## Grade 8 Science, Unit 6

# Thermal Energy

## Overview

### Unit abstract

Students will come to know the difference between energy and temperature. They will understand that the total change of energy in any system is always equal to the total energy transferred into or out of the system. The crosscutting concepts of energy and matter; scale, proportion, and quantity; and influence of science, engineering, and technology on society and the natural world are the organizing concepts for these disciplinary core ideas.

Science and engineering practices include constructing explanations and designing solutions, asking questions and defining problems, engaging in argument from evidence, planning and carrying out investigations, and analyzing and interpreting data. Students will be able to apply an understanding of design to the process of energy transfer. They will also define design problems, develop models, and evaluate competing design solutions to demonstrate understanding of the core ideas.

The goal for middle school students is to define problems more precisely, to conduct a more thorough process of choosing the best solution, and to optimize the final design. These include defining a problem by precisely specifying criteria and constraints for solutions as well as potential impacts on society and the natural environment, systematically evaluating alternative solutions, analyzing data from tests of different solutions and combining the best ideas into an improved solution, and developing a model and iteratively testing and improving it to reach an optimal solution. In physical science, students apply their engineering design capabilities to problems related to the transfer of thermal energy into and out of a system. Assessment does not include calculating the total amount of thermal energy transferred.

### Essential questions

- How can energy be transferred from one object or system to another?
- How will the end user decide whether or not an engineering design is successful?

# Written Curriculum

## Next Generation Science Standards

**MS. Energy**

Students who demonstrate understanding can:

**MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*** [Clarification Statement: Examples of devices could include an insulated box, a solar cooker, and a Styrofoam cup.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.]

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**<br>Constructing explanations and designing solutions in 6–8 builds on K–5 experiences and progresses to include constructing explanations and designing solutions supported by multiple sources of evidence consistent with scientific ideas, principles, and theories.<br>▪ Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3) | **PS3.A: Definitions of Energy**<br>▪ 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. (MS-PS3-3)<br>**PS3.B: Conservation of Energy and Energy Transfer**<br>▪ Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3)<br>**ETS1.A: Defining and Delimiting an Engineering Problem**<br>▪ The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. *(secondary to MS-PS3-3)*<br>**ETS1.B: Developing Possible Solutions**<br>▪ 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 criteria and constraints of a problem. *(secondary to MS-PS3-3)* | **Energy and Matter**<br>▪ The transfer of energy can be tracked as energy flows through a designed or natural system. (MS-PS3-3) |

*Connections to other DCIs in this grade-band*: **MS.PS1.B** (MS-PS3-3); **MS.ESS2.A** (MS-PS3-3); **MS.ESS2.C** (MS-PS3-3); **MS.ESS2.D** (MS-PS3-3)

*Articulation across grade-bands:* **4.PS3.B** (MS-PS3-3); **HS.PS3.B** (MS-PS3-3)

*Common Core State Standards Connections:*

*ELA/Literacy –*

**RST.6-8.3** Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. *(MS-PS3-3)*

**WHST.6-8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-PS3-3)

| MS. Energy |
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| Students who demonstrate understanding can:<br>**MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.** [Clarification Statement: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [Assessment Boundary: Assessment does not include calculating the total amount of thermal energy transferred.] |
| 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 |
|---|---|---|
| **Planning and Carrying Out Investigations**<br>Planning and carrying out investigations to answer questions or test solutions to problems in 6–8 builds on K–5 experiences and progresses to include investigations that use multiple variables and provide evidence to support explanations or design solutions.<br>▪ Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim. (MS-PS3-4)<br>--------------------------------------<br>***Connections to Nature of Science***<br>**Scientific Knowledge is Based on Empirical Evidence**<br>▪ Science knowledge is based upon logical and conceptual connections between evidence and explanations (MS-PS3-4) | **PS3.A: Definitions of Energy**<br>▪ 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. (MS-PS3-4)<br>**PS3.B: Conservation of Energy and Energy Transfer**<br>▪ 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. (MS-PS3-4) | **Scale, Proportion, and Quantity**<br>▪ Proportional relationships (e.g. speed as the ratio of distance traveled to time taken) among different types of quantities provide information about the magnitude of properties and processes. (MS-PS3-4) |

