

High School Conceptual Progressions Model Course II – Bundle 3 Matter and Energy in Organisms

This is the third bundle of the High School Conceptual Progressions Model Course II. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).

Bundle 3 Question: This bundle is assembled to address the question “how does matter and energy cycle within living systems?”

Summary

The bundle organizes performance expectations with a focus on helping students understand the cycling of energy and matter within living systems as energy-rich molecules are formed, moved, and used. Instruction developed from this bundle should always maintain the three-dimensional nature of the standards, but recognize that instruction is not limited to the practices and concepts directly linked with any of the bundle performance expectations.

Connections between bundle DCIs

The concept that when light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat) (PS4.B as in HS-PS4-4) can connect to the ideas that the main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis (PS3.D as in HS-LS2-5), which along with cellular respiration provide most of the energy for life processes (LS2.B as in HS-LS2-3).

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 (LS2.B as in HS-LS2-5). This idea connects to the concepts that as matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products (LS1.C as in HS-LS1-6 and HS-LS1-7) and the hydrocarbon backbones of sugars are used to make amino acids and other carbon-based molecules that can be assembled into larger molecules (LS1.C as in HS-LS1-6).

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 (LS1.C as in HS-LS1-7).

The engineering design concept that models (both physical and computational) can be used in various ways to aid in the engineering design process (ETS1.B as in HS-ETS1-4) could be applied to the concept that 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 (LS2.B as in HS-LS2-5) as well as the concept that the main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis (PS3.D as in HS-LS2-5). Students could make connections through an engineering design task such as comparing and contrasting the utility of different computer simulations to model an alternative energy source to photosynthesis or designing a computer model that helps predict the effects of a disruption in one part of the carbon cycle.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of developing and using a model (HS-LS1-7 and HS-LS2-5), using computational thinking (HS-ETS1-4), constructing explanations (HS-LS1-6 and HS-LS2-3), and obtaining, evaluating, and communicating information (HS-PS4-4). 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 crosscutting concepts of Cause and Effect (HS-PS4-4), Systems and System Models (HS-LS2-5 and HS-ETS1-4), and Energy and Matter (HS-LS1-6, HS-LS1-7, and HS-LS2-3). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations

HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.]

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-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Example Phenomena

Sunburns
Your internal temperature can be 98.6°F even if you sit outside on a 70°F day.

Additional Practices Building to the PEs

Asking Questions and Defining Problems

- Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information.

Students could *ask questions to clarify and seek information* [about how] *the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles.* HS-LS1-7

Additional Practices Building to the PEs (Continued)

Developing and Using Models

- Develop and/or use multiple types of models to provide mechanistic accounts and/or predict phenomena, and move flexibly between model types based on merits and limitations.

Students could *develop multiple types of models to provide mechanistic accounts* [about the idea that] ***as matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.*** HS-LS1-6 and HS-LS1-7

Planning and Carrying Out Investigations

- Plan 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.

Students could *plan an investigation to produce data to serve as the basis for evidence* [that] ***when light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy.*** HS-PS4-4

Analyzing and Interpreting Data

- Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.

Students could consider limitations of data analysis when analyzing and interpreting data [about how] ***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 to support claims [that] ***photosynthesis and cellular respiration are important components of the carbon cycle.*** HS-LS2-5

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 and/or models to link evidence to the claims* [that] ***as matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products.*** HS-LS1-6 and HS-LS1-7

Engaging in Argument from Evidence

- Compare and evaluate competing arguments or design solutions in light of currently accepted explanations, new evidence, limitations (e.g., trade-offs), constraints, and ethical issues.

