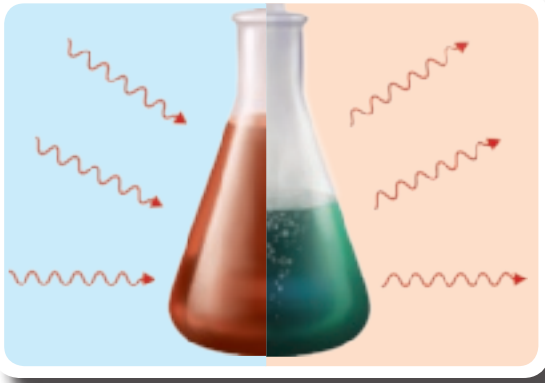
Chemical Reactions and Energy:

How can we use chemical reactions to design a solution to a problem?

Science Literacy

Teacher Guide

Energy in a chemical reaction



Chemically activated hand warmers

Chemical heating of food

GRADE 7 Core Knowledge Science®

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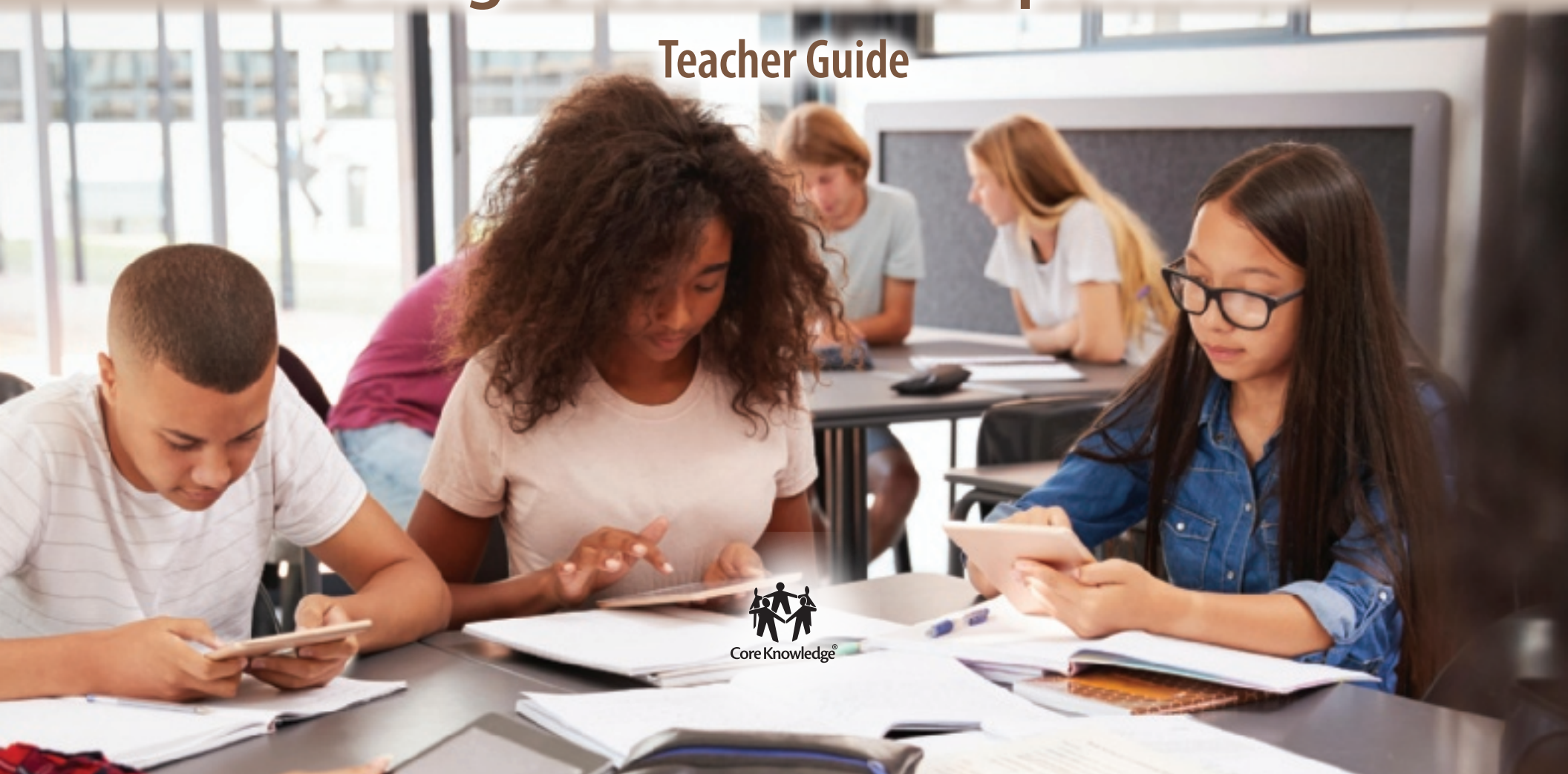
How can we use chemical reactions to design a solution to a problem?

