**DISCIPLINARY CORE IDEAS—LIFE SCIENCES**

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**Core Idea LS1** **From Molecules to Organisms: Structures and Processes**

*How do organisms live, grow, respond to their environment, and reproduce?*

All living organisms are made of cells. Life is the quality that distinguishes living

things—composed of living cells—from nonliving objects or those that have died.

While a simple definition of life can be difficult to capture, all living things—that

is to say all organisms—can be characterized by common aspects of their structure

and functioning. Organisms are complex, organized, and built on a hierarchical

structure, with each level providing the foundation for the next, from the chemical

foundation of elements and atoms, to the cells and systems of individual organisms,

to species and populations living and interacting in complex ecosystems.

Organisms can be made of a single cell or millions of cells working together and

include animals, plants, algae, fungi, bacteria, and all other microorganisms.

Organisms respond to stimuli from their environment and actively maintain

their internal environment through homeostasis. They grow and reproduce, transferring

their genetic information to their offspring. While individual organisms

carry the same genetic information over their lifetime, mutation and the transfer

from parent to offspring produce new combinations of genes. Over generations

natural selection can lead to changes in a species overall; hence, species evolve

over time. To maintain all of these processes and functions, organisms require

materials and energy from their environment; nearly all energy that sustains life

ultimately comes from the sun.

**LS1.A: STRUCTURE AND FUNCTION**

*How do the structures of organisms enable life’s functions?*

A central feature of life is that organisms grow, reproduce, and die. They have characteristic structures (anatomy and morphology), functions (molecular-scale processes to organism-level physiology), and behaviors (neurobiology and, for some animal species, psychology). Organisms and their parts are made of cells, which are the structural units of life and which themselves have molecular substructures that support their functioning.

Organisms range in composition from a single cell (unicellular microorganisms) to multicellular organisms, in which different groups of large numbers of cells work together to form systems of tissues and organs (e.g., circulatory, respiratory, nervous, musculoskeletal), that are specialized for particular functions.

Special structures *within* cells are also responsible for specific cellular functions. The essential functions of a cell involve chemical reactions between many types of molecules, including water, proteins, carbohydrates, lipids, and nucleic acids. All cells contain genetic information, in the form of DNA. Genes are specific regions within the extremely large DNA molecules that form the chromosomes.

Genes contain the instructions that code for the formation of molecules called proteins, which carry out most of the work of cells to perform the essential functions of life. That is, proteins provide structural components, serve as signaling devices, regulate cell activities, and determine the performance of cells through their enzymatic actions.

*Grade Band Endpoints for LS1.A*

***By the end of grade 2*.** All organisms have external parts. Different animals use

their body parts in different ways to see, hear, grasp objects, protect themselves,

move from place to place, and seek, find, and take in food, water and air. Plants

also have different parts (roots, stems, leaves, flowers, fruits) that help them survive,

grow, and produce more plants.

***By the end of grade 5*.** Plants and animals have both internal and external structures

that serve various functions in growth, survival, behavior, and reproduction.

(Boundary: Stress at this grade level is on understanding the macroscale systems

and their function, not microscopic processes.)

***By the end of grade 8.*** All living things are made up of cells, which is the smallest

unit that can be said to be alive. An organism may consist of one single cell (unicellular)

or many different numbers and types of cells (multicellular). Unicellular

organisms (microorganisms), like multicellular organisms, need food, water, a way

to dispose of waste, and an environment in which they can live.

Within cells, special structures are responsible for particular functions, and

the cell membrane forms the boundary that controls what enters and leaves the

cell. In multicellular organisms, the body is a system of multiple interacting subsystems.

These subsystems are groups of cells that work together to form tissues

or organs that are specialized for particular body functions. (Boundary: At this

grade level, only a few major cell structures should be introduced.)

***By the end of grade 12*.** Systems of specialized cells within organisms help them

perform the essential functions of life, which involve chemical reactions that take

place between different types of molecules, such as water, proteins, carbohydrates,

lipids, and nucleic acids. All cells contain genetic information in the form of DNA

molecules. Genes are regions in the DNA that contain the instructions that code

for the formation of proteins, which carry out most of the work of cells.

Multicellular organisms have a hierarchical structural organization, in which

any one system is made up of numerous parts and is itself a component of the

next level. Feedback mechanisms maintain a living system’s internal conditions

within certain limits and mediate behaviors, allowing it to remain alive and functional

even as external conditions change within some range. Outside that range

(e.g., at a too high or too low external temperature, with too little food or water

available), the organism cannot survive. Feedback mechanisms can encourage

(through positive feedback) or discourage (negative feedback) what is going on

inside the living system.

**LS1.B: GROWTH AND DEVELOPMENT OF ORGANISMS**

*How do organisms grow and develop*?

The characteristic structures, functions, and behaviors of organisms change in

predictable ways as they progress from birth to old age. For example, upon reaching

adulthood, organisms can reproduce and transfer their genetic information to

their offspring. Animals engage in behaviors that increase their chances for reproduction,

and plants may develop specialized structures and/or depend on animal

behavior to accomplish reproduction.

