

## High School Conceptual Progressions Model I - Bundle 5

### Changes in Energy

*This is the fifth bundle of the High School Conceptual Progressions Model Course 1. Each bundle has connections to the other bundles in the course, as shown in the [Course Flowchart](#).*

*Bundle 5 Question: This bundle is assembled to address the question of “How is energy transferred between objects?”*

#### **Summary**

The bundle organizes performance expectations with a focus on helping students understand *how energy is transferred between objects*. 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**

Energy can be better understood as part of a system. Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system (PS3.A as in HS-PS3-1). These concepts of energy connect to the idea that at the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy (PS3.A as in HS-PS3-3), and the concept that although energy cannot be destroyed (PS3.A as in HS-PS3-1), it can be converted to less useful forms such as to thermal energy in the surrounding environment (PS3.D as in HS-PS3-3) and conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system (PS3.B as in HS-PS3-1). Finally, the motion and interactions of matter and radiation within that system (PS3.A as in HS-PS3-1) connect to the idea that, in many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present (PS1.B as in HS-PS1-6).

When evaluating solutions, connections could be made for how energy depends on the motion and interactions of matter (PS3.A as in HS-PS3-1) and manifests itself in multiple ways (PS3.A as in HS-PS3-3), and how the changes in the energy of a system (PS3.B as in HS-PS3-1) allow that system to be understood from a design point of view. These connections could be made through an engineering design task such as designing a Rube Goldberg device or wind turbine. 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 when designing solutions (ETS1.B as in HS-ETS1-3). Furthermore, 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 (trade-offs) such as renewable energy or artistic appeal may be needed (ETS1.C as in HS-ETS1-2).

#### **Bundle Science and Engineering Practices**

Instruction leading to this bundle of PEs will help students build toward proficiency in elements of the practices of creating a computational model (HS-PS3-1), refining a solution (HS-PS1-6), designing, evaluating, and/or refining a solution (HS-PS3-3), designing a solution to a complex real-world problem (HS-ETS1-2), and evaluating a solution to a complex real-world problem (HS-ETS1-3). 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 crosscutting concepts of Systems and System Models (HS-PS3-1); Energy and Matter (HS-PS3-3); and Stability and Change (HS-PS1-6). Many other CCC elements can be used in instruction.

*All instruction should be three-dimensional.*

<p><b>Performance Expectations</b></p> <p>HS-ETS1-2 and HS-ETS1-3 are partially assessable</p>	<p>HS-PS1-6. <b>Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.*</b> [Clarification Statement: Emphasis is on the application of Le Chatlier’s Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]</p> <p>HS-PS3-1. <b>Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.</b> [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or <b>computations</b>; to <b>systems of two or three components</b>; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]</p> <p>HS-PS3-3. <b>Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.*</b> [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]</p> <p>HS-ETS1-2. <b>Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.</b></p> <p>HS-ETS1-3. <b>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.</b></p>
<p><b>Example Phenomena</b></p>	<p>Batteries power electronic toys.</p> <p>When a gas grill is turned on, the flame gives off light and heat.</p>
<p><b>Additional Practices Building to the PEs</b></p>	<p><b>Asking Questions and Defining Problems</b></p> <ul style="list-style-type: none"> <li>Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.</li> </ul> <p>Students could <i>define a design problem that involves <b>the conservation of energy</b></i>. HS-PS3-1</p> <p><b>Developing and Using Models</b></p> <ul style="list-style-type: none"> <li>Develop a complex model that allows for manipulation and testing of a proposed process or system.</li> </ul> <p>Students could <i>develop a complex model that allows for manipulation and testing [of] <b>a dynamic and condition-dependent balance between a reaction and the reverse reaction</b></i>. HS-PS1-6</p> <p><b>Planning and Carrying Out Investigations</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul> <p>Students could <i>manipulate variables and collect data to improve performance [for a device that minimizes the] <b>conversion of energy to less useful forms</b></i>. HS-PS3-3</p>

**Additional Practices Building to the PEs (Continued)**

**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 technological tools to make valid scientific claims* [for how] ***the conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.*** HS-PS3-1

**Using Mathematical and Computational Thinking**

- Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model “makes sense” by comparing the outcomes with what is known about the real world.

Students could *use simple limit cases to test mathematical expressions to see if a model “makes sense” by comparing the outcomes with what is known about* [how] ***kinetic energy depends on mass and speed.*** HS-PS3-1

**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 to solve design problems, taking into account possible unanticipated effects* [for a device that] ***converts one form of energy such as motion into another less useful form of energy.*** HS-PS3-3 and HS-ETS1-3

**Engaging in Argument from Evidence**

- Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence, challenging ideas and conclusions, responding thoughtfully to diverse perspectives, and determining additional information required to resolve contradictions.

