Unit 7: Using Engineering Design with Force and Motion Systems

Instructional Days: 15

Unit Summary
How can scientific ideas be applied to design, test, and refine a device that converts energy from one form to another?
In this unit of study, students use evidence to construct an explanation of the relationship between the speed of an object and the energy of that object. Students 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 the *influence of engineering, technology, and science on society and the natural world* are called out as organizing concepts for these disciplinary core ideas. Students are expected to demonstrate grade-appropriate proficiency in *asking questions and defining problems*, *planning and carrying out investigations*, *constructing explanations*, and *designing solutions*. Students are also expected to use these practices to demonstrate their understanding of the core ideas. This unit is based on 4-PS3-4, 3-5-ETS1-1, 3-5-ETS1-2, and 3-5-ETS1-3.
Student Learning Objectives
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.*]* **(4-PS3-4)**
Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. (3-5-ETS1-1)
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. (3-5-ETS1-2)
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. (3-5-ETS1-3)

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4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to
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
3-5-ETS1-2	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.
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.
ETS1.A	Possible solutions to a problem are limited by available materials and resources
ETS1.B	Research on a problem should be carried out before beginning to design a solution
ETS1.C	Different solutions need to be tested in order to determine which of them best solves the problem, given the criteria and the constraints

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Quick Links

Enduring Understandings

- The faster an object is moving, the more energy it possesses.
- The slower an object is moving the less energy it possesses.
- Moving objects, sound, light and heat all have energy.
- Energy can be moved from place to place by moving objects through sound, light or electric currents.

Essential Questions

- What is the relationship between speed and energy?
- How is energy transferable?
- What happens to the energy when objects collide?

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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.
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

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Students who understand the concepts are able to:

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.
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

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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.	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.

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What It Looks Like in the Classroom
Note: 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. o The faster a given object is moving, the more energy it possesses. o Energy is present whenever there are moving objects, sound, light, or heat. o Energy can be transferred in various ways and between objects. o Energy can be moved from place to place by moving objects or through sound, light, or electric currents. o 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. o 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 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:
  - o A simple rubber band car that converts the stored energy in a twisted rubber band into motion energy.
  - o A simple roller coaster that converts the stored energy in a marble held at the top of the roller coaster into motion energy.
  - o A whirly bird that converts stored energy (in a student's muscles) into motion energy.
  - o 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.

Connecting with English Language Arts/Literacy and Mathematics

English Language Arts

Students 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

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?

Modifications
(Note: Teachers identify the modifications that they will use in the unit. See NGSS Appendix D: All Standards, All Students/Case Studies for vignettes and explanations of the modifications.) • Structure lessons around questions that are authentic, relate to students' interests, social/family background and knowledge of their community. • Provide students with multiple choices for how they can represent their understandings (e.g. multisensory techniques-auditory/visual aids; pictures, illustrations, graphs, charts, data tables, multimedia, modeling). • Provide opportunities for students to connect with people of similar backgrounds (e.g. conversations via digital tool such as SKYPE, experts from the community helping with a project, journal articles, and biographies). • Provide multiple grouping opportunities for students to share their ideas and to encourage work among various backgrounds and cultures (e.g. multiple representation and multimodal experiences). • Engage students with a variety of Science and Engineering practices to provide students with multiple entry points and multiple ways to demonstrate their understandings. • Use project-based science learning to connect science with observable phenomena. • Structure the learning around explaining or solving a social or community-based issue. • Provide ELL students with multiple literacy strategies. • Collaborate with after-school programs or clubs to extend learning opportunities. • Restructure lesson using UDL principals (http://www.cast.org/our-work/about-udl.html#.VXmoXcfD_UA).

Research on Student Learning

Students tend to think of force as a property of an object ("an object has force," or "force is within an object") rather than as a relation between objects. In addition, students tend to distinguish between active objects and objects that support or block or otherwise act passively. Students tend to call the active actions "force" but do not consider passive actions as "forces". Teaching students to integrate the concept of passive support into the broader concept of force is a challenging task even at the high-school level (NSDL, 2015).