Understanding how a single cell can give rise to a complex, multicellular

organism builds on the concepts of cell division and gene expression. In multicellular

organisms, cell division is an essential component of growth, development,

and repair. Cell division occurs via a process called mitosis: when a cell divides in

two, it passes identical genetic material to two daughter cells. Successive divisions

produce many cells. Although the genetic material in each of the cells is identical,

small differences in the immediate environments activate or inactivate different

genes, which can cause the cells to develop slightly differently. This process of

differentiation allows the body to form specialized cells that perform diverse functions,

even though they are all descended from a single cell, the fertilized egg. Cell

growth and differentiation are the mechanisms by which a fertilized egg develops

into a complex organism. In sexual reproduction, a specialized type of cell division

called meiosis occurs and results in the production of sex cells, such as gametes

(sperm and eggs) or spores, which contain only one member from each chromosome

pair in the parent cell.

*Grade Band Endpoints for LS1.B*

***By the end of grade 2*.** Plants and animals have predictable characteristics at different

stages of development. Plants and animals grow and change. Adult plants

and animals can have young. In many kinds of animals, parents and the offspring

themselves engage in behaviors that help the offspring to survive.

***By the end of grade 5*.** Reproduction is essential to the continued existence of

every kind of organism. Plants and animals have unique and diverse life cycles

that include being born (sprouting in plants), growing, developing into adults,

reproducing, and eventually dying.

***By the end of grade 8.*** Organisms reproduce, either sexually or asexually, and transfer their genetic information to their offspring. Animals engage in characteristic behaviors that increase the odds of reproduction. Plants reproduce in a variety of ways, sometimes depending on animal behavior and specialized features (such as attractively colored flowers) for reproduction. Plant growth can continue throughout the plant’s life through production of plant matter in photosynthesis. Genetic factors as well as local conditions affect the size of the adult plant. The growth of an animal is controlled by genetic factors, food intake, and interactions with other organisms, and each species has a typical adult size range. (Boundary: Reproduction is not treated in any detail here; for more specifics about grade level, see LS3.A.)

***By the end of grade 12*.** In multicellular organisms individual cells grow and then

divide via a process called mitosis, thereby allowing the organism to grow. The

organism begins as a single cell (fertilized egg) that divides successively to produce

many cells, with each parent cell passing identical genetic material (two variants

of each chromosome pair) to both daughter cells. As successive subdivisions of

an embryo’s cells occur, programmed genetic instructions and small differences

in their immediate environments activate or inactivate different genes, which

cause the cells to develop differently—a process called differentiation. Cellular

division and differentiation produce and maintain a complex organism, composed

of systems of tissues and organs that work together to meet the needs of

the whole organism. In sexual reproduction, a specialized type of cell division

called meiosis occurs that results in the production of sex cells, such as gametes

in animals (sperm and eggs), which contain only one member from each chromosome

pair in the parent cell.

**LS1.C: ORGANIZATION FOR MATTER AND ENERGY FLOW IN ORGANISMS**

*How do organisms obtain and use the matter and energy they need to live and grow?*

Sustaining life requires substantial energy and matter inputs. The complex structural

organization of organisms accommodates the capture, transformation, transport,

release, and elimination of the matter and energy needed to sustain them.

As matter and energy flow through different organizational levels—cells, tissues,

organs, organisms, populations, communities, and ecosystems—of living systems,

chemical elements are recombined in different ways to form different products.

The result of these chemical reactions is that energy is transferred from one system

of interacting molecules to another.

In most cases, the energy needed for life is ultimately derived from the sun

through photosynthesis (although in some ecologically important cases, energy is

derived from reactions involving inorganic chemicals in the absence of sunlight—

e.g., chemosynthesis). Plants, algae (including phytoplankton), and other energyfixing

microorganisms use sunlight, water, and carbon dioxide to facilitate photosynthesis,

which stores energy, forms plant matter, releases oxygen, and maintains

plants’ activities. Plants and algae—being the resource base for animals, the animals

that feed on animals, and the decomposers—are energy-fixing organisms that

sustain the rest of the food web.

*Grade Band Endpoints for LS1.C*

***By the end of grade 2*.** All animals need food in order to live and grow. They

obtain their food from plants or from other animals. Plants need water and light

to live and grow.

***By the end of grade 5*.** Animals and plants alike generally need to take in air and

water, animals must take in food, and plants need light and minerals; anaerobic

life, such as bacteria in the gut, functions without air. Food provides animals with

the materials they need for body repair and growth and is digested to release the

energy they need to maintain body warmth and for motion. Plants acquire their

material for growth chiefly from air and water and process matter they have

formed to maintain their internal conditions (e.g., at night).

***By the end of grade 8*.** Plants, algae (including phytoplankton), and many microorganisms

use the energy from light to make sugars (food) from carbon dioxide

from the atmosphere and water through the process of photosynthesis, which also

releases oxygen. These sugars can be used immediately or stored for growth or

later use. Animals obtain food from eating plants or eating other animals. Within

individual organisms, food moves through a series of chemical reactions in which

it is broken down and rearranged to form new molecules, to support growth,

or to release energy. In most animals and plants, oxygen reacts with carbon-containing

molecules (sugars) to provide energy and produce carbon dioxide;

anaerobic bacteria achieve their energy needs in other chemical processes that do

not require oxygen.

