idea that energy is conserved. Explain, based on the transformation of chemical energy to thermal energy at various trophic levels and on the nature of reactions, the need for constant input of energy into an ecosystem.

LSH-PE.4.2.6 Construct a representation that links the movement of matter (i.e., carbon atom, water molecule) and the transfer of energy through the processes of photosynthesis and cellular respiration. Predict and justify, based on knowledge of energy transfer and matter cycling, what might happen to the mass of a biosystem if the source of energy were limited.

LSH-PE.4.2.7 Construct a model of a food chain that includes a quantification of the distribution and buildup of a potentially damaging chemical that is introduced into an ecosystem. Predict, using the model, consequences at each trophic level as the relative concentration of the chemical increases. Justification includes changes in the number of organisms at each trophic level, matter cycling, and energy transfer from one level to another.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Life processes involve a complex sequence of chemical reactions in which chemical energy is transferred from one system of interacting molecules to another. Some of the energy in these reactions is transferred to the environment as thermal energy (heat).

- All living systems require an input of energy to drive the reactions in essential life functions and to compensate for the inefficient transfer of energy. The chemical reactions in living systems involve the transfer of thermal energy (heat) to the environment. The thermal energy is no longer available to drive chemical reactions; therefore, a continuous source of energy is needed. In many organisms, the energy that keeps the chemical reactions in organisms going comes from food that reacts with oxygen. The energy stored in that food ultimately comes from the Sun.

  *[**BOUNDARY:** Students are not expected to know that chemosynthesis is a process that supplies energy for the synthesis of food in an ecosystem.]*

- The transfer of chemical energy within living systems involves chemical reactions among ATP, ADP and an inorganic phosphate. The conversion of ATP to ADP and an inorganic phosphate drives other essential reactions in living systems.

  *[**BOUNDARY:** Students are not required to know the chemical names or the molecular structures of ATP and ADP.]*

- During cellular respiration, molecules from food — mainly sugars and fats — are converted in the presence of oxygen into carbon dioxide and water, and the chemical energy of that reaction is used to combine ADP and an inorganic phosphate to make ATP.

- During fermentation, molecules from food are partially broken down in cells in the absence of oxygen into smaller molecules (but not completely into carbon dioxide and water). Compared to the chemical reactions that take place during cellular respiration, these reactions result in less ADP being combined with an inorganic phosphate to produce ATP; therefore, less energy is made available during fermentation than during cellular respiration for the chemical reactions that maintain an organism's body functions.

Standard LS.5
Information Transmission, Storage and Retrieval

Living systems have multiple mechanisms that are used to store, retrieve and transmit information.

Students understand that living systems have a variety of ways of communicating information among systems and from one part of a system to another. A special kind of information — that which is transmitted by means of DNA — is transmitted from one generation of organism to another during reproduction. The DNA contains information that determines the structure of various molecules that are responsible for many of the physical (abiotic) and behavioral characteristics of organisms.

Objective LS.5.1
Changing Model of Inheritance

Students describe the historic ideas that led to the identification of DNA as the molecule that contains and transmits genetic information.

*[**BOUNDARY:** The dates and names involved in the historic work are not the focus of this objective. Rather, the historical development of the current understanding of genetic information, as well as the understanding of the transfer of this information, is important.]*

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Cell Function (LS.2.1); Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1D, 3A

Note: For Objective LS.5.1, there are no performance expectations or essential knowledge statements for grades 9–12.

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.1.1 Describe the problem or scientific question that various scientists investigated and the scientists' contributions to the development of the model of inheritance toward modern genetics.

*[**BOUNDARY:** It is suggested that students study Mendel, Watson and Crick, and Franklin; students can, but do not have to, study Sutton and Bateson.]*

LSM-PE.5.1.2 Observe patterns (similar to those observed by Mendel), using data from parent–generation crosses, in traits of parents and offspring.

