High School Conceptual Progressions Model III – Bundle 3
Human Influence on Earth

This is the third bundle of the High School Conceptual Progressions Model Course III. 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 could human activities change the Earth?"

Summary

The bundle organizes performance expectations with a focus on helping students build understanding of how human activities have changed the Earth over time. 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 DCIs

Humans depend on the living world for the resources and other benefits provided by biodiversity, but human activity is affecting biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change (LS4.D as in HS-LS4-6, HS-LS2-7), and these anthropogenic changes can disrupt an ecosystem and threaten the survival of some species (LS2.C as in HS-LS2-7). Biodiversity is increased by the formation of new species and decreased by the loss of species (LS4.D as in HS-LS2-7) which can occur due to changes in the physical environment, whether naturally occurring or human induced (LS4.C as in HS-LS4-6). Additionally, the many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual co-evolution of Earth's surface and the life that exists on it (ESS2.E as in HS-ESS2-7) and includes the gradual atmospheric changes due to plants and other organisms that captured carbon dioxide and released oxygen (ESS2.D as in HS-ESS2-7).

Humans also depend upon the environment for energy, but all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits (ESS3.A as in HS-ESS3-2). Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation (ESS3.C as in HS-ESS3-4) as we continue to make important discoveries about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities (ESS3.D as in HS-ESS3-6). Current models predict that average global temperatures will continue to rise, but this strongly depends on the amount of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere (ESS2.D as in HS-ESS3-6).

The engineering design idea that humanity faces many global challenges today that can be addressed through engineering, and that criteria and constraints include satisfying any requirements set by society 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 concepts, including how human activity is having adverse impacts on biodiversity through overpopulation and how sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspiration value (LS4.D as in HS-LS4-6, HS-LS2-7). Connections could be made through engineering design tasks such as identifying and quantifying the criteria and constraints for minimizing the effects a new road has on local biodiversity, or in minimizing habitat disruption from a new recreational park.

The engineering design idea that when evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts (ETS1.B as in HS-ETS1-3) already connects to several science ideas in the bundle, but could also connect to other ideas, such as how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities (ESS3.D as in HS-ESS3-6). Connections could be made through an engineering design task such as evaluating a given solution for overfishing.

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The engineering design idea that criteria may need to be broken down into smaller ones that can be approached systematically, and decisions about the priority of certain criteria over others may be needed (ETS1.C as in HS-ETS1-2) could connect to many different science ideas, including how all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits (ESS3.A as in HS-ESS3-2) or how scientists and engineers are developing technologies that produce less pollution and waste and that preclude ecosystem degradation (ESS3.C as in HS-ESS3-4). Connections could be made through engineering design tasks such as prioritizing criteria and analyzing various methods of producing energy such as wind, water, coal, or solar, and evaluating the level of pollution that each of these methods produces.

The engineering design idea that both physical models and computers can be used in various ways to aid in the engineering design process (ETS1.B as in HS-ETS1-4) could connect to several science ideas, including how important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities (ESS3.D as in HS-ESS3-6) or to how scientists and engineers are developing technologies that produce less pollution and waste and that preclude ecosystem degradation (ESS3.C as in HS-ESS3-4). Connections could be made through engineering design tasks such as using computer-generated models to analyze data on how marinas or cruise ships can be designed or how landfills can be constructed to minimize waste and pollution to the ocean, atmosphere, and biosphere.

Bundle Science and Engineering Practices

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of defining problems (HS-ETS1-1), using mathematics and computational thinking (HS-LS4-6, HS-ESS3-6, and HS-ETS1-4), designing solutions (HS-LS2-7, HS-ESS3-4, HS-ETS1-2, and HS-ETS1-3), and engaging in argument (HS-ESS2-7 and HS-ESS3-2). 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-LS4-6), Systems and System Models (HS-ESS3-6 and HS-ETS1-4), and Stability and Change (HS-LS2-7, HS-ESS2-7, and HS-ESS3-4). Many other crosscutting concept elements can be used in instruction.