***By the end of grade 12*.** The process of photosynthesis converts light energy to

stored chemical energy by converting carbon dioxide plus water into sugars plus

released oxygen. The sugar molecules thus formed contain carbon, hydrogen,

and oxygen; their hydrocarbon backbones are used to make amino acids and

other carbon-based molecules that can be assembled into larger molecules (such

as proteins or DNA), used for example to form new cells. As matter and energy

flow through different organizational levels of living systems, chemical elements

are recombined in different ways to form different products. As a result of these

chemical reactions, energy is transferred from one system of interacting molecules

to another. For example, aerobic (in the presence of oxygen) cellular respiration

is a chemical process in which the bonds of food molecules and oxygen molecules

are broken and new compounds are formed that can transport energy to muscles.

Anaerobic (without oxygen) cellular respiration follows a different and less efficient

chemical pathway to provide energy in cells. Cellular respiration also releases

the energy needed to maintain body temperature despite ongoing energy loss to

the surrounding environment. Matter and energy are conserved in each change.

This is true of all biological systems, from individual cells to ecosystems.

**LS1.D: INFORMATION PROCESSING**

*How do organisms detect, process, and use information about the environment?*

An organism’s ability to sense and respond to its environment enhances its chance

of surviving and reproducing. Animals have external and internal sensory receptors

that detect different kinds of information, and they use internal mechanisms

for processing and storing it. Each receptor can respond to different inputs (electromagnetic,

mechanical, chemical), some receptors respond by transmitting impulses that travel along nerve cells. In complex organisms, most such inputs travel to the brain, which is divided into several distinct regions and circuits that serve primary roles, in particular functions such as visual perception, auditory perception,

interpretation of perceptual information, guidance of motor movement, and decision making. In addition, some of the brain’s circuits give rise to emotions and store memories. Brain function also involves multiple interactions between the various regions to form an integrated sense of self and the surrounding world.

*Grade Band Endpoints for LS1.D*

***By the end of grade 2.*** Animals have body parts that capture and convey different

kinds of information needed for growth and survival—for example, eyes for light,

ears for sounds, and skin for temperature or touch. Animals respond to these

inputs with behaviors that help them survive (e.g., find food, run from a predator).

Plants also respond to some external inputs (e.g., turn leaves toward the sun).

***By the end of grade 5*.** Different sense receptors are specialized for particular

kinds of information, which may then be processed and integrated by an animal’s

brain, with some information stored as memories. Animals are able to use their

perceptions and memories to guide their actions. Some responses to information

are instinctive—that is, animals’ brains are organized so that they do not have to

think about how to respond to certain stimuli.

***By the end of grade 8.*** Each sense receptor responds to different inputs (electromagnetic,

mechanical, chemical), transmitting them as signals that travel along

nerve cells to the brain. The signals are then processed in the brain, resulting in

immediate behaviors or memories. Changes in the structure and functioning of

many millions of interconnected nerve cells allow combined inputs to be stored as

memories for long periods of time.

***By the end of grade 12.*** In complex animals, the brain is divided into several distinct

regions and circuits, each of which primarily serves dedicated functions, such

as visual perception, auditory perception, interpretation of perceptual information,

guidance of motor movement, and decision making about actions to take in the

event of certain inputs. In addition, some circuits give rise to emotions and memories

that motivate organisms to seek rewards, avoid punishments, develop fears, or

form attachments to members of their own species and, in some cases, to individuals

of other species (e.g., mixed herds of mammals, mixed flocks of birds). The

integrated functioning of all parts of the brain is important for successful interpretation

of inputs and generation of behaviors in response to them.

**Core Idea LS2 Ecosystems: Interactions, Energy, and Dynamics**

*How and why do organisms interact with their environment and what are the*

*effects of these interactions?*

Ecosystems are complex, interactive systems that include both biological communities

(biotic) and physical (abiotic) components of the environment. As with

individual organisms, a hierarchal structure exists; groups of the same organisms

(species) form populations, different populations interact to form communities,

communities live within an ecosystem, and all of the ecosystems on Earth make

up the biosphere. Organisms grow, reproduce, and perpetuate their species by

obtaining necessary resources through interdependent relationships with other

organisms and the physical environment. These same interactions can facilitate or

restrain growth and enhance or limit the size of populations, maintaining the balance

between available resources and those who consume them. These interactions

can also change both biotic and abiotic characteristics of the environment. Like

individual organisms, ecosystems are sustained by the continuous flow of energy,

originating primarily from the sun, and the recycling of matter and nutrients

within the system. Ecosystems are dynamic, experiencing shifts in population composition

and abundance and changes in the physical environment over time, which

ultimately affects the stability and resilience of the entire system.

**LS2.A: INTERDEPENDENT RELATIONSHIPS IN ECOSYSTEMS**

*How do organisms interact with the living and nonliving environments to obtain*

*matter and energy?*

Ecosystems are ever changing because of the interdependence of organisms of the

same or different species and the nonliving (physical) elements of the environment.

Seeking matter and energy resources to sustain life, organisms in an ecosystem

interact with one another in complex feeding hierarchies of producers, consumers,

and decomposers, which together represent a food web. Interactions between organisms may be predatory, competitive, or mutually beneficial. Ecosystems have carrying capacities that limit the number of organisms (within populations) they can support.