Teacher Guide



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Chemical Reactions and Energy:

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BEFORE YOU BEGIN

Before introducing the unit, please become fully acquainted with the program instructional model and classroom routines by reading the online resource **Teacher Handbook: Overview of the Core Knowledge Middle School Science Program**.

Online Resources	Use this link to download the **CKSci Online Resources Guide** for this unit, which includes specific links to: • the unit's comprehensive materials list • a full unit pacing snapshot • lesson guidance slides • all other recommended resources. **www.coreknowledge.org/cksci-online-resources**
Student Work Pages	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources.
Student Books	All student handouts and exercise pages are included in the consumable Student Work Pages book so that there is no need to print copies of these resources. Students also will use the Student Procedure Guide and the Science Literacy Student Reader throughout the unit.

UNIT OVERVIEW

How can we use chemical reactions to design a solution to a problem?

This unit on chemical reactions and energy starts off with students thinking about how they would heat up food without having typical methods available. Then they see images from a real situation, after Superstorm Sandy in New York, during which people were given Meals, Ready-to-Eat (MREs) that can heat up food by just adding water. The class explores the flameless heater from the MRE in action, which seems like some kind of chemical process or possibly a chemical reaction. Students develop an initial model to consider how a flameless heater works, but they also notice some problems with prepackaged MREs. In order to solve some of the identified problems, the class decides to help people in situations in which typical heating methods aren't available to heat up food by designing a homemade flameless heater with instructions that others could follow. After brainstorming criteria and constraints, they individually attempt to create designs for a homemade flameless heater and compare designs with classmates. Issues that arise during the design comparison motivate the class to build a Design Questions Board and gather ideas for investigations that will guide their work to create a successful homemade flameless heater.

The first lesson set focuses on defining and refining the design problem. Students do investigations to gather data about which chemical process might work best in their homemade heater designs. Then, they step back to think about the work they've been doing as engineers and realize that their design work so far can be put into three main categories: Define, Develop Solutions, and Optimize. At the end of this lesson set, the class comes back to refine their criteria and constraints. In the second lesson set, the class shifts their focus to really dig into their design solutions. They investigate how much food and reactants they should include in their homemade heater designs and go through a series of iterative developing, testing, and modifying their designs based on peer feedback and collected data.

Through their investigations, students

- analyze data to determine patterns in the relationship between the total amount of food they can heat and the amount of energy that is transferred from the chemical reaction to the food system;
- undertake a design project to construct and test a solution that meets specific design criteria and constraints, including the transfer of energy;
- respectfully provide and receive critiques about design solutions with respect to how they meet criteria and constraints and consider patterns across multiple designs to determine which design characteristics cause more effective outcomes in performance; and
- optimize performance of a design that transfers energy through a system by prioritizing criteria, making trade-offs, testing, revising, and retesting.

Focal Disciplinary Core Ideas (DCIs): PS1.B, EST1.B, EST1.C

Focal Science and Engineering Practices (SEPs): Planning and Carrying Out Investigations; Constructing Explanations and Designing Solutions

Focal Crosscutting Concepts (CCCs): System and System Models; Matter and Energy

Building Toward NGSS Performance Expectations

MS-PS1-6: Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.

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

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.