LSM-PE.5.1.3 Give examples of various scientists whose ideas built upon and/or revised Mendel's model of inheritance.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Gregor Mendel demonstrated that the inheritance of physical traits in pea plants follows simple mathematical laws.
- The behavior of chromosomes during the division process of sexual reproduction (meiosis) established a physical basis for Mendel's mathematical laws of heredity.
- It was not until the middle of the 20th century that genes were shown to be segments of DNA. The Watson–Crick double-helix model of DNA structure explained how genes are passed on from one generation to the next.

Objective LS.5.2
Genetic Information Transmission

Students understand that during reproduction, genetic information (DNA) is transmitted between parent and offspring. In asexual reproduction the lone parent contributes DNA to the offspring, and in sexual reproduction both parents contribute DNA to the offspring.

*[**BOUNDARY:** There is an assumption that the mechanisms involved in the transmission of genetic information from DNA to protein to trait are a "black box" for students in grades 6–8. The focus should be that there is a link between DNA and traits without being explicit about the mechanisms involved. Students are not expected to know any of the ways in which bacteria reproduce.]*

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Function (LS.2.1); Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4); [Grades 9–12 only: Imperfect Transmission of Genetic Information (LS.5.4)]
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 1D, 2E, 3A, 3B, 3C, 4A, 4B

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.2.1 Evaluate consistency and accuracy of representations illustrating the major components of the Watson–Crick double-helix model of DNA.

LSM-PE.5.2.2 Construct a representation of DNA replication, showing how the helical DNA molecule unzips and how nucleotide bases pair with the DNA template to form a duplicate of the DNA molecule.

LSM-PE.5.2.3 Construct a representation that shows what happens to the chromosomes of the parent organisms during both the process of fertilization and the first stages of cell division of a zygote.

LSM-PE.5.2.4 Explain and justify, using representations, why the DNA of the daughter cells of asexually reproducing organisms are identical to the DNA of parent cells. Explanation and justification are based on knowledge of the mechanisms (e.g., asexual reproduction, DNA replication) of DNA transmission from generation to generation in asexually reproducing organisms.

LSM-PE.5.2.5 Explain and justify why the DNA of the offspring of sexually reproducing organisms are not identical to the DNA of either parent organism. Explanation and justification are based on knowledge of the mechanisms (e.g., fertilization, cell division) of DNA transfer between generations in sexually reproducing organisms.

LIFE SCIENCE

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- DNA is a long, double-stranded, helical molecule that is the primary source of genetic information. Genetic information is contained within the sequence of nucleotide bases (A, C, T and G are the symbols used to represent these bases) that make up a DNA molecule.
- DNA is the source of genetic information that determines an organism's traits.
- Prior to reproduction, each individual DNA molecule makes a copy of itself. This process ensures that the genetic information is copied into each new organism.
- DNA molecules are packaged and organized as chromosomes within cells. There is a single chromosome in some organisms; there is more than one chromosome in other organisms. Every chromosome has a single molecule of DNA.
- In some organisms, all of the DNA molecules come from a single parent (asexual reproduction).[10] These organisms go through a division process (mitosis) that ensures the direct transfer of the genetic information (DNA) from one generation to another.

10. American Association for the Advancement of Science, *Benchmarks for Science Literacy*, 108.

ESSENTIAL KNOWLEDGE (6–8), *continued*

- Sexual reproduction occurs when two different sex cells combine in a process called fertilization. Since each sex cell contains only half of the normal amount of cellular DNA present in body cells, the single cell (zygote) produced will now have a complete complement of genetic information containing two sets of DNA, one set from each sex cell.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.2.1 Estimate and justify how many variations are possible in the set of chromosomes (DNA molecules) that the sex cells of a particular organism (e.g., mosquito, fruit fly or other organism with a low number of chromosomes) receive during sex cell formation. Construct a model that includes a label for each chromosome and that illustrates some of the possible combinations of chromosomes that will be present in the sex cells that are produced.

LSH-PE.5.2.2 Explain, based on knowledge of how sex cells form in sexually reproducing organisms, why there is variation among offspring, even within the same family.

LSH-PE.5.2.3 Observe the variation of traits among the individual organisms within a population. Explain, based on the transmission of genetic information, why there is so much variation within the population.