Students could *respectfully provide critiques on scientific arguments by probing reasoning and evidence* [about how] ***a dynamic balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.*** HS-PS1-6

**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* [for how] ***energy cannot be created or destroyed and can be converted to less useful forms such as thermal energy in the surrounding environment.*** HS-PS3-3

<p><b>Additional Crosscutting Concepts Building to the PEs</b></p>	<p><b>Scale, Proportion, and Quantity</b></p> <ul style="list-style-type: none"> <li>Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. Students could <i>compare models for two different scales</i> [for how] <b><i>energy cannot be created or destroyed, but it can be converted to less useful forms such as thermal energy in the surrounding environment.</i></b> HS-PS3-1 and HS-PS3-3</li> </ul> <p><b>Systems and System Models</b></p> <ul style="list-style-type: none"> <li>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. Students could use <i>models to simulate energy flow within and between systems at different scales</i> [to show that] <b><i>the total change of energy in any system is always equal to the total energy transferred into or out of the system.</i></b> HS-PS3-1</li> </ul> <p><b>Energy and Matter</b></p> <ul style="list-style-type: none"> <li>Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. Students could develop a model for how <i>energy cannot be created or destroyed</i> [by using] <b><i>mathematical expressions, which quantify how the stored energy in a system depends on its configuration and how kinetic energy depends on mass and speed.</i></b> HS-PS3-1</li> </ul>
<p><b>Additional Connections to Nature of Science</b></p>	<p><b>Scientific Knowledge is Based on Empirical Evidence (SEP):</b></p> <ul style="list-style-type: none"> <li>Science knowledge is based on empirical evidence. Students could describe the [importance of using] <i>empirical evidence</i> [to support the claim that] <b><i>the stored energy in a system depends on its configuration and how kinetic energy depends on mass and speed.</i></b> HS-PS3-1</li> </ul> <p><b>Science is a Human Endeavor (CCC):</b></p> <ul style="list-style-type: none"> <li>Technological advances have influenced the progress of science and science has influenced advances in technology. Students could construct an explanation for how <i>technology has influenced the progress of science and for how science has influenced advances in technology</i> [related to devices that] <b><i>convert energy from one form to another such as motion, sound, light, or thermal energy.</i></b> HS-PS3-3</li> </ul>

## HS-PS1-6

Students who demonstrate understanding can:

**HS-PS1-6. Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.\*** [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]

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
<b>Constructing Explanations and Designing Solutions</b> 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. <ul style="list-style-type: none"><li>Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li></ul>	<b>PS1.B: Chemical Reactions</b> <ul style="list-style-type: none"><li>In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.</li></ul> <b>ETS1.C: Optimizing the Design Solution</b> <ul style="list-style-type: none"><li>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 (trade-offs) may be needed. (<i>secondary</i>)</li></ul>	<b>Stability and Change</b> <ul style="list-style-type: none"><li>Much of science deals with constructing explanations of how things change and how they remain stable.</li></ul>

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

1	Using scientific knowledge to generate the design solution
a	Students identify and describe* potential changes in a component of the given chemical reaction system that will increase the amounts of particular species at equilibrium. Students use evidence to describe* the relative quantities of a product before and after changes to a given chemical reaction system (e.g., concentration increases, decreases, or stays the same), and will explicitly use Le Chatelier's principle, including: <ul style="list-style-type: none"><li>i. How, at a molecular level, a stress involving a change to one component of an equilibrium system affects other components;</li><li>ii. That changing the concentration of one of the components of the equilibrium system will change the rate of the reaction (forward or backward) in which it is a reactant, until the forward and backward rates are again equal; and</li><li>iii. A description* of a system at equilibrium that includes the idea that both the forward and backward reactions are occurring at the same rate, resulting in a system that appears stable at the macroscopic level.</li></ul>
2	Describing criteria and constraints, including quantification when appropriate
a	Students describe* the prioritized criteria and constraints, and quantify each when appropriate. Examples of constraints to be considered are cost, energy required to produce a product, hazardous nature and chemical properties of reactants and products, and availability of resources.
3	Evaluating potential solutions
a	Students systematically evaluate the proposed refinements to the design of the given chemical

		system. The potential refinements are evaluated by comparing the redesign to the list of criteria (i.e., increased product) and constraints (e.g., energy required, availability of resources).
4	Refining and/or optimizing the design solution	
	a	Students refine the given designed system by making tradeoffs that would optimize the designed system to increase the amount of product, and describe* the reasoning behind design decisions.