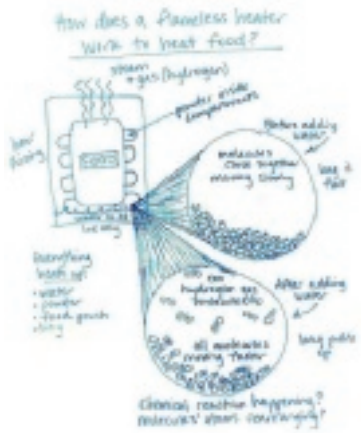
MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

UNIT STORYLINE

How students will engage with each of the phenomena

HANDS-ON/ LAB ACTIVITIES	VIDEOS OR IMAGES	DATA SETS	READINGS	COMPUTER INTERACTIVES

How can we use chemical reactions to design a solution to a problem?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 **3 days** **How can we heat up food when we don't have our typical methods available?** **Anchoring Phenomenon**	 *The flameless heater in a Meal, Ready-to-Eat heats food when water is added.*	We develop an initial model to consider how the flameless heater in an MRE works, but we also notice some problems with prepackaged MREs. After brainstorming criteria and constraints for a homemade flameless heater, we create designs. We build a Design Questions Board and gather ideas for investigations. We figure out: • Prepackaged MREs are useful, but they are expensive, possibly confusing to use, and can be difficult to get to people. • We want to design an effective, inexpensive, easy-to-use flameless heater that people can make at home to heat food when typical methods are not available. • We need to gather more-detailed information from testing and data analysis to inform and improve further redesigns. • We have a lot of questions and ideas for investigations to drive our design work.	

⇩ **Navigation to Next Lesson:** We have initial design ideas and questions about flameless heaters. If we investigate how flameless heaters work, we can figure out how to design a flameless heater for others.

LESSON 2

2 days

How do heaters get warm without a flame?

Investigation

The temperature increases when substances in air-activated hand warmers and flameless heaters are undergoing a chemical reaction.

We revise an investigation to see how hot flameless heaters and hand warmers get. We collect more data to support the idea that a chemical reaction is happening when the devices heat up. We research the different ingredients and observe changes in the substances as they warm up to confirm new substances are made. We model energy transfer in the MRE system using what we learn. We figure out:

- Energy transfers from the system of atoms that rearrange during the chemical reaction to surrounding systems (which includes the water and air inside the heater device, the material the device is made of, the thermometer, the food container, the food, and the environment outside of the MRE).
- We need to maximize energy transfer to the food and minimize transfer to the outside environment.
- The substances in each device we investigated are not good candidates for our heater.

⇩ **Navigation to Next Lesson:** Substances in the MRE and hand warmer are not good candidates for our flameless heater design. We wonder if there is another chemical reaction that we can use.

LESSON 3

3 days

What other chemical reactions could we use to heat up food?

Investigation

Different chemical reactions cause an increase, decrease, or no change in temperature. Changing the amount of reactants changes the amount of energy transferred, and warming more food requires more energy transfer.

We test different chemical reactions to determine if any of them cause an increase in temperature for use in our flameless heater designs. We choose the reaction that increases the temperature the most. We model the reaction as particles and the transfer of energy out of the reaction system to the food system and investigate the weight of each system. We figure out:

- Root killer and aluminum foil mixed in saltwater caused a large increase in temperature.
- Exothermic reactions transfer energy to the surroundings; these reactions feel warm. Energy transfers from the surroundings to an endothermic chemical reaction; these reactions feel cold.
- Chemical reactions can transfer energy to other systems.
- The more reactants we use in a chemical reaction, the more energy is being transferred into or out of the system. The evidence of this is a greater temperature change.
- To raise the temperature of a larger amount of food, more reactants are required.

⇩ **Navigation to Next Lesson:** We figured out a lot of ideas that will help us with our designs. We are ready to use these ideas to plan our designs.

LESSON 4

2 days

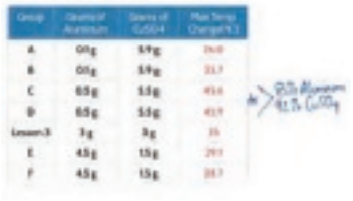
How much of each reactant should we include in our homemade flameless heater?

