

Grade 4 Science, Unit 7

Using Engineering Design with Force and Motion Systems

Overview

Unit abstract

In this unit of study, students are able to use evidence to construct an explanation of the relationship between the speed of an object and the energy of that object. Students are expected to develop an understanding that energy can be transferred from place to place by sound, light, heat, and electrical currents or from objects through collisions. They apply their understanding of energy to design, test, and refine a device that converts energy from one form to another.

The crosscutting concepts of energy and matter and influence of engineering, technology, and science on society and the natural world are called out as organizing concepts for these disciplinary core ideas. In the fourth grade performance expectations, students are expected to demonstrate grade-appropriate proficiency in asking questions and defining problems, planning and carrying out investigations, and constructing explanations and designing solutions. Students are expected to use these practices to demonstrate understanding of the core ideas.

Essential questions

- What is energy and how is it related to motion?
- How is energy transferred?
- How can energy be used to solve a problem?

Written Curriculum

Next Generation Science Standards

4. Energy Students who demonstrate understanding can: 4-PS3-4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.* [Clarification Statement: Examples of devices could include electric circuits that convert electrical energy into motion energy of a vehicle, light, or sound; and, a passive solar heater that converts light into heat. Examples of constraints could include the materials, cost, or time to design the device.] [Assessment Boundary: Devices should be limited to those that convert motion energy to electric energy or use stored energy to cause motion or produce light or sound.]		
The performance expectations above were developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> :		
Science and Engineering Practices Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. <ul style="list-style-type: none"> Apply scientific ideas to solve design problems. (4-PS3-4) 	Disciplinary Core Ideas PS3.B: Conservation of Energy and Energy Transfer <ul style="list-style-type: none"> Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy. (4-PS3-4) PS3.D: Energy in Chemical Processes and Everyday Life <ul style="list-style-type: none"> The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use. (4-PS3-4) ETS1.A: Defining Engineering Problems <ul style="list-style-type: none"> Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (secondary to 4-PS3-4) 	Crosscutting Concepts Energy and Matter <ul style="list-style-type: none"> Energy can be transferred in various ways and between objects. (4-PS3-4) <p style="text-align: center;">-----</p> Connections to Engineering, Technology, and Applications of Science Influence of Engineering, Technology, and Science on Society and the Natural World <ul style="list-style-type: none"> Engineers improve existing technologies or develop new ones. (4-PS3-4) <p style="text-align: center;">-----</p> Connections to Nature of Science Science is a Human Endeavor <ul style="list-style-type: none"> Most scientists and engineers work in teams. (4-PS3-4) Science affects everyday life. (4-PS3-4)
<i>Connections to other DCIs in fourth grade:</i> N/A		
<i>Articulation of DCIs across grade-levels:</i> K.ETS1.A (4-PS3-4); 2.ETS1.B (4-PS3-4); 5.PS3.D (4-PS3-4); 5.LS1.C (4-PS3-4); MS.PS3.A (4-PS3-4); MS.PS3.B (4-PS3-4); MS.ETS1.B (4-PS3-4); MS.ETS1.C (4-PS3-4)		
<i>Common Core State Standards Connections:</i> ELA/Literacy – W.4.7 Conduct short research projects that build knowledge through investigation of different aspects of a topic. (4-PS3-4) W.4.8 Recall relevant information from experiences or gather relevant information from print and digital sources; take notes and categorize information, and provide a list of sources. (4-PS3-4) Mathematics – 4.OA.A.3 Solve multistep word problems posed with whole numbers and having whole-number answers using the four operations, including problems in which remainders must be interpreted. Represent these problems using equations with a letter standing for the unknown quantity. Assess the reasonableness of answers using mental computation and estimation strategies including rounding. (4-PS3-4)		

