High School Modified Domains Model Course III – Life Sciences
Bundle 2: How Organisms Use Matter and Energy

This is the second bundle of the High School Domains Model Course III – Life Sciences. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).

Bundle 2 Question: This bundle is assembled to address the question "how do our bodies function?"

Summary

The bundle organizes performance expectations with a focus on helping students build understanding of how organisms obtain and use the matter and energy they need to live and grow. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, and recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle concepts

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 (LS1.A as in HS-LS1-2). As matter and energy flow through these different organizational levels of living systems, chemical elements are recombined in different ways to form different products (LS1.C as in HS-LS1-6, HS-LS1-7). The complex chemical processes of photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy [and matter] for life processes (LS2.B as in HS-LS2-3) on Earth. The main way that solar energy is captured and stored is through photosynthesis (PS3.D as in HS-LS2-5), which converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen (LS1.C as in HS-LS1-5). Conversely, in cellular respiration, the bonds of sugars or food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles (LS1.C as in HS-LS1-7).

As a result of these chemical reactions, energy is transferred form one system of interacting molecules to another and is released to the surrounding environment, including to maintain body temperature (LS1.C as in HS-LS1-7). All of these processes work together using feedback mechanisms to 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. Feedback mechanisms can encourage or discourage what is going on inside the living system (LS1.A as in HS-LS1-3).

The engineering design idea that criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them (ETS1.A as in HS-ETS1-1) could connect to many different science ideas, such as how the process of photosynthesis converts light energy to stored chemical energy (LS1.C as in HS-LS1-6) or how photosynthesis and cellular respiration are important components of the carbon cycle (LS2.B as in HS-LS2-5). Connections could be made through engineering design tasks, for example, where students analyze the criteria and constraints for developing more efficient solar energy collection using a model of photosynthesis, or for decreasing atmospheric carbon dioxide levels by manipulating photosynthesis.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of asking questions and defining problems (HS-ETS1-1), developing and using models (HS-LS1-2, HS-LS1-5, HS-LS1-7, and HS-LS2-5), planning and carrying out investigations (HS-LS1-3), and constructing explanations and designing solutions (HS-LS1-6 and HS-LS2-3). Many other practice elements can be used in instruction.

Bundle Crosscutting Concepts Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the concepts of Systems and System Models (HS-LS1-2 and HS-LS2-5), Energy and Matter (HS-LS1-6, HS-LS1-7, and HS-LS2-3), and Stability and Change (HS-LS1-3). Many other crosscutting concept elements can be used in instruction. *All instruction should be three-dimensional.*	
Performance Expectations	HS-LS1-2. **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.] HS-LS1-3. **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.** [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] [Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.] HS-LS1-5. **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [Assessment Boundary: Assessment does not include specific biochemical steps.] HS-LS1-6. **Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.** [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.] HS-LS1-7. **Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.** [Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.] HS-LS2-3. **Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.** [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.] HS-LS2-5. **Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.** [Clarification Statement: Examples of models could include simulations and mathematical models.] [Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.] HS-ETS1-1. **Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.**
Example Phenomena	We get sweaty when we exercise. Some bread dough rises if you leave it in a cool, dark place.

Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. Students could *ask questions that arise from examining models of the* ***structural organization of multicellular organisms*** *to clarify relationships* [between body systems]. HS-LS1-2 **Developing and Using Models** • Evaluate merits and limitations of two different models of the same proposed tool, process, mechanism, or system in order to select or revise a model that best fits the evidence or design criteria. Students could *evaluate the merits and limitations of two different models [for how]* ***photosynthesis and cellular respiration provide most of the energy for life processes*** *to select a model that best fits the evidence*. HS-LS2-3 **Planning and Carrying Out Investigations** • Plan an investigation or test a design individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. Students could *plan a [hypothetical] investigation to produce data to serve as the basis for evidence* [that] ***photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen***. HS-LS1-5 **Analyzing and Interpreting Data** • Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution. Students could *analyze data using tools, technologies, and/or models in order to make valid and reliable scientific claims* [that] ***carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes***. HS-LS2-5 **Using Mathematical and Computational Thinking** • Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. Students could *use mathematical representations of phenomena to describe and/or support claims* [that] ***feedback mechanisms maintain living system's internal conditions within certain limits even as external conditions change within some range***. HS-LS1-3