Investigation

Adjusting the proportion of reactants causes different temperature changes and different levels of leftover reactants and products.

We plan and conduct an investigation to determine which proportion of reactants will work best to heat up our food. Then, we reflect on what makes good instructions and identify our stakeholders. Finally, we administer a survey to our potential stakeholders to figure out what aspects they find most important. We figure out:

- The combination of reactants that results in the greatest temperature change is 8% aluminum and 92% $CuSO_4$.
- We identify our stakeholders and decide to survey them to understand their needs.



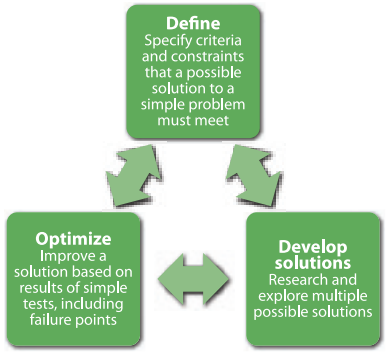
⇩ **Navigation to Next Lesson:** We figured out the optimal proportion of reactants and identified our stakeholders. We wonder what design aspects are most important and how we can incorporate those in our designs.

LESSON 5

1 day

How can we refine our criteria and constraints?

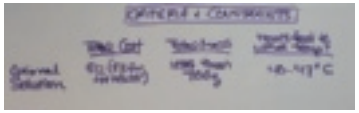
Putting Pieces Together, Investigation



The class seems to be repeating some of the work they are doing as engineers.

We analyze readings about food temperatures to revise our criteria and constraints. We determine the optimal solution for our homemade flameless heater, including total cost and mass. We reorganize and refine our What We Do as Engineers board to reveal the cyclical process of engineering design. We figure out:

- Our optimal solution needs to
  - cost no more than $12 ($3 for the heater),
  - have a total mass of less than 700 grams, and
  - heat food to 40-47°C.
- Engineers use a cyclical process (Define, Develop, Optimize) to design solutions.



⇩ **Navigation to Next Lesson:** Now that we know more-specific criteria and constraints that our designs should be targeting, let's redesign our devices!

LESSON 6

3 days

How can we redesign our homemade flameless heater?

Investigation

Copper sulfate and aluminum in saltwater can be used in a homemade device to heat up food.

We work in teams to draw designs for our homemade flameless heaters. Our teacher checks our plans for safety before we build prototypes and test them using a Design Testing Matrix based on our criteria and constraints. After testing, we complete a self-assessment of how well our team works as engineers and how well we individually meet expectations as teammates. We figure out:

- Designs need to be tested to inform modifications that will lead to a better solution.
- Different kinds of models are helpful for testing design solutions.
- The instructions we write to help people build a heater are critical to the success of the solution.

⇩ **Navigation to Next Lesson:** We want to share our designs and test results so that we can see different ideas that worked, and then we can combine those parts to create an even better solution.

LESSON 7

1 day

How did our design compare to others in the class?

Problematizing

Sharing designs among teams helps to determine which flameless heater design characteristics are more promising than others with respect to the identified criteria and constraints.

We provide and receive critique about our flameless heater designs with other teams and work as a class to identify the most promising design characteristics. We figure out:

- We identify which design characteristics cause the best performance, and we want to optimize our flameless heater designs by incorporating different combinations of these characteristics.
- We need to systematically examine how changes in one part of our design might cause changes in another part.
- We need other groups to test our designs to see if our instructions are clear.

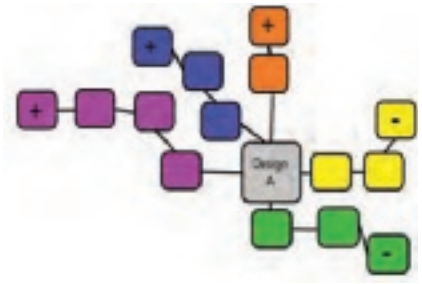
⇩ **Navigation to Next Lesson:** We are wondering how changes to our designs might affect other parts of our design, the solution as a whole, or the people who will use it. As we make decisions about how to revise and optimize our designs, what other possible effects do we need to consider?

LESSON 8

2 days

What effects might result from our design changes?