All instruction should be three-dimensional.

Performance Expectations HS-ESS2-7, HS-ETS1-1, HS-ETS1-2, and HS-ETS1-3 are partially assessable.	**HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*** [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.] **HS-LS4-6. Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*** [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.] **HS-ESS2-7. Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples of include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.]

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Performance Expectations (Continued)	**HS-ESS3-2. Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*** [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.] **HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*** [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).] **HS-ESS3-6. Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.] **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.** **HS-ETS1-2. Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.** **HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.** **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	The bushes in the park died after English Ivy grew over them. The dust bowl affected the United States during the 1930s.
Additional Practices Building to the PEs	**Asking Questions and Defining Problems** • Ask questions to clarify and refine a model, an explanation, or an engineering problem. Students could *ask questions to clarify and refine an engineering problem* [related to how] ***all forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits***. HS-ESS3-2 **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 merits and limitations of two different models in order to select the model that best fits the evidence* [for how] ***the ocean, atmosphere, and biosphere interact and are modified in response to human activities***. HS-ESS3-6

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Additional Practices Building to the PEs (Continued)	**Planning and Carrying Out Investigations** • Manipulate variables and collect data about a complex model of a proposed process or system to identify failure points or improve performance relative to criteria for success or other variables. Students could *manipulate variables in a complex model,* [including] ***the ocean, atmosphere, biosphere, and human activities,*** *and collect data about* [how these] *variables* ***interact***. HS-ESS3-6 **Analyzing and Interpreting Data** • Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. Students could *evaluate the impact of new data on a working model of a proposed* ***technology that produces less pollution and waste and that precludes ecosystem degradation***. HS-ESS3-4 **Using Mathematical and Computational Thinking** • Apply techniques of algebra and functions to represent and solve scientific and engineering problems. Students could *apply techniques of algebra and functions to represent problems* [related to how] ***human activity is having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change***. HS-LS4-6 **Constructing Explanations and Designing Solutions** • Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. Students could *apply scientific ideas and evidence to provide an explanation* [for how] ***the ocean, atmosphere, and biosphere interact and are modified in response to human activities***. HS-ESS3-6 **Engaging in Argument from Evidence** • Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. Students could *evaluate the claims and evidence behind the [relationship between]* ***climate model predictions and the amounts of human-generated greenhouse gases added to the atmosphere each year***. HS-ESS3-6 **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* [about how] ***anthropogenic changes in the environment such as habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change can disrupt an ecosystem and threaten the survival of some species***. HS-LS2-7

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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 *construct an argument about predicted complex cause and effect relationships by examining what is known about smaller scale mechanisms* [of how] ***the ocean, atmosphere, and biosphere interact and are modified in response to human activities***. HS-ESS3-6 **Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. Students could obtain, evaluate, and communicate information about how *the significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs*, [using as an example how] ***human activity is having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change***. HS-LS4-6 **Systems and System Models** • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. Students could construct an argument from evidence about how *models can be used to predict the behavior of a system, but these predictions have limited precision and reliability*, [using as an example models of how] ***feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that exists on it***. HS-ESS2-7
Additional Connections to Nature of Science	**Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena** • A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. Students could obtain, evaluate, and communicate information about how a *scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed, and the science community validates each theory before it is accepted*, [using as an example that] ***feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that exists on it***. HS-ESS2-7 **Science Addresses Questions About the Natural and Material World** • Not all questions can be answered by science. Students could construct an argument for how ***when evaluating solutions, it is important to consider social, cultural, and environmental impacts of human activity on biodiversity*** and [for how] *not all* [of these] *questions can be answered by science*. HS-LS4-6 and HS-ETS1-3

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HS-LS2-7

Students who demonstrate understanding can:

HS-LS2-7. **Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*** [Clarification Statement: Examples of human activities can include urbanization, building dams, and dissemination of invasive species.]