Individual survival and population sizes depend on such factors as predation, disease, availability of resources, and parameters of the physical environment. Organisms rely on physical factors, such as light, temperature, water, soil, and space for shelter and reproduction. Earth’s varied combinations of these factors provide the physical environments in which its ecosystems (e.g., deserts, grasslands, rain forests, and coral reefs) develop and in which the diverse species of the planet live. Within any one ecosystem, the biotic interactions between organisms (e.g., competition, predation, and various types of facilitation, such as pollination) further influence their growth, survival, and reproduction, both individually and in terms of their populations.

*Grade Band Endpoints for LS2.A*

***By the end of grade 2*.** Animals depend on their surroundings to get what they

need, including food, water, shelter, and a favorable temperature. Animals depend

on plants or other animals for food. They use their senses to find food and water,

and they use their body parts to gather, catch, eat, and chew the food. Plants

depend on air, water, minerals (in the soil), and light to grow. Animals can move

around, but plants cannot, and they often depend on animals for pollination or

to move their seeds around. Different plants survive better in different settings

because they have varied needs for water, minerals, and sunlight.

***By the end of grade 5*.** The food of almost any kind of animal can be traced back

to plants. Organisms are related in food webs in which some animals eat plants

for food and other animals eat the animals that eat plants. Either way, they are

“consumers.” Some organisms, such as fungi and bacteria, break down dead

organisms (both plants or plants parts and animals) and therefore operate as

“decomposers.” Decomposition eventually restores (recycles) some materials back

to the soil for plants to use. Organisms can survive only in environments in which

their particular needs are met. A healthy ecosystem is one in which multiple species

of different types are each able to meet their needs in a relatively stable web

of life. Newly introduced species can damage the balance of an ecosystem.

***By the end of grade 8.*** Organisms and populations of organisms are dependent on

their environmental interactions both with other living things and with nonliving

factors. Growth of organisms and population increases are limited by access to

resources. In any ecosystem, organisms and populations with similar requirements

for food, water, oxygen, or other resources may compete with each other for limited

resources, access to which consequently constrains their growth and reproduction.

Similarly, predatory interactions may reduce the number of organisms

or eliminate whole populations of organisms. Mutually beneficial interactions, in

contrast, may become so interdependent that each organism requires the other for

survival. Although the species involved in these competitive, predatory, and mutually

beneficial interactions vary across ecosystems, the patterns of interactions of

organisms with their environments, both living and nonliving, are shared.

***By the end of grade 12*.** Ecosystems have carrying capacities, which are limits to

the numbers of organisms and populations they can support. These limits result

from such factors as the availability of living and nonliving resources and from

such challenges as predation, competition, and disease. Organisms would have the

capacity to produce populations of great size were it not for the fact that environments

and resources are finite. This fundamental tension affects the abundance

(number of individuals) of species in any given ecosystem.

**LS2.B: CYCLES OF MATTER AND ENERGY TRANSFER IN ECOSYSTEMS**

*How do matter and energy move through an ecosystem?*

The cycling of matter and the flow of energy within ecosystems occur through

interactions among different organisms and between organisms and the physical

environment. All living systems need matter and energy. Matter fuels the energy-releasing

chemical reactions that provide energy for life functions and provides the

material for growth and repair of tissue. Energy from light is needed for plants

because the chemical reaction that produces plant matter from air and water

requires an energy input to occur. Animals acquire matter from food, that is, from

plants or other animals. The chemical elements that make up the molecules of

organisms pass through food webs and the environment and are combined and

recombined in different ways. At each level in a food web, some matter provides

energy for life functions, some is stored in newly made structures, and much is discarded

to the surrounding environment. Only a small fraction of the matter consumed

at one level is captured by the next level up. As matter cycles and energy

flows through living systems and between living systems and the physical environment,

matter and energy are conserved in each change.

The carbon cycle provides an example of matter cycling and energy flow in

ecosystems. Photosynthesis, digestion of plant matter, respiration, and decomposition

are important components of the carbon cycle, in which carbon is exchanged

between the biosphere, atmosphere, oceans, and geosphere through chemical,

physical, geological, and biological processes.

*Grade Band Endpoints for LS2.B*

***By the end of grade 2*.** Organisms obtain the materials they need to grow and survive

from the environment. Many of these materials come from organisms and are

used again by other organisms.

***By the end of grade 5***. Matter cycles between the air and soil and among plants,

animals, and microbes as these organisms live and die. Organisms obtain gases,

water, and minerals from the environment and release waste matter (gas, liquid, or

solid) back into the environment.

***By the end of grade 8*.** Food webs are models that demonstrate how matter and

energy is transferred between producers (generally plants and other organisms

that engage in photosynthesis), consumers, and decomposers as the three groups

interact—primarily for food—within an ecosystem. Transfers of matter into and

out of the physical environment occur at every level—for example, when molecules

from food react with oxygen captured from the environment, the carbon

dioxide and water thus produced are transferred back to the environment, and

ultimately so are waste products, such as fecal material. Decomposers recycle

nutrients from dead plant or animal matter back to the soil in terrestrial environments

or to the water in aquatic environments. The atoms that make up the

organisms in an ecosystem are cycled repeatedly between the living and nonliving

parts of the ecosystem.

***By the end of grade 12*.** Photosynthesis and cellular respiration (including anaerobic

processes) provide most of the energy for life processes. Plants or algae

form the lowest level of the food web. At each link upward in a food web,

only a small fraction of the matter consumed at the lower level is transferred

upward, to produce growth and release energy in cellular respiration at the

higher level. Given this inefficiency, there are generally fewer organisms at higher

levels of a food web, and there is a limit to the number of organisms that an

ecosystem can sustain.