Investigation, Putting Pieces Together



When a change is made to a design, there are downstream consequences of varying degrees that may result in different effects on stakeholders.

We consider possible changes to implement in our design and chart the effects on the other characteristics of our homemade heater. We figure out:

- There may be negative consequences for some of our changes.
- We think about the effect on stakeholders to make decisions on which design changes will have the most positive impact overall.
- We use that information to decide which 2-3 changes we will implement in our final design.

⇩ **Navigation to Next Lesson:** We have identified changes that we think are important to make and are ready to dive into updating our designs.

LESSON 9

3 days

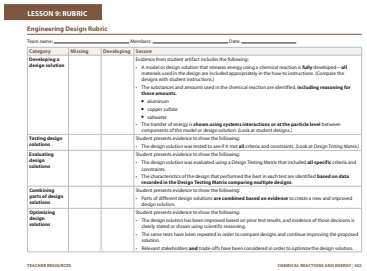
What is our optimal design for a homemade flameless heater?

Investigation

Test results inform the redesign of our homemade flameless heater.

We work in teams to optimize our homemade flameless heaters, build optimized prototypes, and test them using a Design Testing Matrix. We solidify our how-to instructions, and a partner team uses our instructions to build and test our homemade heater. After testing, we complete two self-assessments of how we did as a team in our engineering work. We revisit our Design Questions Board to evaluate and answer any remaining questions. We figure out:

- Design performance needs to be optimized by revising and retesting.
- Parts of different solutions can be combined to create a solution that is better than any of its predecessors.
- Designs and instructions need to be peer tested to inform modifications that will lead to a better solution.


LESSON 9: RUBRIC

Engineering Design Rubric

Team name _____ Members: _____ Date: _____

Category	Missing	Developing	Secure
Developing a design solution			Evidence from student artifact includes the following: • A model or design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design are included appropriately in the how-to instructions. (Compare the designs with student instructions.) • The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts.** ▪ aluminum ▪ copper sulfate ▪ saltwater • The transfer of energy is **shown using systems interactions or at the particle level** between components of the model or design solution. (Look at student designs.)
Testing design solutions			Student presents evidence to show the following: • The design solution was tested to see if it met **all** criteria and constraints. (Look at Design Testing Matrix.)
Evaluating design solutions			Student presents evidence to show the following: • The design solution was evaluated using a Design Testing Matrix that included **all specific** criteria and constraints. • The characteristics of the design that performed the best in each test are identified **based on data recorded in the Design Testing Matrix comparing multiple designs.**
Combining parts of design solutions			Student presents evidence to show the following: • Parts of different design solutions **are combined based on evidence** to create a new and improved design solution.
Optimizing design solutions			Student presents evidence to show the following: • The design solution has been improved based on prior test results, and evidence of those decisions is clearly stated or shown using scientific reasoning. • The same tests have been repeated in order to compare designs and continue improving the proposed solution. • Relevant stakeholders **and** trade-offs have been considered in order to optimize the design solution.

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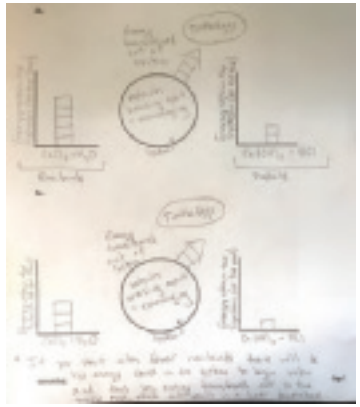
⇩ **Navigation to Next Lesson:** We realize we can answer most of the questions on the DQB. We've learned a lot, and we're ready to apply it to addressing other problems.

LESSON 10 **1 day** **How can we decide between competing designs?** Putting Pieces Together	 *Sea turtle populations in Australia are now over 99% female.*	We demonstrate understanding on a summative assessment transfer task involving sea turtle incubators. In this assessment we evaluate different designs and develop an argument for which sea turtle incubator design or combination of design features would work best based on relevant criteria and constraints. Then we celebrate our designs by thinking of other applications for our homemade heaters.	
LESSONS 1-10 **21 days total**			

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices within the context of hands-on investigations and demonstration, whether this is in a traditional science laboratory or in the field. In this way, teachers need to be aware of any school or district safety policies, legal safety standards, and better professional practices that are applicable to hands-on science activities being undertaken.