## HS-PS3-1

Students who demonstrate understanding can:

- HS-PS3-1. Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.** [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]

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><b>Using Mathematics and Computational Thinking</b></p> <p>Mathematical and computational thinking at the 9–12 level builds on K–8 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"> <li>Create a computational model or simulation of a phenomenon, designed device, process, or system.</li> </ul>	<p><b>PS3.A: Definitions of Energy</b></p> <ul style="list-style-type: none"> <li>Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.</li> </ul> <p><b>PS3.B: Conservation of Energy and Energy Transfer</b></p> <ul style="list-style-type: none"> <li>Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.</li> <li>Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.</li> <li>Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g., relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.</li> <li>The availability of energy limits what can occur in any system.</li> </ul>	<p><b>Systems and System Models</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul> <hr style="border-top: 1px dashed #ccc;"/> <p style="text-align: center;"><b>Connections to Nature of Science</b></p> <p><b>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</b></p> <ul style="list-style-type: none"> <li>Science assumes the universe is a vast single system in which basic laws are consistent.</li> </ul>

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

1	Representation
	a Students identify and describe* the components to be computationally modeled, including: <ol style="list-style-type: none"> <li>i. The boundaries of the system and that the reference level for potential energy = 0 (the potential energy of the initial or final state does not have to be zero);</li> <li>ii. The initial energies of the system’s components (e.g., energy in fields, thermal energy, kinetic energy, energy stored in springs — all expressed as a total amount of Joules in</li> </ol>

		each component), including a quantification in an algebraic description to calculate the total initial energy of the system;
		iii. The energy flows in or out of the system, including a quantification in an algebraic description with flow into the system defined as positive; and
		iv. The final energies of the system components, including a quantification in an algebraic description to calculate the total final energy of the system.
2	<b>Computational Modeling</b>	
	a	Students use the algebraic descriptions of the initial and final energy state of the system, along with the energy flows to create a computational model (e.g., simple computer program, spreadsheet, simulation software package application) that is based on the principle of the conservation of energy.
	b	Students use the computational model to calculate changes in the energy of one component of the system when changes in the energy of the other components and the energy flows are known.
3	<b>Analysis</b>	
	a	Students use the computational model to predict the maximum possible change in the energy of one component of the system for a given set of energy flows.
	b	Students identify and describe* the limitations of the computational model, based on the assumptions that were made in creating the algebraic descriptions of energy changes and flows in the system.

## HS-PS3-3

Students who demonstrate understanding can:

- HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.\*** [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]

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><b>Constructing Explanations and Designing Solutions</b></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"> <li>Design, evaluate, and/or refine a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li> </ul>	<p><b>PS3.A: Definitions of Energy</b></p> <ul style="list-style-type: none"> <li>At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.</li> </ul> <p><b>PS3.D: Energy in Chemical Processes</b></p> <ul style="list-style-type: none"> <li>Although energy cannot be destroyed, it can be converted to less useful forms — for example, to thermal energy in the surrounding environment.</li> </ul> <p><b>ETS1.A: Defining and Delimiting an Engineering Problem</b></p> <ul style="list-style-type: none"> <li>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. (<i>secondary</i>)</li> </ul>	<p><b>Energy and Matter</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul> <p>-----</p> <p><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Influence of Science, Engineering and Technology on Society and the Natural World</b></p> <ul style="list-style-type: none"> <li>Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks.</li> </ul>

### 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 device that converts one form of energy into another form of energy.
	b Students develop a plan for the device in which they:
	i. Identify what scientific principles provide the basis for the energy conversion design;
	ii. Identify the forms of energy that will be converted from one form to another in the designed system;
	iii. Identify losses of energy by the design system to the surrounding environment;
	iv. Describe* the scientific rationale for choices of materials and structure of the device, including how student-generated evidence influenced the design; and
	v. Describe* that this device is an example of how the application of scientific knowledge and engineering design can increase benefits for modern civilization while decreasing costs and risk.
2	Describing criteria and constraints, including quantification when appropriate

	a	Students describe* and quantify (when appropriate) prioritized criteria and constraints for the design of the device, along with the tradeoffs implicit in these design solutions. Examples of constraints to be considered are cost and efficiency of energy conversion.
3	Evaluating potential solutions	
	a	Students build and test the device according to the plan.
	b	Students systematically and quantitatively evaluate the performance of the device against the criteria and constraints.
4	Refining and/or optimizing the design solution	
	a	Students use the results of the tests to improve the device performance by increasing the efficiency of energy conversion, keeping in mind the criteria and constraints, and noting any modifications in tradeoffs.

## 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
<p><b>Constructing Explanations and Designing Solutions</b></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"> <li>Design a solution to a complex real-world problem based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li> </ul>	<p><b>ETS1.C: Optimizing the Design Solution</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul>	

### 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.

## 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
<p><b>Constructing Explanations and Designing Solutions</b></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"> <li>Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.</li> </ul>	<p><b>ETS1.B: Developing Possible Solutions</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul>	<p style="text-align: center;">-----</p> <p style="text-align: center;"><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Influence of Science, Engineering, and Technology on Society and the Natural World</b></p> <ul style="list-style-type: none"> <li>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.</li> </ul>

### 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: <ol style="list-style-type: none"> <li>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;</li> <li>ii. Assign priorities for each criterion and constraint that allows for a logical and systematic evaluation of alternative solution proposals;</li> <li>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;</li> <li>iv. Describe* possible barriers to implementing each solution, such as cultural, economic, or other sources of resistance to potential solutions; and</li> <li>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.</li> </ol>
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.