Students could *compare and evaluate competing arguments* [about the idea that] ***shorter wavelength electromagnetic radiation can ionize atoms and cause damage to living cells.*** HS-PS4-4

<p>Additional Practices Building to the PEs (Continued)</p>	<p>Obtaining, Evaluating, and Communicating Information</p> <ul style="list-style-type: none"> Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). <p>Students could <i>communicate scientific information orally and graphically</i> [about how] <i>photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.</i> HS-LS2-3</p>
<p>Additional Crosscutting Concepts Building to the PEs</p>	<p>Systems and System Models</p> <ul style="list-style-type: none"> 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. <p>Students could <i>define the boundaries of the carbon cycle and analyze [its] inputs and outputs.</i> HS-LS2-5</p> <p>Energy and Matter</p> <ul style="list-style-type: none"> The total amount of energy and matter in closed systems is conserved. <p>Students could develop a model [showing that] <i>the total amount of energy and matter in closed systems is conserved</i> [when] <i>energy is transferred from one system of interacting molecules to another as the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles.</i> HS-LS1-7</p> <p>Structure and Function</p> <ul style="list-style-type: none"> Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. <p>Students could construct an argument for [why] <i>designing a new</i> [use for the] <i>components of sugar requires a detailed examination of [its] structure</i> [as well as] <i>the properties of [each of its molecular] components.</i> HS-LS1-6</p>
<p>Additional Connections to Nature of Science</p>	<p>Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena (SEP):</p> <ul style="list-style-type: none"> Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. <p>Students could construct an argument for how <i>models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory</i> [about how] <i>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.</i> HS-LS2-5</p> <p>Science is a Way of Knowing (CCC):</p> <ul style="list-style-type: none"> Science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review. <p>Students describe how <i>science distinguishes itself from other ways of knowing through use of empirical standards, logical arguments, and skeptical review</i> [by describing the characteristics of a scientific argument that] <i>photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.</i> HS-LS2-3</p>

HS-PS4-4

Students who demonstrate understanding can:

HS-PS4-4. Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter. [Clarification Statement: Emphasis is on the idea that photons associated with different frequencies of light have different energies, and the damage to living tissue from electromagnetic radiation depends on the energy of the radiation. Examples of published materials could include trade books, magazines, web resources, videos, and other passages that may reflect bias.] [Assessment Boundary: Assessment is limited to qualitative descriptions.]

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
<p>Obtaining, Evaluating, and Communicating Information Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.</p> <ul style="list-style-type: none"> Evaluate the validity and reliability of multiple claims that appear in scientific and technical texts or media reports, verifying the data when possible. 	<p>PS4.B: Electromagnetic Radiation</p> <ul style="list-style-type: none"> When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells. 	<p>Cause and Effect</p> <ul style="list-style-type: none"> 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.

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

1	Obtaining information	
	a	Students obtain at least two claims proposed in published material (using at least two sources per claim) regarding the effect of electromagnetic radiation that is absorbed by matter. One of these claims deals with the effect of electromagnetic radiation on living tissue.
2	Evaluating information	
	a	Students use reasoning about the data presented, including the energies of the photons involved (i.e., relative wavelengths) and the probability of ionization, to analyze the validity and reliability of each claim.
	b	Students determine the validity and reliability of the sources of the claims.
	c	Students describe* the cause and effect reasoning in each claim, including the extrapolations to larger scales from cause and effect relationships of mechanisms at small scales (e.g., extrapolating from the effect of a particular wavelength of radiation on a single cell to the effect of that wavelength on the entire organism).

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
<p>Constructing Explanations and Designing Solutions</p> <p>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.</p> <ul style="list-style-type: none"> 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. 	<p>LS1.C: Organization for Matter and Energy Flow in Organisms</p> <ul style="list-style-type: none"> 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. 	<p>Energy and Matter</p> <ul style="list-style-type: none"> 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
	<p>a Students construct an explanation that includes:</p> <p>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</p> <p>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.</p>
2	Evidence
	<p>a Students identify and describe* the evidence to construct the explanation, including:</p> <p>i. All organisms take in matter (allowing growth and maintenance) and rearrange the atoms in chemical reactions.</p> <p>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.</p> <p>iii. Sugar molecules are composed of carbon, oxygen, and hydrogen atoms.</p> <p>iv. Amino acids and other complex carbon-based molecules are composed largely of carbon, oxygen, and hydrogen atoms.</p> <p>v. Chemical reactions can create products that are more complex than the reactants.</p> <p>vi. Chemical reactions involve changes in the energies of the molecules involved in the reaction.</p>