3-5. Engineering Design		
Students who demonstrate understanding can: 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.		
The performance expectations above were developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> :		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems Asking questions and defining problems in 3–5 builds on grades K–2 experiences and progresses to specifying qualitative relationships. <ul style="list-style-type: none"> Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost. (3-5-ETS1-1) 	ETS1.A: Defining and Delimiting Engineering Problems <ul style="list-style-type: none"> Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. (3-5-ETS1-1) 	Influence of Science, Engineering, and Technology on Society and the Natural World <ul style="list-style-type: none"> People’s needs and wants change over time, as do their demands for new and improved technologies. (3-5-ETS1-1)
<i>Connections to 3-5-ETS1.A: Defining and Delimiting Engineering Problems include:</i> Fourth Grade: 4-PS3-4		
<i>Articulation of DCIs across grade-bands:</i> K-2.ETS1.A (3-5-ETS1-1); MS.ETS1.A (3-5-ETS1-1); MS.ETS1.B (3-5-ETS1-1)		
<i>Common Core State Standards Connections:</i>		
<i>ELA/Literacy –</i>		
W.5.7 Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. (3-5-ETS1-1)		
W.5.8 Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources. (3-5-ETS1-1)		
W.5.9 Draw evidence from literary or informational texts to support analysis, reflection, and research. (3-5-ETS1-1)		
<i>Mathematics –</i>		
MP.2 Reason abstractly and quantitatively. (3-5-ETS1-1)		
MP.4 Model with mathematics. (3-5-ETS1-1)		
MP.5 Use appropriate tools strategically. (3-5-ETS1-1)		
3-5.OA Operations and Algebraic Thinking (3-5-ETS1-1)		

3-5. Engineering Design		
Students who demonstrate understanding can: 3-5-EST-1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.		
The performance expectations above were developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> :		
Science and Engineering Practices Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. <ul style="list-style-type: none"> Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem. (3-5-ETS1-2) 	Disciplinary Core Ideas ETS1.B: Developing Possible Solutions <ul style="list-style-type: none"> Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions. (3-5-ETS1-2) At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (3-5-ETS1-2) 	Crosscutting Concepts Influence of Science, Engineering, and Technology on Society and the Natural World <ul style="list-style-type: none"> Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands. (3-5-ETS1-2)
<i>Articulation of DCIs across grade-bands:</i> K-2.ETS1.A (3-5-ETS1-2); K-2.ETS1.B (3-5-ETS1-2); K-2.ETS1.C (3-5-ETS1-2); MS.ETS1.B (3-5-ETS1-2); MS.ETS1.C (3-5-ETS1-2)		
<i>Common Core State Standards Connections:</i> ELA/Literacy – RI.5.1 Quote accurately from a text when explaining what the text says explicitly and when drawing inferences from the text. (3-5-ETS1-2) RI.5.7 Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently. (3-5-ETS1-2) RI.5.9 Integrate information from several texts on the same topic in order to write or speak about the subject knowledgeably. (3-5-ETS1-2) Mathematics – MP.2 Reason abstractly and quantitatively. (3-5-ETS1-2) MP.4 Model with mathematics. (3-5-ETS1-2) MP.5 Use appropriate tools strategically. (3-5-ETS1-2) 3-5.OA Operations and Algebraic Thinking (3-5-ETS1-2)		

3-5. Engineering Design		
Students who demonstrate understanding can: 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.		
The performance expectations above were developed using the following elements from the NRC document <i>A Framework for K-12 Science Education</i> :		
Science and Engineering Practices Planning and Carrying Out Investigations Planning and carrying out investigations to answer questions or test solutions to problems in 3–5 builds on K–2 experiences and progresses to include investigations that control variables and provide evidence to support explanations or design solutions. <ul style="list-style-type: none"> Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered. (3-5-ETS1-3) 	Disciplinary Core Ideas ETS1.B: Developing Possible Solutions <ul style="list-style-type: none"> Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved. (3-5-ETS1-3) ETS1.C: Optimizing the Design Solution <ul style="list-style-type: none"> Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints. (3-5-ETS1-3) 	N/A
<i>Articulation of DCIs across grade-bands: K-2.ETS1.A (3-5-ETS1-3); K-2.ETS1.C (3-5-ETS1-3); MS.ETS1.B (3-5-ETS1-3); MS.ETS1.C (3-5-ETS1-3)</i>		
<i>Common Core State Standards Connections:</i>		
<i>ELA/Literacy –</i>		
W.5.7 Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. (3-5-ETS1-3)		
W.5.8 Recall relevant information from experiences or gather relevant information from print and digital sources; summarize or paraphrase information in notes and finished work, and provide a list of sources. (3-5-ETS1-3)		
W.5.9 Draw evidence from literary or informational texts to support analysis, reflection, and research. (3-5-ETS1-3)		
<i>Mathematics –</i>		
MP.2 Reason abstractly and quantitatively. (3-5-ETS1-3)		
MP.4 Model with mathematics. (3-5-ETS1-3)		
MP.5 Use appropriate tools strategically. (3-5-ETS1-3)		

Clarifying the standards

Prior learning

The following disciplinary core ideas are prior learning for the concepts in this unit of study. By the end of the K–2 grade span, students know that:

- A situation that people want to change or create can be approached as a problem to be solved through engineering.
- Asking questions, making observations, and gathering information are helpful in thinking about problems.
- Before beginning to design a solution it is important to clearly understand the problem.
- Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem’s solutions to other people.