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| *Connections to other DCIs in this grade-band*: **MS.PS1.A** (MS-PS3-4); **MS.PS2.A** (MS-PS3-4); **MS.ESS2.C** (MS-PS3-4); **MS.ESS2.D** (MS-PS3-4); **MS.ESS3.D** (MS-PS3-4) |
| *Articulation across grade-bands:* **4.PS3.C** (MS-PS3-4); **HS.PS1.B** (MS-PS3-4); **HS.PS3.A** (MS-PS3-4); **HS.PS3.B** (MS-PS3-4) |
| *Common Core State Standards Connections:*<br>*ELA/Literacy –*<br>**RST.6-8.3** Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks. (MS-PS3-4)<br>**WHST.6-8.7** Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. *(MS-PS3-4)*<br>*Mathematics –*<br>**MP.2** Reason abstractly and quantitatively. (MS-PS3-4)<br>**6.SP.B.5** Summarize numerical data sets in relation to their context. *(MS-PS3-4)* |

**MS. Engineering Design**

Students who demonstrate understanding can:

**MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**

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 |
|---|---|---|
| **Asking Questions and Defining Problems**<br>Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.<br>▪ Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1) | **ETS1.A: Defining and Delimiting Engineering Problems**<br>▪ The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1) | **Influence of Science, Engineering, and Technology on Society and the Natural World**<br>▪ All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ETS1-1)<br>▪ The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-ETS1-1) |

*Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include: Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include:*

**Physical Science:** MS-PS3-3

*Connections to MS-ETS1.B: Developing Possible Solutions Problems include:*

**Physical Science:** MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5

*Connections to MS-ETS1.C: Optimizing the Design Solution include:*

**Physical Science**: MS-PS1-6

*Articulation of DCIs across grade-bands:* **3-5.ETS1.A** (MS-ETS1-1); **3-5.ETS1.C** (MS-ETS1-1); **HS.ETS1.A** (MS-ETS1-1); **HS.ETS1.B** (MS-ETS1-1)

*Common Core State Standards Connections:*

*ELA/Literacy –*

**RST.6-8.1** Cite specific textual evidence to support analysis of science and technical texts. (MS-ETS1-1)

**WHST.6-8.8** Gather relevant information from multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources. (MS-ETS1-1)

*Mathematics –*

**MP.2** Reason abstractly and quantitatively. *(MS-ETS1-1)*

**7.EE.3** Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-1)*

**MS. Engineering Design**

Students who demonstrate understanding can:

**MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.**

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 |
| --- | --- | --- |
| **Engaging in Argument from Evidence**<br>Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world.<br>▪ Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2) | **ETS1.B: Developing Possible Solutions**<br>▪ There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2) | N/A |

*Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include:*
**Physical Science:** MS-PS3-3
*Connections to MS-ETS1.B: Developing Possible Solutions Problems include:*
**Physical Science:** MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5
*Connections to MS-ETS1.C: Optimizing the Design Solution include:*
**Physical Science**: MS-PS1-6

*Articulation of DCIs across grade-bands:* **3-5.ETS1.A** (MS-ETS1-2); **3-5.ETS1.B** (MS-ETS1-2); **3-5.ETS1.C** (MS-ETS1-2); **HS.ETS1.A** (MS-ETS1-2); **HS.ETS1.B** (MS-ETS1-2)

*Common Core State Standards Connections:*

*ELA/Literacy –*

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| **RST.6-8.1** | Cite specific textual evidence to support analysis of science and technical texts. *(MS-ETS1-2)* |
| **RST.6-8.9** | Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-2) |
| **WHST.6-8.7** | Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration. (MS-ETS1-2) |
| **WHST.6-8.9** | Draw evidence from informational texts to support analysis, reflection, and research. *(MS-ETS1-2)* |

*Mathematics –*

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| **MP.2** | Reason abstractly and quantitatively. *(MS-ETS1-2)* |
| **7.EE.3** | Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-2)* |

**MS. Engineering Design**

Students who demonstrate understanding can:

**MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.**

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 |
|---|---|---|
| **Analyzing and Interpreting Data**<br>Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.<br>▪ Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3) | **ETS1.B: Developing Possible Solutions**<br>▪ There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-3)<br>▪ Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)<br>**ETS1.C: Optimizing the Design Solution**<br>▪ Although one design may not perform the best across all tests, identifying the characteristics of the design that performed 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. (MS-ETS1-3) | N/A |

*Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include:*
**Physical Science:** MS-PS3-3
*Connections to MS-ETS1.B: Developing Possible Solutions Problems include:*
**Physical Science:** MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5
*Connections to MS-ETS1.C: Optimizing the Design Solution include:*
**Physical Science**: MS-PS1-6

*Articulation of DCIs across grade-bands:* **3-5.ETS1.A** (MS-ETS1-3); **3-5.ETS1.B** (MS-ETS1-3); **3-5.ETS1.C** (MS-ETS1-3); **HS.ETS1.B** (MS-ETS1-3); **HS.ETS1.C** (MS-ETS1-3)

*Common Core State Standards Connections:*

*ELA/Literacy –*

| | |
|---|---|
| **RST.6-8.1** | Cite specific textual evidence to support analysis of science and technical texts. *(MS-ETS1-3)* |
| **RST.6-8.7** | Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table). (*MS-ETS1-3)* |
| **RST.6-8.9** | Compare and contrast the information gained from experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic. (MS-ETS1-3) |

*Mathematics –*

| | |
|---|---|
| **MP.2** | Reason abstractly and quantitatively. *(MS-ETS1-3)* |
| **7.EE.3** | Solve multi-step real-life and mathematical problems posed with positive and negative rational numbers in any form (whole numbers, fractions, and decimals), using tools strategically. Apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computation and estimation strategies. *(MS-ETS1-3)* |

**MS. Engineering Design**

Students who demonstrate understanding can:

**MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.**

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 |
|---|---|---|
| **Developing and Using Models**<br>Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.<br>▪ Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4) | **ETS1.B: Developing Possible Solutions**<br>▪ A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)<br>▪ Models of all kinds are important for testing solutions. (MS-ETS1-4)<br>**ETS1.C: Optimizing the Design Solution**<br>▪ 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. (MS-ETS1-4) | N/A |

*Connections to MS-ETS1.A: Defining and Delimiting Engineering Problems include:*
**Physical Science:** MS-PS3-3
*Connections to MS-ETS1.B: Developing Possible Solutions Problems include:*
**Physical Science:** MS-PS1-6, MS-PS3-3, **Life Science:** MS-LS2-5
*Connections to MS-ETS1.C: Optimizing the Design Solution include:*
**Physical Science**: MS-PS1-6

*Articulation of DCIs across grade-bands:* **3-5.ETS1.B** (MS-ETS1-4); **3-5.ETS1.C** (MS-ETS1-4); **HS.ETS1.B** (MS-ETS1-4); **HS.ETS1.C** (MS-ETS1-4)

*Common Core State Standards Connections:*

*ELA/Literacy –*

| | |
|---|---|
| **SL.8.5** | Include multimedia components and visual displays in presentations to clarify claims and findings and emphasize salient points. *(MS-ETS1-4)* |

*Mathematics –*

| | |
|---|---|
| **MP.2** | Reason abstractly and quantitatively. *(MS-ETS1-4)* |
| **7.SP** | Develop a probability model and use it to find probabilities of events. Compare probabilities from a model to observed frequencies; if the agreement is not good, explain possible sources of the discrepancy. *(MS-ETS1-4)* |

## 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 Grade 5, students know that:

- Energy is present whenever there are moving objects, sound, light, or heat. 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.
- Light transfers energy from place to place.
- Energy can be transferred from place to place by electric currents, which can then be used locally to produce motion, sound, heat, or light.
- Transforming the energy of motion into electrical energy may have produced the currents to begin with.
- When objects collide, the contact forces transfer energy so as to change the objects' motions.

### *Progression of current learning*

<table>
<tr><th colspan="2">Driving question 1<br>What are the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of a sample?</th></tr>
<tr><td>Concepts<br>• There are relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of the sample.<br>• Temperature is a measure of the average kinetic energy of particles of matter.<br>• The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.<br>• 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.<br>• Proportional relationships among the amount of energy transferred, the mass, and the change in the average kinetic energy of particles as measured by temperature of the sample provide information about the magnitude of properties and processes.</td><td>Practices<br>• Individually and collaboratively plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of the sample.<br>• As part of a planned investigation, identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim.<br>• Make logical and conceptual connections between evidence and explanations.</td></tr>
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**Driving question 2**
How can scientific principles be applied to design, construct, and test a device that either minimizes or maximizes thermal energy transfer?