Additional Practices Building to the PEs (Continued)	**Constructing Explanations and Designing Solutions** • Apply scientific reasoning, theory, and/or models to link evidence to the claims to assess the extent to which the reasoning and data support the explanation or conclusion. Students could *apply scientific reasoning to assess the extent to which the reasoning and data support the explanation* [that] ***carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes.*** HS-LS2-5 **Engaging in Argument from Evidence** • Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. Students could *make and defend a claim based on evidence* [of how] ***feedback mechanisms allow*** [an organism] ***to remain alive and functional even as external conditions change within some range***. HS-LS1-3 **Obtaining, Evaluating, and Communicating Information** • Compare, integrate and evaluate sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a scientific question or solve a problem. Students could *compare, integrate and evaluate sources of information presented in different media or formats* [for how] ***cellular respiration releases energy to maintain body temperature***. HS-LS1-7
Additional Crosscutting Concepts Building to the PEs	**Cause and Effect** • Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. Students could suggest cause and effect relationships [for how] ***feedback mechanisms maintain a living system's internal conditions***. HS-LS1-3 **Systems and System Models** • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. Students could define the boundaries, initial conditions, the inputs, and outputs of the system model [of] ***the process of photosynthesis***. HS-LS1-5 **Energy and Matter** • The total amount of energy and matter in closed systems is conserved. Students could use mathematical representations [to show that] ***carbon*** *is conserved* ***[as it] is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes***. HS-LS2-5

Additional Connections to Nature of Science	**Scientific Knowledge is Based on Empirical Evidence** • Science disciplines share common rules of evidence used to evaluate explanations about natural systems. Students could communicate information [about why] *science disciplines share common rules of evidence when evaluating explanations*, [and how these common rules of evidence have affected our understanding of how] ***chemical elements are recombined in different ways to form different products.*** HS-LS1-6 and HS-LS1-7 **Science is a Way of Knowing** • Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. Students could communicate [how] *science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review*, [and how this way of knowing led to our understanding that] ***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***. HS-LS1-2

HS-LS1-2

Students who demonstrate understanding can:

HS-LS1-2. **Develop and use a model to illustrate the hierarchical organization of interacting systems that provide specific functions within multicellular organisms.** [Clarification Statement: Emphasis is on functions at the organism system level such as nutrient uptake, water delivery, and organism movement in response to neural stimuli. An example of an interacting system could be an artery depending on the proper function of elastic tissue and smooth muscle to regulate and deliver the proper amount of blood within the circulatory system.] [*Assessment Boundary: Assessment does not include interactions and functions at the molecular or chemical reaction level.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system.	**LS1.A: Structure and Function** • 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.	**Systems and System Models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students develop a model in which they identify and describe* the relevant parts (e.g., organ system, organs, and their component tissues) and processes (e.g., transport of fluids, motion) of body systems in multicellular organisms.	
2	Relationships		
	a	In the model, students describe* the relationships between components, including:	
		i.	The functions of at least two major body systems in terms of contributions to overall function of an organism;
		ii.	Ways the functions of two different systems affect one another; and
		iii.	A system's function and how that relates both to the system's parts and to the overall function of the organism.
3	Connections		
	a	Students use the model to illustrate how the interaction between systems provides specific functions in multicellular organisms.	
	b	Students make a distinction between the accuracy of the model and actual body systems and functions it represents.	

HS-LS1-3

Students who demonstrate understanding can:

HS-LS1-3. **Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis.** [Clarification Statement: Examples of investigations could include heart rate response to exercise, stomate response to moisture and temperature, and root development in response to water levels.] [*Assessment Boundary: Assessment does not include the cellular processes involved in the feedback mechanism.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Planning and Carrying Out Investigations
Planning and carrying out investigations in 9-12 builds on K-8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly.

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Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.

Disciplinary Core Ideas

LS1.A: Structure and Function

- 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. Feedback mechanisms can encourage (through positive feedback) or discourage (negative feedback) what is going on inside the living system.