The chemical elements that make up the molecules of organisms pass

through food webs and into and out of the atmosphere and soil and are combined

and recombined in different ways. At each link in an ecosystem, matter

and energy are conserved; some matter reacts to release energy for life functions,

some matter is stored in newly made structures, and much is discarded.

Competition among species is ultimately competition for the matter and energy

needed for life.

Photosynthesis and cellular respiration are important components of the carbon

cycle, in which carbon is exchanged between the biosphere, atmosphere, oceans,

and geosphere through chemical, physical, geological, and biological processes.

**LS2.C: ECOSYSTEM DYNAMICS, FUNCTIONING, AND RESILIENCE**

*What happens to ecosystems when the environment changes?*

Ecosystems are dynamic in nature; their characteristics fluctuate over time,

depending on changes in the environment and in the populations of various species.

Disruptions in the physical and biological components of an ecosystem—

which can lead to shifts in the types and numbers of the ecosystem’s organisms,

to the maintenance or the extinction of species, to the migration of species into

or out of the region, or to the formation of new species (speciation)—occur for a

variety of natural reasons. Changes may derive from the fall of canopy trees in a

forest, for example, or from cataclysmic events, such as volcanic eruptions. But

many changes are induced by human activity, such as resource extraction, adverse

land use patterns, pollution, introduction of nonnative species, and global climate

change. Extinction of species or evolution of new species may occur in response to

significant ecosystem disruptions.

Species in an environment develop behavioral and physiological patterns

that facilitate their survival under the prevailing conditions, but these patterns may

be maladapted when conditions change or new species are introduced. Ecosystems

with a wide variety of species—that is, greater biodiversity—tend to be more resilient

to change than those with few species.

*Grade Band Endpoints for LS2.C*

***By the end of grade 2*.** The places where plants and animals live often change,

sometimes slowly and sometimes rapidly. When animals and plants get too hot

or too cold, they may die. If they cannot find enough food, water, or air, they

may die.

***By the end of grade 5*.** When the environment changes in ways that affect a place’s

physical characteristics, temperature, or availability of resources, some organisms

survive and reproduce, others move to new locations, yet others move into the

transformed environment, and some die.

***By the end of grade 8*.** Ecosystems are dynamic in nature; their characteristics can

vary over time. Disruptions to any physical or biological component of an ecosystem

can lead to shifts in all of its populations.

Biodiversity describes the variety of species found in Earth’s terrestrial and

oceanic ecosystems. The completeness or integrity of an ecosystem’s biodiversity is

often used as a measure of its health.

***By the end of grade 12*.** A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability. Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

**LS2.D: SOCIAL INTERACTIONS AND GROUP BEHAVIOR**

*How do organisms interact in groups so as to benefit individuals?*

Group behaviors are found in organisms ranging from unicellular slime molds to

ants to primates, including humans. Many species, with a strong drive for social

affiliation, live in groups formed on the basis of genetic relatedness, physical proximity,

or other recognition mechanisms (which may be species specific). Group

behavior evolved because group membership can increase the chances of survival

for individuals and their relatives. While some groups are stable over long periods

of time, others are fluid, with members moving in and out. Groups often dissolve

if their size or operation becomes counterproductive, if dominant members lose

their place, or if other key members are removed from the group. Group interdependence

is so strong that animals that usually live in groups suffer, behaviorally

as well as physiologically, when reared in isolation, even if all of their physical

needs are met.

*Grade Band Endpoints for LS2.D*

***By the end of grade 2*.** Being part of a group helps animals obtain food, defend

themselves, and cope with changes. Groups may serve different functions and vary

dramatically in size.

***By the end of grade 5*.** Groups can be collections of equal individuals, hierarchies

with dominant members, small families, groups of single or mixed gender, or

groups composed of individuals similar in age. Some groups are stable over long

periods of time; others are fluid, with members moving in and out. Some groups

assign specialized tasks to each member; in others, all members perform the same

or a similar range of functions.

***By the end of grade 8.*** Groups may form because of genetic relatedness, physical

proximity, or other recognition mechanisms (which may be species specific).

They engage in a variety of signaling behaviors to maintain the group’s integrity

or to warn of threats. Groups often dissolve if they no longer function to

meet individuals’ needs, if dominant members lose their place, or if other key

members are removed from the group through death, predation, or exclusion by

other members.

***By the end of grade 12*.** Animals, including humans, having a strong drive for

social affiliation with members of their own species and will suffer, behaviorally

as well as physiologically, if reared in isolation, even if all of their physical

needs are met. Some forms of affiliation arise from the bonds between offspring

and parents. Other groups form among peers. Group behavior has evolved

because membership can increase the chances of survival for individuals and

their genetic relatives.