Progression of current learning

Driving question 1

How can scientific ideas be applied to design, test, and refine a device that converts energy from one form to another?

Concepts

- Science affects everyday life.
- Most scientists and engineers work in teams.
- Engineers improve existing technologies or develop new ones.
- People’s needs and wants change over time, as do their demands for new and improved technologies.
- Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal demands.
- Energy can be transferred in various ways and between objects.
- Energy can also be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light. The currents may have been produced to begin with by transforming the energy of motion into electrical energy.

Practices

- Describe the various ways that energy can be transferred between objects.
- Apply scientific ideas to solve design problems.
- Apply scientific ideas to design, test, and refine a device that converts energy from one form to another. (Devices should be limited to those that convert motion energy to electric energy or use stored energy to cause motion or produce light or sound.) Examples of devices could include electric circuits that convert electrical energy into motion energy of a vehicle, light, or sound or passive solar heater that converts light into heat. Examples of constraints could include the materials, cost, or time to design the device.
- Define a simple design problem that can be solved through the development of an object, tool, process, or system and includes several criteria for success and constraints on materials, time, or cost.

- The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use.
 - Possible solutions to a problem are limited by available materials and resources (constraints).
 - The success of a designed solution is determined by considering the desired features of a solution (criteria).
 - Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account.
 - Research on a problem should be carried out before beginning to design a solution.
 - Testing a solution involves investigating how well it performs under a range of likely conditions.
 - At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.
 - Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved.
 - Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.
- Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
 - Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design problem.
 - Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
 - Plan and conduct an investigation collaboratively to produce data to serve as the basis for evidence, using fair tests in which variables are controlled and the number of trials considered.
 - Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Integration of content, practices, and crosscutting concepts

In the prior unit of study, students observed objects in motion in order to understand the relationship between the speed of an object and its energy, and they investigated the transfer of energy from one object to another, as well as from one form to another. In this unit, students will apply scientific ideas about force, motion, and energy in order to design, test, and refine a device that converts energy from one form to another. Through this process, students will learn that science affects everyday life and that engineers often work in teams, using scientific ideas, in order to meet people’s needs for new or improved technologies.

To begin the **engineering design process**, students must be presented with the problem of designing a device that converts energy from one form to another. This process should include the following steps:

- As a class, students should create a list of all the concepts that they have learned about force, motion, and energy.
 - The faster a given object is moving, the more energy it possesses.
 - Energy is present whenever there are moving objects, sound, light, or heat.
 - Energy can be transferred in various ways and between objects.
 - Energy can be moved from place to place by moving objects or through sound, light, or electric currents.
 - When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.
 - When objects collide, the contact forces transfer energy so as to change the objects' motions.
- Have students brainstorm examples of simple devices that convert energy from one form to another. As students give examples, the teacher should draw one or two and have students describe how each device converts energy from one form to another.
- Next, the teacher can present a “Design Challenge” to students: Design and build a simple device that converts energy from one form to another. Please note that teachers should limit the devices to those that convert motion energy to electric energy or that use stored energy to cause motion or produce light or sound.
- Small groups of students should conduct research, using several sources of information, to build understanding of “stored energy.” Students can look for examples of objects that have stored energy. Stretched rubber bands, compressed springs, wound or twisted rubber bands, batteries, wind-up toys, and objects at the top of a ramp or held at a height above the ground all have stored energy.
- As a class, determine criteria and possible constraints on the design solutions. For example, devices are only required to perform a single energy conversion (i.e., transfer energy from one form to another), and devices must transfer stored energy to either motion, light, or sound. Constraints could include the use of materials readily available in the classroom or provided by the teacher. (An assortment of materials can be provided, including batteries, wires, bulbs, buzzers, springs, string, tape, cardboard, balls, rubber tubing, suction cups, rubber bands of various sizes, construction paper, craft sticks, wooden dowels or skewers, buttons, spools, glue, brads, paper clips, plastic cups, paper plates, plastic spoons, straws, Styrofoam, and cloth.) A time constraint could also be set, if desired. All criteria and constraints should be posted on chart paper so that groups can refer to them as needed.
- Students should work in small, collaborative groups to design and build their device. Examples of possible devices could include:
 - A simple rubber band car that converts the stored energy in a twisted rubber band into motion energy.
 - A simple roller coaster that converts the stored energy in a marble held at the top of the roller coaster into motion energy.
 - A whirly bird that converts stored energy (in a student's muscles) into motion energy.
 - A ball launcher that converts stored energy in a compressed spring, compressed suction cup, or stretched rubber band into motion energy when the ball is launched.