| Concepts | Practices |
|---|---|
| • Temperature is a measure of the average kinetic energy of particles of matter.<br>• The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present.<br>• Energy is spontaneously transferred out of hotter regions or objects and into colder ones.<br>• The transfer of energy can be tracked as energy flows through a designed or natural system.<br>• The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.<br>• Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions.<br>• A solution needs to be tested and then modified on the basis of the test results in order to improve it.<br>• There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. | • Apply scientific ideas or principles to design, construct, and test a design of a device that either minimizes or maximizes thermal energy transfer.<br>• Determine design criteria and constraints for a device that either minimizes or maximizes thermal energy transfer.<br>• Test design solutions and modify them on the basis of the test results in order to improve them.<br>• Use a systematic process for evaluating solutions with respect to how well they meet criteria and constraints. |

*Integration of content, practices, and crosscutting concepts*

In Unit 5, students learned about the interactions between kinetic and potential energy. In this unit, they will be introduced to the idea of thermal energy and will explore how it relates to the interactions from Unit 5. Prior to planning an investigation, students will need to understand that temperature is actually a measure of the average kinetic energy of the particles in a sample of matter.

Students will begin this unit by individually and collaboratively planning an investigation to determine energy transfer relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of the sample. Students could start with an individual, small-group, or whole-class brainstorm to determine what might happen if they changed the temperature in a sample of matter. This brainstorm could take the form of a sketch, graphic organizer, or written response, and it could include everyday activities like taking a can of soda out of the refrigerator and setting it on a table or putting an ice cube into a warm beverage.

After brainstorming, students may need some guidance to determine what variables they would like to test in their experiment. Students could examine how the mass of ice cubes added to the beverage affects the temperature change. They could also investigate how the mass of the can of soda affects the temperature change as it sits on the table after being removed from the refrigerator. Examples of experiments could include a comparison of final temperatures after different masses of ice have melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials as they cool or heat in the environment, or the same material with different masses when a specific amount of thermal energy is added. Another example could include placing heated steel washers into water to investigate temperature changes. Each of these examples helps to show the proportional relationship between different masses of the same substance and the change in average kinetic energy when thermal energy is added to or removed from the system. In planning, students will identify independent and dependent variables and controls, decide what tools and materials are needed, how measurements will be recorded, and how many data are needed to support their claim. Once experiments have been planned and performed, students will move into the engineering process to solve a problem using this content.

In Unit 4, students used the design and engineering process to maximize a solution to a problem. In this unit of study, students will combine the concepts of thermal energy and engineering processes to design, construct, and test a device that either minimizes or maximizes thermal energy transfer. Examples of devices could include an insulated box, a solar cooker, or a Styrofoam cup. Calculation of the total amount of thermal energy is not to be assessed at this time.

Based on their brainstorm and investigations, students will identify a device to control the transfer of thermal energy into or out of the system they studied. Once students have identified the type of device they will construct, they can begin to define the criteria and constraints of the design problem that will help to minimize or maximize the transfer of thermal energy. Using informational texts to support this process is important. Students will draw evidence from these texts in order to support their analysis, reflection, and research.

When students consider constraints, they should conduct short research projects to examine factors such as societal and individual needs, cost effectiveness, available materials and natural resources, current scientific knowledge, and current advancements in science and technology. They should also consider limitations (design constraints) due to the properties of the materials of their design (i.e., Styrofoam vs. glass). While conducting their research, students will need to gather their information from multiple print and digital sources and assess the credibility of each source. When they quote or paraphrase the data and conclusions found in their resources, they will need to avoid plagiarism and provide basic bibliographic information for each source. After comparing the information gained from their research, experiments, simulations, video, or other multimedia sources, they will be able to determine precise design criteria and constraints that lead to a successful solution.

Students will need to jointly develop and agree upon the design criteria that will be used to evaluate their competing design solutions. Some of the criteria could include the ability of the system to control thermal energy transfer over a given amount of time, within a temperature range, or portability of the system or device. For example, if students are designing a solar cooker for backpackers, it should be small, lightweight, and should efficiently transfer thermal energy. Students can use a rubric, checklist, or decision tree to assist them in evaluating the design solution they selecte.

Once students have constructed their devices, they should gather necessary data from tests performed on their design solutions. They will analyze and interpret these data to determine similarities and differences in findings. This is when they are deciding whether different parts of their solutions can be combined to maximize efficiency.