Science safety practices in laboratories or classrooms require engineering controls and personal protective equipment (e.g., safety goggles, non-latex aprons and gloves, eyewash/shower station, fume hood, and fire extinguishers). Science investigations should always be directly supervised by qualified adults, and safety procedures should be reviewed annually prior to initiating any hands-on activities or demonstration. Prior to each investigation, students should also be reminded specifically of the safety procedures that need to be followed. Each of the lessons within the units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as taking down, disposing of, and storing materials.

Prior to the first science investigation of the year, a safety acknowledgement form for students and parents or guardians should be provided and signed. You can access a model safety acknowledgement form for middle school activities from the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**.

Disclaimer: The safety precautions of each activity are based in part on use of the specifically recommended materials and instructions, legal safety standards, and better professional safety practices. Be aware that the selection of alternative materials or procedures for these activities may jeopardize the level of safety and therefore is at the user's own risk.

Please follow these lab safety recommendations for any lesson with an investigation:

- Wear safety goggles (specifically, indirectly vented chemical splash goggles), a non-latex apron, and nitrile gloves during the setup, hands-on investigation, and take down segments of the activity.
- Immediately wipe up any spilled water and/or granules on the floor, as this is a slip and fall hazard.
- Follow your *Teacher Guide* for instructions on disposing of waste materials and/or storage of materials.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.

Specific safety precautions are called out within the lesson using this icon and a callout box.

Information about the Copper Sulfate/Aluminum Foil Reaction

The amounts of aluminum and copper sulfate reactants were chosen based on the stoichiometry of the chemical reaction. Stoichiometry can be used to find the right proportion of reactants needed to "completely" react one reactant with the other reactant, resulting in no leftover reactants when the reaction takes place. In this case, when the *molar* ratio of $CUSO_4$ $5H_2O$ to Al is 1.5 (3:2), the reactants are present in more or less stoichiometric amounts, i.e., neither is present in excess (this is approximate, as we are not accounting for any Al_2O_3 on the surface of the aluminum foil). Therefore, the combination of 0.5 grams of aluminum to 5.5 grams of $CUSO_4$ yields the greatest temperature change. This explanation is beyond grade band; however, students should qualitatively see that, for the other proportions of the reactants tested in this lesson that did not perform as well, there is an excess of one of the reactants (e.g., excess foil or the solution remains blue with less copper forming).

Additional Guidance: Students may notice tiny bubbles on the surface of the root killer and aluminum reaction when they take the lid off of the cup after monitoring the temperature for 5 minutes. Although we may think of aluminum foil as being pure aluminum metal, it is actually covered with a very thin layer of aluminum oxide, since aluminum reacts very rapidly with oxygen in the air. Sodium chloride in the saltwater is able to disrupt the aluminum oxide layer to expose pure aluminum, which not only reacts with the root killer but can also react with water to produce hydrogen gas. Since students will be using this reaction in their design, you can share this explanation with them if it comes up.

TEACHER BACKGROUND KNOWLEDGE

What are the Disciplinary Core Ideas (DCIs) in the context of the phenomenon?

Disciplinary core ideas are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

In this unit, students are introduced to the anchoring phenomenon—a flameless heater in a Meal, Ready-to-Eat (MRE) that provides hot food to people by just adding water. Students individually develop an initial model to consider how a flameless heater works, but they also notice some problems with prepackaged MREs. To remedy those problems, the class decides to design a homemade flameless heater and lists situations in which a flameless heater to warm up food could be useful. In doing so, they identify stakeholders and come to realize anyone could need these, so our family and friends are stakeholders as well. This gives us a great opportunity to interact directly with stakeholders to get some of their initial ideas using a survey. After brainstorming ideas from the survey and developing some initial criteria and constraints, students attempt to create designs for a homemade flameless heater and compare their designs with classmates. Then the class builds a Design Questions Board and gathers ideas for investigations to guide their work. There are two lesson sets that span across the length of this 21-day unit.