Prior Learning

Kindergarten Unit 1: Pushes and Pulls

- Pushes and pulls can have different strengths and directions.
- Pushing or pulling on an object can change the speed or direction of its motion and can start or stop it.
- A situation that people want to change or create can be approached as a problem to be solved through engineering. Such problems may have many acceptable solutions. *(secondary)*

Grade 3 Unit 2: Force and Motion

- Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object’s speed or direction of motion. (Boundary: Qualitative and conceptual understandings used at this level.)
- The patterns of an object’s motion in various situations can be observed and measured; when that past motion exhibits a regular pattern, future motion can be predicted from it.

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Future Learning

Grade 5 Unit 3: Energy and Matter in Ecosystems

- 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).
- Plants acquire their material for growth chiefly from air and water.

Grade 8 Unit 5: Relationships among Forms of Energy

- 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.
- A system of objects may also contain stored (potential) energy, depending on their relative positions.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.

Grade 8 Unit 6: Thermal Energy

- 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.
- 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.
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

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Connections to Other Units
In **Unit 5, Transfer of Energy,** students developed the understanding that energy can be transferred from place to place by sound, light, heat, and electrical currents. In **Unit 6, Forces and Motion,** 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.

Sample of Open Education Resources
The Sound of Science: Students are given a scenario/problem that needs to be solved: Their school is on a field trip to the city to listen to a rock band concert. After arriving at the concert, the students find out that the band's instruments were damaged during travel. The band needs help to design and build a stringed instrument with the available materials, satisfying the following criteria and constraints: 1) Produce three different pitched sounds. 2) Include at least one string. 3) Use only available materials. 4) Be no longer than 30 cm / 1 foot. The challenge is divided into 4 activities. Each activity is designed to build on students' understanding of the characteristics and properties of sound. By using what they learn about sound from these activities, students are then encouraged to apply what they know about sound to complete the engineering design challenge. Energy Makes Things Happen: The Boy Who Harnessed the Wind: This article from Science and Children provides ideas for using the trade book, The Boy Who Harnessed the Wind, as a foundation for a lesson on generators. This beautiful book is the inspiring true story of a teenager in Malawi who built a generator from found materials to create much-needed electricity. The lesson allows students to explore the concept of energy transfer using crank generators. Students then design improvements to the crank mechanism on the generator. The lesson may be extended by having students build their own generators. Light Your Way: Using the engineering design process, students will be designing and building a lantern that they will hypothetically be taking with them as they explore a newly discovered cave. The criteria of the completed lantern will include: hands need to be free for climbing, the lantern must have an on/off switch, it must point ahead when they are walking so they can see in the dark, and the lantern must be able to stay lit for at least 15 minutes. The constraints of the activity will be limited materials with which to build. At the completion of the activity, the students will present their final lantern to the class explaining how they revised and adapted the lantern to meet the criteria of the project. Students will include in the presentation the sketch of the model they created prior to building showing the labeled circuit they designed. This activity was one of numerous engineering lessons from the Virginia Children's Engineering Council geared towards Grades 1-5. http://www.childrensengineering.org/technology/designbriefs.php.

Teacher Professional Learning Resources
NGSS Appendix I – Appendix I provides an explanation how engineering is treated in the NGSS. Engineering Design in the NGSS The Next Generation Science Standards (NGSS) represent a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels, from kindergarten to grade 12. ***NGSS* Crosscutting Concepts: Energy and Matter—Flows, Cycles, and Conservation** The presenters were Charles W. (Andy) Anderson and Joyce Parker from Michigan State University. Dr. Anderson and Dr. Parker began the web seminar by discussing the role of energy and matter as a crosscutting concept. They talked about energy and matter at different scales, from the atomic to the macroscopic. The presenters shared information about how students learn about this crosscutting concept and how to address preconceptions. They then described instructional strategies such as modeling that can help students better understand the flow of energy and matter. ***NGSS* Crosscutting Concepts: Scale, Proportion, and Quantity** The presenters were Amy Taylor and Kelly Riedinger from the University of North Carolina Wilmington. Dr. Taylor began the presentation by discussing the definition of scale. Next, Dr. Riedinger talked about the role of scale, proportion, and quantity in NGSS. Participants shared their own experiences teaching about scale in the classroom before the presenters described additional instructional strategies that can provide students with a real-world understanding of this crosscutting concept. Dr. Taylor and Dr. Riedinger showed examples of activities from elementary, middle, and high school. They shared video clips and other resources that can help educators build their capacity for teaching about scale.