LSH-PE.5.2.4 Construct a representation — or several representations — of sex cell formation, demonstrating that the DNA of the daughter cells is different from the DNA of the parent cell. Representation includes the process of replication, the separation of homologous chromosomes (first stage of meiosis), and the separation of the replicated chromosomes to create cells with just a single version of each chromosome (second stage of meiosis).

LSH-PE.5.2.5 Construct a model of a particular gene on a pair of DNA molecules. Construct a new model that incorporates the DNA molecule model into a model of homologous chromosomes in a cell nucleus.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Sex cells are formed by a process of division (meiosis) in which the number of chromosomes, and thus the amount of DNA, per cell is halved after replication.

- With the exception of sex chromosomes, for each DNA molecule (chromosome) in the body cells of a multicellular organism, there is a similar, but not identical, chromosome (homologous pair). Although these pairs of similar chromosomes can carry the same genes, they may have slightly different versions of the genes (alleles). During the formation of sex cells (meiosis), one chromosome from each pair is randomly passed on (independent assortment) to form sex cells, resulting in a multitude of possible genetic combinations.

- The cell produced during fertilization has one “set” of DNA molecules from each parent. The cell (zygote) then divides asexually as the organism grows and develops so that the body cells of the organism have two “sets” of DNA molecules.

Objective LS.5.3
DNA to Trait

Students understand that genetic information (DNA) is used to produce proteins that largely determine the traits of an organism. These traits often result from the interactions and expression of many genes.

> **Suggested Connections**
> *Within Life Science:* Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Structure (LS.2.2); Cell Differentiation (LS.2.4)
>
> *Between Life Science and Other Disciplines:* Bonding (C.1.3)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 1A, 1B, 3A, 3B, 3C, 4A, 4B, 4C

Note: For Objective LS.5.3, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.3.1 Analyze the primary structure (amino acid sequence) of specific proteins (e.g., insulin and hemoglobin). Create a table showing which amino acids make up each protein molecule, and the numbers of each amino acid that make up these proteins.

*[**BOUNDARY:** Emphasis should be placed on the differences among protein composition, NOT on the memorization of amino acid structure, types or sequence.]*

LSH-PE.5.3.2 Evaluate and, if necessary, revise representations that illustrate the processes of transcription and translation to show how the sequence of nucleotide bases produces a complementary strand of bases in RNA (ribonucleic acid), and how each sequence of three bases in RNA codes for specific amino acids that are linked together to make proteins.

*[**BOUNDARY:** Emphasis should be placed on the bigger ideas of form and function and following the transmission of information, not on the details (e.g., components of a ribosome, structure of tRNA, directionality) of the mechanism.]*

LSH-PE.5.3.3 Construct a representation that illustrates the process of the production of the amino acid sequence of a section of a given protein molecule from an organism. Representation should first show the relationship between these amino acids and a sequence of nucleotide bases in RNA, and then show the relationship between that sequence of nucleotide bases in RNA and the sequence of bases in DNA.

LSH-PE.5.3.4 Give examples, using information gathered from print and electronic resources, of traits that result from specific proteins. Include examples of the following types of proteins: structural, regulatory and enzymatic. Examples should span structural, behavioral and physiological traits.

*[**BOUNDARY:** This performance expectation is intended to focus on the fact that proteins in the form of enzymes determine traits, not on the details of the cascade of reactions or the chemical structures involved.]*

LSH-PE.5.3.5 Describe how traits in organisms are the result of DNA structure. Include ideas about the connection between traits and proteins, the connection between protein structure and the sequence of bases in RNA, and the connection between RNA sequence and DNA sequence.

LSH-PE.5.3.6 Give examples, using information gathered from print and electronic resources, of traits that depend on the quantity of protein produced, which, in turn, is dependent on the number of copies of a particular version of a gene. Predict and justify how zero, one or two copies of a particular version of a gene might affect the expression of a particular trait.