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

Science and Engineering Practices

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.

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

LS2.C: Ecosystem Dynamics, Functioning, and Resilience

- 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.

LS4.D: Biodiversity and Humans

- Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction). *(secondary)*
- 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. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. *(secondary) (Note: This Disciplinary Core Idea is also addressed by HS-LS4-6.)*

ETS1.B: Developing Possible Solutions

- When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural and environmental impacts. *(secondary)*

Crosscutting Concepts

Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable.

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Observable features of the student performance by the end of the course:		
1	Using scientific knowledge to generate the design solution	
	a	Students design a solution that involves reducing the negative effects of human activities on the environment and biodiversity, and that relies on scientific knowledge of the factors affecting changes and stability in biodiversity. Examples of factors include but are not limited to:
		i. Overpopulation;
		ii. Overexploitation;
		iii. Habitat destruction;
		iv. Pollution;
		v. Introduction of invasive species; and
		vi. Changes in climate.
	b	Students describe* the ways the proposed solution decreases the negative effects of human activity on the environment and biodiversity.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe* and quantify (when appropriate) the criteria (amount of reduction of impacts and human activities to be mitigated) and constraints (for example, cost, human needs, and environmental impacts) for the solution to the problem, along with the tradeoffs in the solution.
3	Evaluating potential solutions	
	a	Students evaluate the proposed solution for its impact on overall environmental stability and changes.
	b	Students evaluate the cost, safety, and reliability, as well as social, cultural, and environmental impacts, of the proposed solution for a select human activity that is harmful to an ecosystem.
4	Refining and/or optimizing the design solution	
	a	Students refine the proposed solution by prioritizing the criteria and making tradeoffs as necessary to further reduce environmental impact and loss of biodiversity while addressing human needs.

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HS-LS4-6

Students who demonstrate understanding can:

HS-LS4-6. **Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.*** [Clarification Statement: Emphasis is on designing solutions for a proposed problem related to threatened or endangered species, or to genetic variation of organisms for multiple species.]

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
Using Mathematics and Computational Thinking 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. • Create or revise a simulation of a phenomenon, designed device, process, or system.	**LS4.C: Adaptation** • 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. **LS4.D: Biodiversity and Humans** • 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. Thus sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. *(Note: This Disciplinary Core Idea is also addressed by HS-LS2-7.)* **ETS1.B: Developing Possible Solutions** • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)* • 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. *(secondary)*	**Cause and Effect** • Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.

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Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students create or revise a simulation that:
		i. Models effects of human activity (e.g., overpopulation, overexploitation, adverse habitat alterations, pollution, invasive species, changes in climate) on a threatened or endangered species or to the genetic variation within a species; and
		ii. Provides quantitative information about the effect of the solutions on threatened or endangered species.
	b	Students describe* the components that are modeled by the computational simulation, including human activity (e.g., overpopulation, overexploitation, adverse habitat alterations, pollution, invasive species, changes in climate) and the factors that affect biodiversity.
	c	Students describe* the variables that can be changed by the user to evaluate the proposed solutions, tradeoffs, or other decisions.
2	Computational modeling	
	a	Students use logical and realistic inputs for the simulation that show an understanding of the reliance of ecosystem function and productivity on biodiversity, and that take into account the constraints of cost, safety, and reliability as well as cultural, and environmental impacts.
	b	Students use the simulation to identify possible negative consequences of solutions that would outweigh their benefits.
3	Analysis	
	a	Students compare the simulation results to expected results.
	b	Students analyze the simulation results to determine whether the simulation provides sufficient information to evaluate the solution.
	c	Students identify the simulation's limitations.
	d	Students interpret the simulation results, and predict the effects of the specific design solutions on biodiversity based on the interpretation.
4	Revision	
	a	Students revise the simulation as needed to provide sufficient information to evaluate the solution.