**Core Idea LS3: Heredity: Inheritance and Variation of Traits**

*How are characteristics of one generation passed to the next?*

*How can individuals of the same species and even siblings have different characteristics?*

Heredity explains why offspring resemble, but are not identical to, their parents

and is a unifying biological principle. Heredity refers to specific mechanisms by

which characteristics or traits are passed from one generation to the next via

genes. Genes encode the information for making specific proteins, which are

responsible for the specific traits of an individual. Each gene can have several variants,

called alleles, which code for different variants of the trait in question. Genes

reside in a cell’s chromosomes, each of which contains many genes. Every cell of

any individual organism contains the identical set of chromosomes. When organisms

reproduce, genetic information is transferred to their offspring. In species

that reproduce sexually, each cell contains two variants of each chromosome, one

inherited from each parent. Thus sexual reproduction gives rise to a new combination

of chromosome pairs with variations between parent and offspring. Very

rarely, mutations also cause variations, which may be harmful, neutral, or occasionally

advantageous for an individual. Environmental as well as genetic variation

and the relative dominance of each of the genes in a pair play an important

role in how traits develop within an individual. Complex relationships between

genes and interactions of genes with the environment determine how an organism

will develop and function.

**LS3.A: INHERITANCE OF TRAITS**

*How are the characteristics of one generation related to the previous generation?*

In all organisms, the genetic instructions for forming species’ characteristics are

carried in the chromosomes. Each chromosome consists of a single very long

DNA molecule, and each gene on the chromosome is a particular segment of

that DNA. DNA molecules contain four different kinds of building blocks, called

nucleotides, linked together in a sequential chain. The sequence of nucleotides

spells out the information in a gene. Before a cell divides, the DNA sequence of its

chromosomes is replicated and each daughter cell receives a copy. DNA controls

the expression of proteins by being transcribed into a “messenger” RNA, which is

translated in turn by the cellular machinery into a protein. In effect, proteins build

an organism’s identifiable traits. When organisms reproduce, genetic information

is transferred to their offspring, with half coming from each parent in sexual

reproduction. Inheritance is the key factor causing the similarity among individuals

in a species population.

*Grade Band Endpoints for LS3.A*

***By the end of grade 2*.** Organisms have characteristics that can be similar or different.

Young animals are very much, but not exactly, like their parents and also

resemble other animals of the same kind. Plants also are very much, but not exactly,

like their parents and resemble other plants of the same kind.

***By the end of grade 5*.** Many characteristics of organisms are inherited from their

parents. Other characteristics result from individuals’ interactions with the environment,

which can range from diet to learning. Many characteristics involve both

inheritance and environment.

***By the end of grade 8*.** Genes are located in the chromosomes of cells, with each

chromosome pair containing two variants of each of many distinct genes. Each

distinct gene chiefly controls the production of a specific protein, which in turn

affects the traits of the individual (e.g., human skin color results from the actions

of proteins that control the production of the pigment melanin). Changes (mutations)

to genes can result in changes to proteins, which can affect the structures

and functions of the organism and thereby change traits.

Sexual reproduction provides for transmission of genetic information to offspring through egg and sperm cells. These cells, which contain only one chromosome of each parent’s chromosome pair, unite to form a new individual (offspring). Thus offspring possess one instance of each parent’s chromosome pair (forming a new chromosome pair). Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited or (more rarely) from mutations. (Boundary: The stress here is on the impact of gene transmission in reproduction, not the mechanism.)

***By the end of grade 12*.** In all organisms the genetic instructions for forming species’ characteristics are carried in the chromosomes. Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species’ characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. Not all DNA codes for a protein; some segments of DNA are involved in regulatory or structural functions, and some have no as-yet known function.

**LS3.B: VARIATION OF TRAITS**

*Why do individuals of the same species vary in how they look, function, and behave?*

Variation among individuals of the same species can be explained by both genetic

and environmental factors. Individuals within a species have similar but not identical

genes. In sexual reproduction, variations in traits between parent and offspring

arise from the particular set of chromosomes (and their respective multiple genes)

inherited, with each parent contributing half of each chromosome pair. More rarely,

such variations result from mutations, which are changes in the information

that genes carry. Although genes control the general traits of any given organism,

other parts of the DNA and external environmental factors can modify an individual’s

specific development, appearance, behavior, and likelihood of producing

offspring. The set of variations of genes present, together with the interactions of

genes with their environment, determines the distribution of variation of traits in a

population.

*Grade Band Endpoints for LS3.B*

***By the end of grade 2*.** Individuals of the same kind of plant or animal are recognizable

as similar but can also vary in many ways.

***By the end of grade 5*.** Offspring acquire a mix of traits from their biological parents.

Different organisms vary in how they look and function because they have

different inherited information. In each kind of organism there is variation in the

traits themselves, and different kinds of organisms may have different versions of

the trait. The environment also affects the traits that an organism develops—differences

in where they grow or in the food they consume may cause organisms

that are related to end up looking or behaving differently.

***By the end of grade 8*.** In sexually reproducing organisms, each parent contributes

half of the genes acquired (at random) by the offspring. Individuals have two of

each chromosome and hence two alleles of each gene, one acquired from each parent.

These versions may be identical or may differ from each other.

In addition to variations that arise from sexual reproduction, genetic information

can be altered because of mutations. Though rare, mutations may result

in changes to the structure and function of proteins. Some changes are beneficial,

others harmful, and some neutral to the organism.