*[**BOUNDARY:** Emphasis should not be placed on the mechanisms of gene expression, the cascade of reactions, or any specific details of mechanisms. The amount of protein produced also depends on the type of promoter and the rate of synthesis, but these concepts are not within the scope of the 9–12 grade band.]*

LSH-PE.5.3.7 Identify functions performed by DNA segments that do not code for proteins.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Genes are segments of DNA that are in locatable regions on the DNA molecules that specify protein sequence and, in turn, an organism's traits.
- Not all DNA segments specify proteins; some segments of DNA are involved in regulation or structural functions. Some segments of DNA have no known function.
- The protein information contained in the sequence of nucleotide bases that makes up a strand of DNA is transmitted to a messenger RNA molecule (transcription). The messenger RNA molecule, with the help of other RNA molecules (ribosomal and transfer), then guides the production of a specific amino acid sequence of a particular protein (translation). These messenger RNA molecules degrade into nucleotide bases, which are then recycled into new RNA.

  *[**BOUNDARY:** In order for this statement to be accurate, the following concepts must be understood: Not all DNA is transcribed, and not all RNA is translated. However, this is not essential knowledge for the student.]*
- Proteins are long, folded chains (polymers) composed of 20 different amino acids (monomers). Amino acid sequence determines the shape and function of the protein molecule that is produced.
- Protein molecules are responsible for the observable traits of an organism and for most of the life functions that take place within an organism. The enzymes that catalyze chemical reactions in organisms are proteins.
- Traits (phenotype) can be structural, physiological or behavioral; they can include readily observable features at the organism level as well as less observable features at the cellular and molecular levels.
- Sexually reproducing organisms contain two similar, but not identical, versions of each chromosome (i.e., the chromosomes have some genes [alleles] that are the same on both versions of the chromosome and some that are not). Each trait that results from these different gene combinations depends on the nature and amount of the protein that each gene produces, as well as on the interactions among those proteins.

Objective LS.5.4
Imperfect Transmission of Genetic Information

Students understand that there are various ways in which the transmission of genetic information can be imperfect, and that these imperfections may have positive, negative or no consequences to the organism.

Suggested Connections
Within Life Science: Evidence of Common Ancestry and Divergence (LS.1.1); Natural Selection (LS.1.2); Genetic Variation Within Populations (LS.1.3); Cell Growth and Repair (LS.2.3); Genetic Information Transmission (LS.5.2)

Prepares students for the following AP Enduring Understandings: AP Biology 1A, 1B, 1C, 3A, 3B, 3C, 4B, 4C

PERFORMANCE EXPECTATIONS (6–8)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSM-PE.5.4.1 Describe three ways (e.g., insertion, deletion or substitution) that changes in DNA (mutations) can occur during replication.

LSM-PE.5.4.2 Predict and justify, based on the type of cell, whether a particular error in copying DNA during replication will be transmitted to the offspring.

ESSENTIAL KNOWLEDGE (6–8)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- DNA is transmitted from one generation to the next during both sexual and asexual reproduction. However, mistakes that involve changes in the sequence of nucleotide bases (mutations) may occur during DNA replication or during the division process. These changes can be transmitted to the offspring, depending on the organism and cell type.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.4.1 Explain why an insertion, deletion or substitution of an individual nucleotide base affects not only the amino acid sequence of the proteins that are produced but also the protein structure that results from the altered amino acid sequence.

LSH-PE.5.4.2 Explain, using information on a particular error in copying DNA during replication for a specific trait (e.g., insertion, deletion or substitution), why there could be an alteration in that trait. Justification is based on knowledge of the relationship among DNA, proteins and traits.

LSH-PE.5.4.3 Give examples, using evidence gathered from print and electronic resources, of genetic diseases (e.g., cystic fibrosis, sickle-cell anemia, Tay-Sachs disease or phenylketonuria) that result from mutations to a single gene. Identify, for each example, the specific type of mutation that causes the change in amino acid sequence and ultimately the change in the protein that is produced.