Crosscutting Concepts

Stability and Change

- Feedback (negative or positive) can stabilize or destabilize a system.

Observable features of the student performance by the end of the course:

1	Identifying the phenomenon under investigation		
	a	Students describe* the phenomenon under investigation, which includes the following idea: that feedback mechanisms maintain homeostasis.	
2	Identifying the evidence to answer this question		
	a	Students develop an investigation plan and describe* the data that will be collected and the evidence to be derived from the data, including:	
		i.	Changes within a chosen range in the external environment of a living system; and
		ii.	Responses of a living system that would stabilize and maintain the system's internal conditions (homeostasis), even though external conditions change, thus establishing the positive or negative feedback mechanism.
	b	Students describe* why the data will provide information relevant to the purpose of the investigation.	
3	Planning for the investigation		
	a	In the investigation plan, students describe*:	
		i.	How the change in the external environment is to be measured or identified;
		ii.	How the response of the living system will be measured or identified;

		iii.	How the stabilization or destabilization of the system's internal conditions will be measured or determined;
		iv.	The experimental procedure, the minimum number of different systems (and the factors that affect them) that would allow generalization of results, the evidence derived from the data, and identification of limitations on the precision of data to include types and amounts; and
		v.	Whether the investigation will be conducted individually or collaboratively.
4	Collecting the data		
	a	Students collect and record changes in the external environment and organism responses as a function of time.	
5	Refining the design		
	a	Students evaluate their investigation, including:	
		i.	Assessment of the accuracy and precision of the data, as well as limitations (e.g., cost, risk, time) of the investigation, and make suggestions for refinement; and
		ii.	Assessment of the ability of the data to provide the evidence required.
	b	If necessary, students refine the investigation plan to produce more generalizable data.	

HS-LS1-5

Students who demonstrate understanding can:

HS-LS1-5. **Use a model to illustrate how photosynthesis transforms light energy into stored chemical energy.** [Clarification Statement: Emphasis is on illustrating inputs and outputs of matter and the transfer and transformation of energy in photosynthesis by plants and other photosynthesizing organisms. Examples of models could include diagrams, chemical equations, and conceptual models.] [*Assessment Boundary: Assessment does not include specific biochemical steps.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Use a model based on evidence to illustrate the relationships between systems or between components of a system.	**LS1.C: Organization for Matter and Energy Flow in Organisms** • The process of photosynthesis converts light energy to stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From the given model, students identify and describe* the components of the model relevant for illustrating that photosynthesis transforms light energy into stored chemical energy by converting carbon dioxide plus water into sugars plus released oxygen, including:	
		i.	Energy in the form of light;
		ii.	Breaking of chemical bonds to absorb energy;
		iii.	Formation of chemical bonds to release energy; and
		iv.	Matter in the form of carbon dioxide, water, sugar, and oxygen.
2	Relationships		
	a	Students identify the following relationship between components of the given model: Sugar and oxygen are produced by carbon dioxide and water by the process of photosynthesis.	
3	Connections		
	c	Students use the given model to illustrate:	
		i.	The transfer of matter and flow of energy between the organism and its environment during photosynthesis; and
		ii.	Photosynthesis as resulting in the storage of energy in the difference between the energies of the chemical bonds of the inputs (carbon dioxide and water) and outputs (sugar and oxygen).

HS-LS1-6

Students who demonstrate understanding can:

HS-LS1-6. **Construct and revise an explanation based on evidence for how carbon, hydrogen, and oxygen from sugar molecules may combine with other elements to form amino acids and/or other large carbon-based molecules.** [Clarification Statement: Emphasis is on using evidence from models and simulations to support explanations.] [*Assessment Boundary: Assessment does not include the details of the specific chemical reactions or identification of macromolecules.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	**LS1.C: Organization for Matter and Energy Flow in Organisms** • 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.	**Energy and Matter** • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes:	
		i.	The relationship between the carbon, hydrogen, and oxygen atoms from sugar molecules formed in or ingested by an organism and those same atoms found in amino acids and other large carbon-based molecules; and
		ii.	That larger carbon-based molecules and amino acids can be a result of chemical reactions between sugar molecules (or their component atoms) and other atoms.
2	Evidence		
	a	Students identify and describe* the evidence to construct the explanation, including:	
		i.	All organisms take in matter (allowing growth and maintenance) and rearrange the atoms in chemical reactions.
		ii.	Cellular respiration involves chemical reactions between sugar molecules and other molecules in which energy is released that can be used to drive other chemical reactions.
		iii.	Sugar molecules are composed of carbon, oxygen, and hydrogen atoms.
		iv.	Amino acids and other complex carbon-based molecules are composed largely of carbon, oxygen, and hydrogen atoms.
		v.	Chemical reactions can create products that are more complex than the reactants.
		vi.	Chemical reactions involve changes in the energies of the molecules involved in the reaction.