- Students should create a poster that includes a diagram of the device and a description of how the device transfers energy from one form to another. Every group should have the opportunity to present their device and explain how it works.
- As a class, students compare each of the design solutions based on how well they meet criteria and constraints, giving evidence to support their thinking. When giving feedback to the groups, students should identify which criteria were/were not met, and how the design might be improved.
- Small groups should then have the opportunity to refine their designs based on the feedback from the class.

At every stage, communicating with peers is an important part of the design process, because shared ideas can lead to improved designs. It is also important that students describe the ways in which energy is transferred between objects and from one form to another.

Integration of engineering

Engineering design performance expectations are an integral part of this unit of study. Students are expected to define a simple design problem, including specified criteria for success and constraints on materials, time, or cost; generate and compare possible design solutions based on how well each is likely to meet the criteria and constraints of the problem; and plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of the design solution that can be improved. This process is outlined in greater detail in the previous section.

Integration of DCI from prior units within this grade level

In Grade 4, students will engage in engineering design in two additional units of study: Unit 2, Earth Processes, and Unit 8, Waves and Information. During this grade level, students will learn that:

- Research on a problem should be carried out before beginning to design a solution. Testing a solution involves investigating how well it performs under a range of likely conditions.
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs.
- Tests are often designed to identify failure points or difficulties, which suggest the elements of the design that need to be improved.
- Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints.

In Unit 6, Force and Motion, students observed objects in motion in order to understand the relationship between the speed of an object and its energy. They investigated the transfer of energy from one object to another, as well as from one form to another, during collisions. As students observed the interactions between moving objects, they gathered evidence in order to construct explanations.

Integration of English language arts and mathematics

English language arts

To support integration of the CCSS for English language arts in this unit, students will conduct research that builds their understanding of energy transfers. They will gather relevant information from their investigations and from multiple print or digital sources, take notes, and categorize their findings. They should use this information to construct explanations and support their thinking.

Mathematics

During this unit of study, students have multiple opportunities to integrate the CCSS for mathematics. Students can:

- Solve multistep word problems, using the four operations.
- Represent these problems using equations with a letter standing for the unknown quantity.
- Assess the reasonableness of answers using mental computation and estimating strategies, including rounding.

For example, “The class has 144 rubber bands with which to make rubber band cars. If each car uses 6 rubber bands, how many cars can be made? If there are 28 students in the class, how many rubber bands can each car have (if every car has the same number of rubber bands)?”

Students can also analyze constraints on materials, time, or cost to determine what implications the constraints have for design solutions. For example, if a design calls for 20 screws and screws are sold in boxes of 150, how many copies of the design can be made?

Future learning

The following disciplinary core ideas are future learning related to concepts in this unit of study.

In Grade 5, students will know that:

- The energy released from food was once energy from the sun that was captured by plants in the chemical process that forms plant matter (from air and water).
- Food provides animals with the materials they need for body repair and growth and the energy they need to maintain body warmth and for motion.
- Plants acquire their material for growth chiefly from air and water.

In middle school, students will know that:

- The term “heat” as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects.
- Temperature is not a measure of energy; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- Motion energy is properly called kinetic energy; it is proportional to the mass of the moving object and grows with the square of its speed.
- As system of objects may also contain stored (potential) energy, depending on their relative positions.
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.
- When the kinetic energy of an object changes, there is inevitably some other change in energy at the same time.
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

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- The more precisely a design task’s criteria and constraints can be defined, the more likely it is that the design solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions.
- A solution needs to be tested and then modified on the basis of the test results in order to improve it.
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.
- Models of all kinds are important for testing solutions.
- Although one design may not perform the best across all tests, identifying the characteristics of the design that perform the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.

Number of Instructional Days

Recommended number of instructional days: 21 (1 day = approximately 45–60 minutes)

Note—The recommended number of days is an estimate based on the information available at this time. Teachers are strongly encouraged to review the entire unit of study carefully and collaboratively to determine whether adjustments to this estimate need to be made.