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Appendix A: NGSS and Foundations for the Unit		
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.*]* **(4-PS3-4)**		
Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. (3-5-ETS1-1)		
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. (3-5-ETS1-2)		
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. (3-5-ETS1-3)		
The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:		
Science and Engineering Practices	**Disciplinary Core Ideas**	**Crosscutting Concepts**
Constructing Explanations and Designing Solutions • Apply scientific ideas to solve design problems. (4-PS3-4) • 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)	**PS3.B: Conservation of Energy and Energy Transfer** • 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)	**Energy and Matter** • Energy can be transferred in various ways and between objects. (4-PS3-4) - ***Connections to Engineering, Technology, and Applications of Science***

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Asking Questions and Defining Problems	PS3.C: Relationship Between Energy and Forces	Influence of Engineering, Technology, and Science on Society and the Natural World
• 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) **Planning and Carrying Out Investigations** • 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)	• When objects collide, the contact forces transfer energy so as to change the objects' motions. (4-PS3-3) **PS3.D: Energy in Chemical Processes and Everyday Life** • 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 and Delimiting Engineering Problems** • 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	• Engineers improve existing technologies or develop new ones. (4-PS3-4) -*Connections to Nature of Science* **Science is a Human Endeavor** • Most scientists and engineers work in teams. (4-PS3-4) • Science affects everyday life. (4-PS3-4) **Influence of Science, Engineering, and Technology on Society and the Natural World** • People's needs and wants change over time, as do their demands for new and improved technologies. (3-5-ETS1-1) • Engineers improve existing technologies or develop new ones to increase their benefits, decrease known risks, and meet societal

	the constraints into account. (3-5-ETS1-1) **ETS1.B: Developing Possible Solutions** • 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) • 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** • 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)	demands. (3-5-ETS1-2)

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English Language Arts	Mathematics
Conduct short research projects that build knowledge through investigation of different aspects of a topic. (4-PS3-4) **W.4.7** 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) **W.4.8** Quote accurately from a text when explaining what the text says explicitly and when drawing inferences from the text. (3-5-ETS1-2) **RI.5.1** 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.5.1** Integrate information from several texts on the same topic in order to write or speak about the subject knowledgeably. (3-5-ETS1-2) **RI.5.9** Conduct short research projects that use several sources to build knowledge through investigation of different aspects of a topic. (3-5-ETS1-1),(3-5-ETS1-3) **W.5.7** 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),(3-5-ETS1-3) **W.5.8** Draw evidence from literary or informational texts to support analysis, reflection, and research. (3-5-ETS1-1),(3-5-ETS1-3) **W.5.9**	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) **4.OA.A.3** Mathematics - Operations and Algebraic Thinking (3-ETS1-1),(3-ETS1-2) **3.OA** Reason abstractly and quantitatively. (3-5-ETS1-1),(3-5-ETS1-2),(3-5-ETS1-3) **MP.2** Model with mathematics. (3-5-ETS1-1),(3-5-ETS1-2),(3-5-ETS1-3) **MP.4** Use appropriate tools strategically. (3-5-ETS1-1),(3-5-ETS1-2),(3-5-ETS1-3) MP.5 Operations and Algebraic Thinking (3-ETS1-1),(3-ETS1-2) **3-5.OA**

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Common Vocabulary	
Flow	Applied force
Lever arm	Balanced force
Magnet	Collide
Pulley	Collision
Force	Controlled
Exert	Force strength
Store	Friction
Transfer	Position over time
Relative	