In the first lesson set, students explore the inside of an MRE flameless heater, then do investigations to collect evidence to support the idea that this heater and another type of flameless heater (a single-use hand warmer) are undergoing chemical reactions as they get warm. Students decide the substances that make prepackaged MRE heaters and hand warmers heat up will not fit the criteria for a homemade design solution, and students test different chemical reactions to determine which process to use in their homemade heaters. Then, they investigate energy transfer from that system using Energy Transfer Models. The lesson set concludes by reflecting on the engineering design process, defining stakeholders, and refining the criteria and constraints for the design solution.

The second lesson set focuses on students developing their design solutions. They investigate how much food and reactants they should include in their homemade heater designs and go through a series of iterative testing and redesigning. This iterative design cycle includes peer feedback, consideration of design modification consequences, and analysis of impacts on stakeholders. Finally, students optimize their designs and have another team test their homemade heater instructions.

This unit builds toward the following NGSS Performance Expectations (PEs):

- **MS-PS1-6:** Undertake a design project to construct, test, and modify a device that either releases or absorbs thermal energy by chemical processes.
- **MS-ETS1-2:** Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
- **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.
- **MS-ETS1-4:** Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process so that an optimal design can be achieved.

This unit expands students' understanding of energy in chemical reactions in the context of engineering design. These are the Grades 6–8 DCI elements:

PS1.B: Chemical Reactions

- Some chemical reactions release energy, while others store energy.

ETS1.B: Developing Possible Solutions

- Models of all kinds are important for testing 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.

ETS1.C: Optimizing the Design Solution

- 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 the 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.

What should my students know from earlier grades or units?

- This unit directly builds on ideas that students figured out in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*. If your students have not done those units prior to beginning this unit, it is critical to supplement their understanding of the following DCIs:

PS1.A Structure and Properties of Matter

- Substances are made from different types of atoms, which combine with one another in various ways.
  - This unit uses chemical formulas to describe various substances and reactions that students investigate. Students should understand that substances are made up of atoms and be familiar with seeing atomic symbols to represent substances.
- Gases and liquids are made of molecules or inert atoms that are moving about relative to each other.
  - This unit includes sensemaking around gases, liquids, and solids. It is critical that students know that all states of matter are made of particles, even if we cannot see them.

PS1.B Chemical Reactions

- Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
  - Students use this prior knowledge to determine if a chemical reaction is taking place in the MRE heater. Then the class figures out how to design a homemade device that transfers energy using a chemical reaction
- The total number of each type of atom is conserved, and thus the mass does not change.
  - Students account for the conservation of matter in the reaction between the copper sulfate (root killer) and aluminum. They should have prior knowledge that no "new" matter is being created nor destroyed during a chemical process; rather, molecules are breaking apart and rearranging.

PS3.A: Definitions of Energy

- 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.
  - In this unit, students track energy transfers into or out of the various systems involved (the substances themselves, as well as the cup holding them, the air, the thermometer, etc.) to help figure out that the energy from a chemical process could be transferred to heat up the food in our homemade Meal, Ready-to-Eat.
- 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.
  - Students should come into the unit understanding that an increase of the average kinetic energy of particles of matter would show a higher temperature. Models at the particle level are used to compare when more or less energy is transferred from the chemical process system to the surrounding systems (e.g., packaging materials, food, thermometer, etc.).
- The temperature of a system is proportional to the average internal kinetic energy and potential energy per atom or molecule (whichever is the appropriate building block for the system's material). The details of that relationship depend on the type of atom or molecule and the interactions among the atoms in the material. Temperature is not a direct measure of a system's total thermal energy. The total thermal energy (sometimes called the total internal energy) of a system depends jointly on the temperature, the total number of atoms in the system, and the state of the material.
  - Students will model the movement of molecules at different temperatures, indicating an increase in speed at higher temperatures.

PS3.B: Conservation of Energy and Energy Transfer

- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. 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.
  - In Lesson 5, students will further investigate how the amount of energy transfer needed to change the temperature of matter depends on the size of the sample—they analyze data of energy transfer from a chemical reaction to various amounts of food. However, it is assumed that students understand how energy transfers from hotter regions or objects into colder ones through particle collisions.
- When the motion energy of an object changes, there is inevitably some other change in energy at the same time.
  - This DCI element is applied at the particle level when students are thinking about how to maximize or minimize energy transfer in their homemade heaters.