	b	Students use a variety of valid and reliable sources for the evidence (e.g., theories, simulations, students' own investigations).
3	Reasoning	
	a	Students use reasoning to connect the evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct the explanation that atoms from sugar molecules may combine with other elements via chemical reactions to form other large carbon-based molecules. Students describe* the following chain of reasoning for their explanation:
		i. The atoms in sugar molecules can provide most of the atoms that comprise amino acids and other complex carbon-based molecules.
		ii. The energy released in respiration can be used to drive chemical reactions between sugars and other substances, and the products of those reactions can include amino acids and other complex carbon-based molecules.
		iii. The matter flows in cellular processes are the result of the rearrangement of primarily the atoms in sugar molecules because those are the molecules whose reactions release the energy needed for cell processes.
4	Revising the explanation	
	a	Given new evidence or context, students revise or expand their explanation about the relationships between atoms in sugar molecules and atoms in large carbon-based molecules, and justify their revision.

HS-LS1-7

Students who demonstrate understanding can:

HS-LS1-7. **Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy.**[Clarification Statement: Emphasis is on the conceptual understanding of the inputs and outputs of the process of cellular respiration.] [*Assessment Boundary: Assessment should not include identification of the steps or specific processes involved in cellular respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds. • Use a model based on evidence to illustrate the relationships between systems or between components of a system.	**LS1.C: Organization for Matter and Energy Flow in Organisms** • 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. 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. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment.	**Energy and Matter** • Energy cannot be created or destroyed; it only moves between one place and another place, between objects and/or fields, or between systems.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	From a given model, students identify and describe* the components of the model relevant for their illustration of cellular respiration, including:	
		i.	Matter in the form of food molecules, oxygen, and the products of their reaction (e.g., water and CO_2);
		ii.	The breaking and formation of chemical bonds; and
		iii.	Energy from the chemical reactions.
2	Relationships		
	a	From the given model, students describe* the relationships between components, including:	
		i.	Carbon dioxide and water are produced from sugar and oxygen by the process of cellular respiration; and
		ii.	The process of cellular respiration releases energy because the energy released when the bonds that are formed in CO_2 and water is greater than the energy required to break the bonds of sugar and oxygen.
3	Connections		
	a	Students use the given model to illustrate that:	
		i.	The chemical reaction of oxygen and food molecules releases energy as the matter is rearranged, existing chemical bonds are broken, and new chemical bonds are formed, but matter and energy are neither created nor destroyed.

		ii. Food molecules and oxygen transfer energy to the cell to sustain life's processes, including the maintenance of body temperature despite ongoing energy transfer to the surrounding environment.

HS-LS2-3

Students who demonstrate understanding can:

HS-LS2-3. **Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.** [Clarification Statement: Emphasis is on conceptual understanding of the role of aerobic and anaerobic respiration in different environments.] [*Assessment Boundary: Assessment does not include the specific chemical processes of either aerobic or anaerobic respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, and peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. - - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** • Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** • Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.	**Energy and Matter** • Energy drives the cycling of matter within and between systems.