LSH-PE.5.4.4 Give examples, using evidence gathered from print and electronic resources, of instances when viruses are linked to cancer. Explain, based on knowledge of viral gene insertions and of the relationship among DNA, proteins and traits, how a viral insertion into DNA can cause cancer.

LSH-PE.5.4.5 Give examples, using evidence gathered from print and electronic resources, of the potential of using viruses for curing genetic diseases via gene therapy. Make a claim about, and justify, based on knowledge of viral DNA and viral insertions, why some viruses are appropriate for this application.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Mutations involve changes to an organism's DNA and may be caused by internal factors (i.e., errors that occur during DNA replication or the division process) or by external factors (i.e., radiation or chemicals). Mutations may occur at the individual gene level or at the chromosomal level, but all mutations involve changes to DNA.

- Mutations may cause no change in an organism's traits (phenotype), cause a detrimental change or cause a beneficial change.

- Mutations that alter the sequence of DNA may lead to a change in the protein produced. Changes to any of the proteins responsible for traits may result in an alternative trait (phenotype).

- Not everything that carries genetic information is a cell. A virus, which is not a cell, contains either DNA or RNA as its genetic information. To reproduce, a virus uses its own DNA or RNA but also uses the cellular machinery of the host cell. Often, the viral genes are incorporated into the host DNA or RNA, disrupting the DNA sequence within the host cell.

Objective LS.5.5
Nongenetic Information Transmission

Students understand that nongenetic transmission of information within and among organisms involves specialized molecules, cell structures and cell systems.

[***BOUNDARY:*** *Only very basic models (e.g., single receptor and single transmitter) and a very basic distinction between direct communication and distance communication via molecules are necessary. Focus should be on the basic input/output regulation of a system; model of communication or feedback should be very simple (e.g., few steps and a small number of molecules involved in the mechanism).]*

> **Suggested Connections**
> *Within Life Science:* Cell Function (LS.2.1); Cell Structure (LS.2.2); [Grades 9–12 only: Cell Growth and Repair (LS.2.3); Cell Differentiation (LS.2.4); DNA to Trait (LS.5.3)]
>
> *Between Life Science and Other Disciplines:* Structure–Property Relationships (C.2.2); Chemical Kinetics (C.2.5)
>
> *Prepares students for the following AP Enduring Understandings:* AP Biology 2B, 2C, 3B, 3D, 3E, 4A, 4B

<u>Note</u>: For Objective LS.5.5, there are no performance expectations or essential knowledge statements for grades 6–8.

PERFORMANCE EXPECTATIONS (9–12)

Ways in which students know and use, as well as engage with, the essential knowledge in order to understand, or enhance their understanding of, the objective:

LSH-PE.5.5.1 Construct a model that represents the molecular communication that takes place between cells that are in direct cell-to-cell contact, and a model that represents the molecular communication among cells in which molecules are released from one cell and target other cells in the vicinity of the emitting cell (e.g., neurotransmitters, local hormones, growth factors).

LSH-PE.5.5.2 Construct a model to describe the communication between distant cells (e.g., hormones, pheromones, chemotaxis) and the process by which molecular communication between distant cells leads to particular outcomes.

LSH-PE.5.5.3 Evaluate and, if necessary, revise representations of how drugs such as alcohol, nicotine, morphine, tetrahydrocannabinol (THC) and methamphetamines affect neurotransmitters and the communication that normally takes place between and/or among cells.

LSH-PE.5.5.4 Construct a simple representation of a feedback mechanism that maintains the internal conditions of a living system within certain limits as the external conditions change. Describe, using the representation, the response of the system to some particular system imbalance (e.g., lack of water causing stomata to contract).

LSH-PE.5.5.5 Construct a representation of the interaction of the endocrine and nervous systems (e.g., hormones and electrochemical impulses) as they interact with other body systems to respond to a change in the environment (e.g., touching a hot stove). Explain how the representation is like and unlike the phenomenon it is representing.