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HS-ESS2-7

Students who demonstrate understanding can:

HS-ESS2-7. **Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.** [Clarification Statement: Emphasis is on the dynamic causes, effects, and feedbacks between the biosphere and Earth's other systems, whereby geoscience factors control the evolution of life, which in turn continuously alters Earth's surface. Examples include how photosynthetic life altered the atmosphere through the production of oxygen, which in turn increased weathering rates and allowed for the evolution of animal life; how microbial life on land increased the formation of soil, which in turn allowed for the evolution of land plants; or how the evolution of corals created reefs that altered patterns of erosion and deposition along coastlines and provided habitats for the evolution of new life forms.] [*Assessment Boundary: Assessment does not include a comprehensive understanding of the mechanisms of how the biosphere interacts with all of Earth's other systems.*]

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
Engaging in Argument from Evidence Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about the natural and designed world(s). Arguments may also come from current scientific or historical episodes in science. • Construct an oral and written argument or counter-arguments based on data and evidence.	**ESS2.D: Weather and Climate** • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. **ESS2.E Biogeology** • The many dynamic and delicate feedbacks between the biosphere and other Earth systems cause a continual coevolution of Earth's surface and the life that exists on it.	**Stability and Change** • Much of science deals with constructing explanations of how things change and how they remain stable.

Observable features of the student performance by the end of the course:			
1	Developing the claim		
	a	Students develop a claim, which includes the following idea: that there is simultaneous coevolution of Earth's systems and life on Earth. This claim is supported by generalizing from multiple sources of evidence.	
2	Identifying scientific evidence		
	a	Students identify and describe* evidence supporting the claim, including:	
		i.	Scientific explanations about the composition of Earth's atmosphere shortly after its formation;
		ii.	Current atmospheric composition;
		iii.	Evidence for the emergence of photosynthetic organisms;
		iv.	Evidence for the effect of the presence of free oxygen on evolution and processes in other Earth systems;
		v.	In the context of the selected example(s), other evidence that changes in the biosphere affect other Earth systems.
3	Evaluating and critiquing		
	a	Students evaluate the evidence and include the following in their evaluation:	

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		i.	A statement regarding how variation or uncertainty in the data (e.g., limitations, low signal-to-noise ratio, collection bias, etc.) may affect the usefulness of the data as sources of evidence; and
		ii.	The ability of the data to be used to determine causal or correlational effects between changes in the biosphere and changes in Earth's other systems.
4	Reasoning and synthesis		
	a	Students use at least two examples to construct oral and written logical arguments. The examples:	
		i.	Include that the evolution of photosynthetic organisms led to a drastic change in Earth's atmosphere and oceans in which the free oxygen produced caused worldwide deposition of iron oxide formations, increased weathering due to an oxidizing atmosphere and the evolution of animal life that depends on oxygen for respiration; and
		ii.	Identify causal links and feedback mechanisms between changes in the biosphere and changes in Earth's other systems.

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HS-ESS3-2

Students who demonstrate understanding can:

HS-ESS3-2. **Evaluate competing design solutions for developing, managing, and utilizing energy and mineral resources based on cost-benefit ratios.*** [Clarification Statement: Emphasis is on the conservation, recycling, and reuse of resources (such as minerals and metals) where possible, and on minimizing impacts where it is not. Examples include developing best practices for agricultural soil use, mining (for coal, tar sands, and oil shales), and pumping (for petroleum and natural gas). Science knowledge indicates what can happen in natural systems—not what should happen.]

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

Science and Engineering Practices

Engaging in Argument from Evidence
Engaging in argument from evidence in 9–12 builds on K–8 experiences and progresses to using appropriate and sufficient evidence and scientific reasoning to defend and critique claims and explanations about natural and designed world(s). Arguments may also come from current scientific or historical episodes in science.

- Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and logical arguments regarding relevant factors (e.g., economic, societal, environmental, ethical considerations).