	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
<p>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.</p> <ul style="list-style-type: none"> Use a model based on evidence to illustrate the relationships between systems or between components of a system. 	<p>LS1.C: Organization for Matter and Energy Flow in Organisms</p> <ul style="list-style-type: none"> 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. 	<p>Energy and Matter</p> <ul style="list-style-type: none"> 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
	<p>a From a given model, students identify and describe* the components of the model relevant for their illustration of cellular respiration, including:</p> <p>i. Matter in the form of food molecules, oxygen, and the products of their reaction (e.g., water and CO₂);</p> <p>ii. The breaking and formation of chemical bonds; and</p> <p>iii. Energy from the chemical reactions.</p>
2	Relationships
	<p>a From the given model, students describe* the relationships between components, including:</p> <p>i. Carbon dioxide and water are produced from sugar and oxygen by the process of cellular respiration; and</p> <p>ii. The process of cellular respiration releases energy because the energy released when the bonds that are formed in CO₂ and water is greater than the energy required to break the bonds of sugar and oxygen.</p>
3	Connections
	<p>a Students use the given model to illustrate that:</p> <p>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.</p>

	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.
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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
<p>Constructing Explanations and Designing Solutions</p> <p>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.</p> <ul style="list-style-type: none"> 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. <hr style="border-top: 1px dashed #ccc;"/> <p style="text-align: center;">Connections to Nature of Science</p> <p>Scientific Knowledge is Open to Revision in Light of New Evidence</p> <ul style="list-style-type: none"> Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence. 	<p>LS2.B: Cycles of Matter and Energy Transfer in Ecosystems</p> <ul style="list-style-type: none"> Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes. 	<p>Energy and Matter</p> <ul style="list-style-type: none"> 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										
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	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
<p>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).</p> <ul style="list-style-type: none"> Develop a model based on evidence to illustrate the relationships between systems or components of a system. 	<p>LS2.B: Cycles of Matter and Energy Transfer in Ecosystems</p> <ul style="list-style-type: none"> 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. <p>PS3.D: Energy in Chemical Processes</p> <ul style="list-style-type: none"> The main way that solar energy is captured and stored on Earth is through the complex chemical process known as photosynthesis. <i>(secondary)</i> 	<p>Systems and System Models</p> <ul style="list-style-type: none"> 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: <ol style="list-style-type: none"> 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: <ol style="list-style-type: none"> 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-ETS1-4

Students who demonstrate understanding can:

HS-ETS1-4. Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

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
<p>Using Mathematics and Computational Thinking</p> <p>Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. 	<p>ETS1.B: Developing Possible Solutions</p> <ul style="list-style-type: none"> Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. 	<p>Systems and System Models</p> <ul style="list-style-type: none"> 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	Representation								
	a Students identify the following components from a given computer simulation: <table border="1" style="width: 100%;"> <tbody> <tr> <td>i.</td> <td>The complex real-world problem with numerous criteria and constraints;</td> </tr> <tr> <td>ii.</td> <td>The system that is being modeled by the computational simulation, including the boundaries of the systems;</td> </tr> <tr> <td>iii.</td> <td>What variables can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions; and</td> </tr> <tr> <td>iv.</td> <td>The scientific principle(s) and/or relationship(s) being used by the model.</td> </tr> </tbody> </table>	i.	The complex real-world problem with numerous criteria and constraints;	ii.	The system that is being modeled by the computational simulation, including the boundaries of the systems;	iii.	What variables can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions; and	iv.	The scientific principle(s) and/or relationship(s) being used by the model.
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ii.	The system that is being modeled by the computational simulation, including the boundaries of the systems;								
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iv.	The scientific principle(s) and/or relationship(s) being used by the model.								
2	Computational Modeling								
	a Students use the given computer simulation to model the proposed solutions by: <table border="1" style="width: 100%;"> <tbody> <tr> <td>i.</td> <td>Selecting logical and realistic inputs; and</td> </tr> <tr> <td>ii.</td> <td>Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.</td> </tr> </tbody> </table>	i.	Selecting logical and realistic inputs; and	ii.	Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.				
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3	Analysis								
	a Students compare the simulated results to the expected results.								
	b Students interpret the results of the simulation and predict the effects of the proposed solutions within and between systems relevant to the problem based on the interpretation.								
	c Students identify the possible negative consequences of solutions that outweigh their benefits.								
	d Students identify the simulation's limitations.								