ESSENTIAL KNOWLEDGE (9–12)

Students apply, as well as engage and reason with, the following concepts in the performance expectations:

- Communication takes place at the molecular level by means of specialized molecules that send and receive information.
- Molecular communication takes place when molecules from one cell interact with molecules from other cells; these interactions often take place with the help of proteins in the cell membrane.
- There are systems (e.g., endocrine and nervous [sensory]) within and between organisms that send, receive and process information over short and long distances by using specialized molecules.
- The output of one system can be the input to another system. Molecules produced in one system can encourage or discourage what is going on in another system.

ESSENTIAL KNOWLEDGE (9–12), *continued*

- Feedback communication maintains a living system's internal conditions within certain limits (e.g., temperature, molecular concentration, pH), allowing it to remain alive and functional even as external conditions are changing.
- Feedback systems may involve enzymes, membrane proteins and/or gene regulators, and their communication can be affected by environmental conditions.
- Many drugs affect the normal communication among cells by interacting with or altering the proteins in the cell's membranes, or by altering the molecule that is transmitting information.

Unpacking the Performance Expectations: Life Science

Why "unpack" a performance expectation?

- The science practices standards appear to be separate from the discipline-specific standards, but they are intended to be integrated with disciplinary content knowledge.
- Unpacking a performance expectation establishes clear, specific targets of learning.
- Unpacking a performance expectation illustrates that any one performance expectation may involve multiple science practices.
- The unpacking is intended to provide a model for interpreting the science practices for a specific discipline.

How should an unpacked performance expectation be used?

- The sample unpacked performance expectation provided should be used as a model so that teachers can unpack all of the performance expectations within the discipline-specific standards.
- All of the unpacked performance expectations can be used for guidance in developing instructional strategies and curricula that offer opportunities for students to develop a robust understanding of the science practices and disciplinary content knowledge.
- All of the unpacked performance expectations can be used to develop curricula, instruction and assessments that are aligned with each other.
- Unpacking all of the performance expectations within a specific discipline enables teachers and curriculum supervisors to delineate the multiple science practices and content knowledge that are facilitated, and ultimately to link or map the performance expectations to existing curricula or to use the performance expectations as a basis for the establishment of curricular structure.
- All of the unpacked performance expectations allow decisions about instruction and curriculum design to be made in a more principled way.

SAMPLE UNPACKED PERFORMANCE EXPECTATION (6–8)

Construct an analogical model (analogy) of the interaction of the internal components of a cell (e.g., working parts of a city, factory or automobile. Predict and justify, using the model, the impact on the cell or on the organism if one of the components fails to function properly.

This is **LSM-PE.2.2.2**. The two components should be performed together.

This is part of science practices **Objective SP.4.2**.

Unpacking the construction of an analogy in the performance expectation:

- Describe the phenomenon to be modeled (i.e., the components of a cell system interact for the greater good of an organism).
- Identify the purpose for constructing the analogy (to make a prediction), and identify the key components of interactions within a cell system that must be present in the representation to meet the purpose of making a prediction about the failure of a cellular component.
- Select an analogy (e.g., cell as a city or factory) that best represents the phenomenon, and articulate how the analogy best fits the phenomenon of cell system interactions as well as the purpose of making a prediction about the failure of a cellular component.
- Ensure that the key components (e.g., appropriate subcellular structures) and processes (e.g., protein synthesis, lysosome waste removal) of the phenomenon are represented in the selected analogy.

The **essential knowledge from the science practices** informed these interrelated activities associated with constructing an analogy.

Unpacking the prediction in the performance expectation:

This is science practices **Objective SP.1.2**.

- Select from the key components of the phenomenon which one is going to fail.
- Predict the effect on the cell if the cellular component fails, or predict the effect on the organism if the cellular component fails.

Unpacking the justification of the prediction in the performance expectation:

Including a **justification with all predictions** demonstrates students' thought patterns as they make their predictions.

- Connect the failed component to the outcome of the cell or the organism.
- Support the justification by articulating the connection between the terms of the analogy to the actual function of the component of the cell.
- Describe how the key elements of the analogy and the cell are similar.
- Describe how the analogy and the actual function are inaccurate.