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***By the end of grade 12*.** The information passed from parents to offspring is

coded in the DNA molecules that form the chromosomes. In sexual reproduction,

chromosomes can sometimes swap sections during the process of meiosis

(cell division), thereby creating new genetic combinations and thus more genetic

variation. Although DNA replication is tightly regulated and remarkably accurate,

errors do occur and result in mutations, which are also a source of genetic

variation. Environmental factors can also cause mutations in genes, and viable

mutations are inherited. Environmental factors also affect expression of traits,

and hence affect the probability of occurrences of traits in a population. Thus

the variation and distribution of traits observed depend on both genetic and

environmental factors.

**Core Idea LS4** **Biological Evolution: Unity and Diversity**

*How can there be so many similarities among organisms yet so many different*

*kinds of plants, animals, and microorganisms?*

*How does biodiversity affect humans?*

Biological evolution explains both the unity and the diversity of species and provides

a unifying principle for the history and diversity of life on Earth. Biological

evolution is supported by extensive scientific evidence ranging from the fossil

record to genetic relationships among species. Researchers continue to use new

and different techniques, including DNA and protein sequence analyses, to test

and further their understanding of evolutionary relationships. Evolution, which is

continuous and ongoing, occurs when natural selection acts on the genetic variation

in a population and changes the distribution of traits in that population gradually

over multiple generations. Natural selection can act more rapidly after sudden

changes in conditions, which can lead to the extinction of species. Through

natural selection, traits that provide an individual with an advantage to best meet

environmental challenges and reproduce are the ones most likely to be passed on

to the next generation. Over multiple generations, this process can lead to the

emergence of new species. Evolution thus explains both the similarities of genetic

material across all species and the multitude of species existing in diverse conditions

on Earth—its biodiversity—which humans depend on for natural resources

and other benefits to sustain themselves.

**LS4.A: EVIDENCE OF COMMON ANCESTRY AND DIVERSITY**

*What evidence shows that different species are related?*

Biological evolution, the process by which all living things have evolved over

many generations from shared ancestors, explains both the unity and the diversity

of species. The unity is illustrated by the similarities found betwen species;

which can be explained by the inheritance of similar characteristics from related

ancestors. The diversity of species is also consistent with common ancestry; it is

explained by the branching and diversification of lineages as populations adapted,

primarily through natural selection, to local circumstances.

Evidence for common ancestry can be found in the fossil record, from

comparative anatomy and embryology, from the similarities of cellular processes

and structures, and from comparisons of DNA sequences between species. The

understanding of evolutionary relationships has recently been greatly accelerated

by using new molecular tools to study developmental biology, with researchers

dissecting the genetic basis for some of the changes seen in the fossil record, as

well as those that can be inferred to link living species (e.g., the armadillo) to their

ancestors (e.g., glyptodonts, a kind of extinct gigantic armadillo).

*Grade Band Endpoints for LS4.A*

***By the end of grade 2*.** Some kinds of plants and animals that once lived on Earth

(e.g., dinosaurs) are no longer found anywhere, although others now living (e.g.,

lizards) resemble them in some ways.

***By the end of grade 5*.** Fossils provide evidence about the types of organisms (both

visible and microscopic) that lived long ago and also about the nature of their

environments. Fossils can be compared with one another and to living organisms

according to their similarities and differences.

***By the end of grade 8*.** Fossils are mineral replacements, preserved remains, or traces of organisms that lived in the past. Thousands of layers of sedimentary rock not only provide evidence of the history of Earth itself but also of changes in organisms whose fossil remains have been found in those layers. The collection of fossils and their placement in chronological order (e.g., through the location of the sedimentary layers in which they are found or through radioactive dating) is known as the fossil record. It documents the existence, diversity, extinction, and change of many life forms throughout the history of life on Earth. Because of the conditions necessary for their preservation, not all types of organisms that existed in the past have left fossils that can be retrieved.

Anatomical similarities and differences between various organisms living today and between them and organisms in the fossil record enable the reconstruction of evolutionary history and the inference of lines of evolutionary descent. Comparison of the embryological development of different species also reveals similarities that show relationships not evident in the fully formed anatomy.

***By the end of grade 12*.** Genetic information, like the fossil record, also provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence.

**LS4.B: NATURAL SELECTION**

*How does genetic variation among organisms affect survival and reproduction?*

Genetic variation in a species results in individuals with a range of traits. In any

particular environment individuals with particular traits may be more likely than

others to survive and produce offspring. This process is called natural selection

and may lead to the predominance of certain inherited traits in a population and

the suppression of others. Natural selection occurs only if there is variation in the

genetic information within a population that is expressed in traits that lead to differences

in survival and reproductive ability among individuals under specific environmental

conditions. If the trait differences do not affect reproductive success,

then natural selection will not favor one trait over others.

*Grade Band Endpoints for LS4.B*

***By the end of grade 2*. [**Intentionally left blank.]

***By the end of grade 5.*** Sometimes the differences in characteristics between

individuals of the same species provide advantages in surviving, finding mates,

and reproducing.

***By the end of grade 8*.** Genetic variations among individuals in a population give

some individuals an advantage in surviving and reproducing in their environment.

This is known as natural selection. It leads to the predominance of certain traits

in a population and the suppression of others. In *artificial* selection, humans have

the capacity to influence certain characteristics of organisms by selective breeding.

One can choose desired parental traits determined by genes, which are then passed

on to offspring.

***By the end of grade 12*.** Natural selection occurs only if there is both (1) variation

in the genetic information between organisms in a population and (2) variation

in the expression of that genetic information—that is, trait variation—that

leads to differences in performance among individuals. The traits that positively

affect survival are more likely to be reproduced and thus are more common in

the population.