Disciplinary Core Ideas

ESS3.A: Natural Resources

- All forms of energy production and other resource extraction have associated economic, social, environmental, and geopolitical costs and risks as well as benefits. New technologies and social regulations can change the balance of these factors.

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

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

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.
- Analysis of costs and benefits is a critical aspect of decisions about technology.

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Connections to Nature of Science

Science Addresses Questions About the Natural and Material World

- Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Science knowledge indicates what can happen in natural systems — not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge.
- Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.

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Observable features of the student performance by the end of the course:		
1	Supported claims	
	a	Students describe* the nature of the problem each design solution addresses.
	b	Students identify the solution that has the most preferred cost-benefit ratios.
2	Identifying scientific evidence	
	a	Students identify evidence for the design solutions, including:
		i. Societal needs for that energy or mineral resource;
		ii. The cost of extracting or developing the energy reserve or mineral resource;
		iii. The costs and benefits of the given design solutions; and
		iv. The feasibility, costs, and benefits of recycling or reusing the mineral resource, if applicable.
3	Evaluation and critique	
	a	Students evaluate the given design solutions, including:
		i. The relative strengths of the given design solutions, based on associated economic, environmental, and geopolitical costs, risks, and benefits;
		ii. The reliability and validity of the evidence used to evaluate the design solutions; and
		iii. Constraints, including cost, safety, reliability, aesthetics, cultural effects environmental effects.
4	Reasoning/synthesis	
	a	Students use logical arguments based on their evaluation of the design solutions, costs and benefits, empirical evidence, and scientific ideas to support one design over the other(s) in their evaluation.
	b	Students describe* that a decision on the “best” solution may change over time as engineers and scientists work to increase the benefits of design solutions while decreasing costs and risks.

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HS-ESS3-4

Students who demonstrate understanding can:

HS-ESS3-4. **Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.*** [Clarification Statement: Examples of data on the impacts of human activities could include the quantities and types of pollutants released, changes to biomass and species diversity, or areal changes in land surface use (such as for urban development, agriculture and livestock, or surface mining). Examples for limiting future impacts could range from local efforts (such as reducing, reusing, and recycling resources) to large-scale geoengineering design solutions (such as altering global temperatures by making large changes to the atmosphere or ocean).]

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

Science and Engineering Practices

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 knowledge, principles and theories.

- Design or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.

Disciplinary Core Ideas

ESS3.C: Human Impacts on Earth Systems

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. *(secondary)*

Crosscutting Concepts

Stability and Change

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

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Connections to Engineering, Technology, and Applications of Science

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

- Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.

Observable features of the student performance by the end of the course:			
1	Using scientific knowledge to generate the design solution		
	a	Students use scientific information to generate a number of possible refinements to a given technological solution. Students:	
		i.	Describe* the system being impacted and how the human activity is affecting that system;
		ii.	Identify the scientific knowledge and reasoning on which the solution is based;
		iii.	Describe* how the technological solution functions and may be stabilizing or destabilizing the natural system;
		iv.	Refine a given technological solution that reduces human impacts on natural systems; and
		v.	Describe* that the solution being refined comes from scientists and engineers in the real world who develop technologies to solve problems of environmental degradation.
2	Describing criteria and constraints, including quantification when appropriate		
	a	Students describe* and quantify (when appropriate):	
		i.	Criteria and constraints for the solution to the problem; and
		ii.	The tradeoffs in the solution, considering priorities and other kinds of research-driven tradeoffs in explaining why this particular solution is or is not needed.
3	Evaluating potential refinements		

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	a	In their evaluation, students describe* how the refinement will improve the solution to increase benefits and/or decrease costs or risks to people and the environment.
	b	Students evaluate the proposed refinements for:
		i. Their effects on the overall stability of and changes in natural systems; and
		ii. Cost, safety, aesthetics, and reliability, as well as cultural and environmental impacts.