Observable features of the student performance by the end of the course:			
1	Articulating the explanation of phenomena		
	a	Students construct an explanation that includes that:	
		i.	Energy from photosynthesis and respiration drives the cycling of matter and flow of energy under aerobic or anaerobic conditions within an ecosystem.
		ii.	Anaerobic respiration occurs primarily in conditions where oxygen is not available.
2	Evidence		
	a	Students identify and describe* the evidence to construct the explanation, including:	
		i.	All organisms take in matter and rearrange the atoms in chemical reactions.
		ii.	Photosynthesis captures energy in sunlight to create chemical products that can be used as food in cellular respiration.
		iii.	Cellular respiration is the process by which the matter in food (sugars, fats) reacts chemically with other compounds, rearranging the matter to release energy that is used by the cell for essential life processes.

	b	Students use a variety of valid and reliable sources for the evidence, which may include theories, simulations, peer review, and students' own investigations.
3	Reasoning	
	a	Students use reasoning to connect evidence, along with the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future, to construct their explanation. Students describe* the following chain of reasoning used to construct their explanation:
		i. Energy inputs to cells occur either by photosynthesis or by taking in food.
		ii. Since all cells engage in cellular respiration, they must all produce products of respiration.
		iii. The flow of matter into and out of cells must therefore be driven by the energy captured by photosynthesis or obtained by taking in food and released by respiration.
		iv. The flow of matter and energy must occur whether respiration is aerobic or anaerobic.
4	Revising the explanation	
	a	Given new data or information, students revise their explanation and justify the revision (e.g., recent discoveries of life surrounding deep sea ocean vents have shown that photosynthesis is not the only driver for cycling matter and energy in ecosystems).

HS-LS2-5

Students who demonstrate understanding can:

HS-LS2-5. **Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.** [Clarification Statement: Examples of models could include simulations and mathematical models.] [*Assessment Boundary: Assessment does not include the specific chemical steps of photosynthesis and respiration.*]

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Develop a model based on evidence to illustrate the relationships between systems or components of a system.	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** • Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans, and geosphere through chemical, physical, geological, and biological processes. **PS3.D: Energy in Chemical Processes** • The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. *(secondary)*	**Systems and System Models** • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions — including energy, matter and information flows — within and between systems at different scales.

Observable features of the student performance by the end of the course:			
1	Components of the model		
	a	Students use evidence to develop a model in which they identify and describe* the relevant components, including:	
		i.	The inputs and outputs of photosynthesis;
		ii.	The inputs and outputs of cellular respiration; and
		iii.	The biosphere, atmosphere, hydrosphere, and geosphere.
2	Relationships		
	a	Students describe* relationships between components of their model, including:	
		i.	The exchange of carbon (through carbon-containing compounds) between organisms and the environment; and
		ii.	The role of storing carbon in organisms (in the form of carbon-containing compounds) as part of the carbon cycle.
3	Connections		
	a	Students describe* the contribution of photosynthesis and cellular respiration to the exchange of carbon within and among the biosphere, atmosphere, hydrosphere, and geosphere in their model.	
	b	Students make a distinction between the model's simulation and the actual cycling of carbon via photosynthesis and cellular respiration.	

HS-ETS1-1

Students who demonstrate understanding can:

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

The performance expectation above was developed using the following elements from *A Framework for K-12 Science Education*:

Science and Engineering Practices

Asking Questions and Defining Problems
Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.

- Analyze complex real-world problems by specifying criteria and constraints for successful solutions.

Disciplinary Core Ideas

ETS1.A: Defining and Delimiting Engineering Problems

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crosscutting Concepts

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Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

- New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.

Observable features of the student performance by the end of the course:			
1	Identifying the problem to be solved		
	a	Students analyze a major global problem. In their analysis, students:	
		i.	Describe* the challenge with a rationale for why it is a major global challenge;
		ii.	Describe*, qualitatively and quantitatively, the extent and depth of the problem and its major consequences to society and/or the natural world on both global and local scales if it remains unsolved; and
		iii.	Document background research on the problem from two or more sources, including research journals.
2	Defining the process or system boundaries, and the components of the process or system		
	a	In their analysis, students identify the physical system in which the problem is embedded, including the major elements and relationships in the system and boundaries so as to clarify what is and is not part of the problem.	
	b	In their analysis, students describe* societal needs and wants that are relative to the problem (e.g., for controlling CO_2 emissions, societal needs include the need for cheap energy).	
3	Defining the criteria and constraints		
	a	Students specify qualitative and quantitative criteria and constraints for acceptable solutions to the problem.	