**LS4.C: ADAPTATION**

*How does the environment influence populations of organisms over multiple*

*generations?*

When an environment changes, there can be subsequent shifts in its supply of

resources or in the physical and biological challenges it imposes. Some individuals

in a population may have morphological, physiological, or behavioral traits

that provide a reproductive advantage in the face of the shifts in the environment.

Natural selection provides a mechanism for species to adapt to changes in their

environment. The resulting selective pressures influence the survival and reproduction

of organisms over many generations and can change the distribution of

traits in the population. This process is called adaptation. Adaptation can lead to

organisms that are better suited for their environment because individuals with

the traits adaptive to the environmental change pass those traits on to their offspring,

whereas individuals with traits that are less adaptive produce fewer or no

offspring. Over time, adaptation can lead to the formation of new species. In some

cases, however, traits that are adaptive to the changed environment do not exist in

the population and the species becomes extinct. Adaptive changes due to natural

selection, as well as the net result of speciation minus extinction, have strongly

contributed to the planet’s biodiversity.

Adaption by natural selection is ongoing. For example it is seen in the emergence

of antibiotic-resistant bacteria. Organisms like bacteria, in which multiple

generations occur over shorter time spans, evolve more rapidly than those for

which each generation takes multiple years.

*Grade Band Endpoints for LS4.C*

***By the end of grade 2*.** Living things can survive only where their needs are met.

If some places are too hot or too cold or have too little water or food, plants and

animals may not be able to live there.

***By the end of grade 5*.** Changes in an organism’s habitat are sometimes beneficial

to it and sometimes harmful. For any particular environment, some kinds of

organisms survive well, some survive less well, and some cannot survive at all.

***By the end of grade 8*.** Adaptation by natural selection acting over generations is

one important process by which species change over time in response to changes

in environmental conditions. Traits that support successful survival and reproduction

in the new environment become more common; those that do not become

less common. Thus, the distribution of traits in a population changes. In separated

populations with different conditions, the changes can be large enough that the

populations, provided they remain separated (a process called reproductive isolation),

evolve to become separate species.

***By the end of grade 12*.** Natural selection is the result of four factors: (1) the

potential for a species to increase in number, (2) the genetic variation of individuals

in a species due to mutation and sexual reproduction, (3) competition

for an environment’s limited supply of the resources that individuals need in

order to survive and reproduce, and (4) the ensuing proliferation of those organisms

that are better able to survive and reproduce in that environment. Natural

selection leads to adaptation—that is, to a population dominated by organisms

that are anatomically, behaviorally, and physiologically well suited to survive

and reproduce in a specific environment. That is, the differential survival and

reproduction of organisms in a population that have an advantageous heritable

trait leads to an increase in the proportion of individuals in future generations

that have the trait and to a decrease in the proportion of individuals that do not.

Adaptation also means that the distribution of traits in a population can change

when conditions change.

Changes in the physical environment, whether naturally occurring or human

induced, have thus contributed to the expansion of some species, the emergence

of new distinct species as populations diverge under different conditions, and the

decline—and sometimes the extinction—of some species. Species become extinct

because they can no longer survive and reproduce in their altered environment. If

members cannot adjust to change that is too fast or too drastic, the opportunity

for the species’ evolution is lost.

**LS4.D: BIODIVERSITY AND HUMANS**

*What is biodiversity, how do humans affect it, and how does it affect humans?*

Human beings are part of and depend on the natural world. Biodiversity—the

multiplicity of genes, species, and ecosystems—provides humans with renewable

resources, such as food, medicines, and clean water. Humans also benefit from

“ecosystem services,” such as climate stabilization, decomposition of wastes, and

pollination that are provided by healthy (i.e., diverse and resilient) ecosystems.

The resources of biological communities can be used within sustainable limits, but

in many cases humans affect these ecosystems in ways—including habitat destruction,

pollution of air and water, overexploitation of resources, introduction of

invasive species, and climate change—that prevent the sustainable use of resources

and lead to ecosystem degradation, species extinction, and the loss of valuable

ecosystem services.

*Grade Band Endpoints for LS4.D*

***By the end of grade 2*.** There are many different kinds of living things in any area,

and they exist in different places on land and in water.

***By the end of grade 5*.** Scientists have identified and classified many plants and

animals. Populations of organisms live in a variety of habitats, and change in

those habitats affects the organisms living there. Humans, like all other organisms,

obtain living and nonliving resources from their environments.

***By the end of grade 8.*** Biodiversity is the wide range of existing life forms that have adapted to the variety of conditions on Earth, from terrestrial to marine ecosystems. Biodiversity

includes genetic variation within a species, in addition to species variation in different habitats and ecosystem types (e.g., forests, grasslands, wetlands). Changes in biodiversity can influence humans’ resources, such as food, energy, and medicines, as well as ecosystem services that humans rely on—for example, water purification and recycling.

***By the end of grade 12.*** Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). Biological extinction, being irreversible, is a critical factor in reducing the planet’s natural capital. Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. These problems have the potential to cause a major wave of biological extinctions—as many species or populations of a given species, unable to survive in changed environments, die out—and the effects may be harmful to humans and other living things. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity alsoaids humanity by preserving landscapes of recreational or inspirational value.