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HS-ESS3-6

Students who demonstrate understanding can:

HS-ESS3-6. **Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.** [Clarification Statement: Examples of Earth systems to be considered are the hydrosphere, atmosphere, cryosphere, geosphere, and/or biosphere. An example of the far-reaching impacts from a human activity is how an increase in atmospheric carbon dioxide results in an increase in photosynthetic biomass on land and an increase in ocean acidification, with resulting impacts on sea organism health and marine populations.] [*Assessment Boundary: Assessment does not include running computational representations but is limited to using the published results of scientific computational models.*]

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
Using Mathematics and Computational Thinking 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. • Use a computational representation of phenomena or design solutions to describe and/or support claims and/or explanations.	**ESS2.D: Weather and Climate** • Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. *(secondary)* **ESS3.D: Global Climate Change** • Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.	**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.

Observable features of the student performance by the end of the course:		
1	Representation	
	a	Students identify and describe* the relevant components of each of the Earth systems modeled in the given computational representation, including system boundaries, initial conditions, inputs and outputs, and relationships that determine the interaction (e.g., the relationship between atmospheric CO_2 and production of photosynthetic biomass and ocean acidification).
2	Computational modeling	
	a	Students use the given computational representation of Earth systems to illustrate and describe* relationships among at least two of Earth's systems, including how the relevant components in each individual Earth system can drive changes in another, interacting Earth system.
3	Analysis	
	b	Students use evidence from the computational representation to describe* how human activity could affect the relationships between the Earth's systems under consideration.

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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	Disciplinary Core Ideas	Crosscutting Concepts
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.	**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.	- ***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.	

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HS-ETS1-2

Students who demonstrate understanding can:

HS-ETS1-2. **Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.**

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. • Design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**ETS1.C: Optimizing the Design Solution** • Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed.	

Observable features of the student performance by the end of the course:		
1	Using scientific knowledge to generate the design solution	
	a	Students restate the original complex problem into a finite set of two or more sub-problems (in writing or as a diagram or flow chart).
	b	For at least one of the sub-problems, students propose two or more solutions that are based on student-generated data and/or scientific information from other sources.
	c	Students describe* how solutions to the sub-problems are interconnected to solve all or part of the larger problem.
2	Describing criteria and constraints, including quantification when appropriate	
	a	Students describe* criteria and constraints for the selected sub-problem.
	b	Students describe* the rationale for the sequence of how sub-problems are to be solved, and which criteria should be given highest priority if tradeoffs must be made.

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HS-ETS1-3

Students who demonstrate understanding can:

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

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. • Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	**ETS1.B: Developing Possible Solutions** • When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.	- ***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	Evaluating potential solutions		
	a	In their evaluation of a complex real-world problem, students:	
		i.	Generate a list of three or more realistic criteria and two or more constraints, including such relevant factors as cost, safety, reliability, and aesthetics that specifies an acceptable solution to a complex real-world problem;
		ii.	Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;
		iii.	Analyze (quantitatively where appropriate) and describe* the strengths and weaknesses of the solution with respect to each criterion and constraint, as well as social and cultural acceptability and environmental impacts;
		iv.	Describe* possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and
		v.	Provide an evidence-based decision of which solution is optimum, based on prioritized criteria, analysis of the strengths and weaknesses (costs and benefits) of each solution, and barriers to be overcome.
2	Refining and/or optimizing the design solution		
	a	In their evaluation, students describe* which parts of the complex real-world problem may remain even if the proposed solution is implemented.	

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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
Using Mathematics and Computational Thinking 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. • Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.	**ETS1.B: Developing Possible Solutions** • 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.	**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	Representation		
	a	Students identify the following components from a given computer simulation:	
		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.
2	Computational Modeling		
	a	Students use the given computer simulation to model the proposed solutions by:	
		i.	Selecting logical and realistic inputs; and
		ii.	Using the model to simulate the effects of different solutions, tradeoffs, or other decisions.
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.	

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