Students will need to consider both qualitative and quantitative data when drawing conclusions about the various design solutions. It is important that students handle mathematical data appropriately. They should use variables to represent quantities and construct simple equations and inequalities to solve problems. While analyzing numerical data, students will need to solve mathematical problems that show both positive and negative values and apply properties of operations to calculate with numbers in any form; convert between forms as appropriate; and assess the reasonableness of answers using mental computations and estimation strategies. Support from mathematics teachers will help students with the mathematics required for this type of analysis.

At the conclusion of this unit of study, students will redesign their devices. During this process, they will need to consider the benefits and drawbacks of various devices in order to optimize the design solution. Their final products should be presented to strengthen claims and evidence regarding materials used and their impact on the efficiency of the students' redesigned devices.

### *Integration of engineering*

Throughout this unit of study, students will be engaged in the engineering design process. Students started by examining changes in thermal energy transfer (i.e., comparing final water temperatures after different masses of ice are melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added). Using what they have identified, students will begin to define the criteria and constraints of the design problem that will help to design, construct and test a device that either minimizes or maximizes thermal energy transfer. When students consider criteria, they may examine factors such as societal and individual needs, cost effectiveness, available materials and natural resources, current scientific knowledge, and current advancements in science and technology.

Students will need to jointly develop and agree upon the design criteria that will be used to evaluate their competing design solutions (i.e., an insulated box, a solar cooker, a Styrofoam cup). Students can use a rubric, checklist, or decision tree to assist them in evaluating the design solution they select.

Students will collect data from tests performed on their design solutions. They will analyze and interpret these data to determine which design best minimizes or maximizes thermal energy transfer. For example, the materials of a particular design may be superior and/or the structure of another design may be more successful. Once students have evaluated competing solutions and analyzed and interpreted data, they may then begin to modify their original designs. It is important that students consider the benefits of each design solution. The final goal is for students to identify the parts of each design solution that best fit their criteria and constraints, and combine these parts into a design solution that is better than any of its predecessors.

*Integration of DCI from prior units within this grade level*

- The skills gained from the engineering practice in Unit 4 will be helpful in the engineering and design process in Unit 6.

*Integration of mathematics and English language arts/literacy*

*Mathematics*

- Reason abstractly and quantitatively while collecting and analyzing numerical and symbolic data as part of an investigation that has been planned individually and collaboratively.
- Summarize numerical data sets in relation to the amount of energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles in the sample as measured by the temperature of the sample.
- Reason abstractly and quantitatively while collecting and analyzing numerical and symbolic data as part of a systematic process for evaluating solutions with respect to how well they meet criteria and constraints of a problem involving the design of a device that either minimizes or maximizes thermal energy transfer.

*English language arts/literacy*

- Follow precisely a multistep procedure for an investigation that has been planned individually and collaboratively to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
- Conduct short research projects to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of particles as measured by the temperature of the sample, drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.
- Follow precisely a multistep process for the design, construction, and testing of a device that either minimizes or maximizes thermal energy transfer.
- Conduct short research projects to apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer, drawing on several sources and generating additional related, focused questions that allow for multiple avenue of exploration.
- Gather relevant information to inform the design, construction, and testing of a device that either minimizes or maximizes thermal energy transfer using multiple print and digital sources; assess the credibility of each source; and quote or paraphrase the data and conclusions of others while avoiding plagiarism and providing basic bibliographic information for sources.
- Draw evidence from informational texts to support analysis, reflection, and research that informs the design, construction, and testing of a device that either minimizes or maximizes thermal energy transfer.
- Cite specific textual evidence to support analysis of science and technical texts that provide information about the application of scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
- Compare and contrast the information gained from experiments, simulations, or multimedia sources with that gained from reading text about devices that either minimize or maximize energy transfer.

## ***Future learning***

### *Physical science*

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- 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.
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- 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.
- At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- 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. Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- 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.
- The availability of energy limits what can occur in any system.
- Uncontrolled systems always evolve toward more stable states— that is, toward more uniform energy distribution (e.g., water flows down hill, objects hotter than their surrounding environment cool down).
- 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.
- 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.
- Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical and in making a persuasive presentation to a client about how a given design will meet his or her needs.

- 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.

## Number of Instructional Days

*Recommended number of instructional days: 30 (1 day = approximately 50 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.