ETS1.A: Defining and Delimiting Engineering Problems

- 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.
  - It would be helpful to have prior exposure to this DCI element built into the *Cup Design Unit* or *Unit 6.5: Where do natural hazards happen and how do we prepare for them? (Tsunami Unit).* If students have not encountered this DCI before, then extra support in defining criteria and constraints will be needed in Lesson 1.

It will be helpful to have students familiar with using the following focal crosscutting concepts (CCCs) for this unit, specifically around the elements listed here from the 3–5 grade band. Systems and System Modeling has been listed here because this is an important lens for students to work with in the unit as well.

Energy and Matter

- Matter is made of particles.
- Matter flows and cycles can be tracked in terms of the weight of the substances before and after a process occurs.
- The total weight of the substances does not change. This is what is meant by conservation of matter. Matter is transported into, out of, and within systems.
- Energy can be transferred in various ways and between objects.
- Matter is conserved because atoms are conserved in physical and chemical processes (from the 6–8 grade band).

Systems and System Models

- A system is a group of related parts that make up a whole and can carry out functions its individual parts cannot.
- A system can be described in terms of its components and their interactions.

Students should be familiar with using the following focal science and engineering practices (SEPs) for this unit, specifically around the elements listed here from the 3–5 grade band.

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.
- Evaluate appropriate methods and/or tools for collecting data.
- Make observations and/or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or test a design solution.
- Make predictions about what would happen if a variable changes.
- Test two different models of the same proposed object, tool, or process to determine which better meets criteria for success.

Constructing Explanations and Designing Solutions

- Construct an explanation of observed relationships.
- Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.
- Identify the evidence that supports particular points in an explanation.
- Apply scientific ideas to solve design problems.
- Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution.

What are some common ideas that students might have?

This unit will focus a great deal on energy transfer between systems. However, at the start of this unit, students may or may not identify the heater and food as two distinct systems, and they may not yet name energy transfer as the cause for the food heating up. Working with students to use the CCC

lens of Systems and System Models will help them accurately identify energy transfers to and from chemical reactions.

A common partial understanding students may have is that, during an exothermic reaction, when the thermometer detects a temperature increase, energy is being put into the system in order for it to feel warmer. This seems logical at first because in the *Cup Design Unit* unit students learned that, when objects heat up, energy is being transferred to them. The difference here is that the system of reactants itself is not gaining energy—the system releases energy so that the other surrounding systems, such as the environment, thermometer, and food items, get energy transferred to them and, thus, heat up. As the unit progresses, students will identify that, during an exothermic reaction, energy is transferred to other systems from the chemical reaction system. For instance, the chemical reaction system transfers energy to the thermometer, its container, the outside environment, and the food. That's why those objects feel warmer.

What modifications will I need to make if this unit is taught out of sequence?

This is the second unit taught in 7th grade in the Scope and Sequence. If this unit is taught earlier in the middle-school curriculum, the following modifications would need to be made:

- Introducing the students to the concept of a Driving Question Board and a shared set of classroom norms. This would not be necessary if taught after other units.
- Supplemental teaching of several PEs from *Cup Design Unit*:
  - **MS-PS1-4:** *Develop a model that predicts and describes changes in particle motion, temperature, and state of a pure substance when thermal energy is added or removed.*
  - **MS-PS3-3:** *Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.*
  - **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.*
  - **MS-PS3-5:** *Construct, use, and present arguments to support the claim that, when the kinetic energy of an object changes, energy is transferred to or from the object.*
  - **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.*
- Supplemental teaching of several PEs from *Bath Bombs Unit*:
  - **MS-PS1-1:** *Develop models to describe the atomic composition of simple molecules and extended structures.* Chemical formulas of substances are used in this unit. It is assumed that students understand the DCI element that substances are made from different types of atoms, which combine with one another in various ways.
  - **MS-PS1-2:** *Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.* This unit does not teach students how to identify if a chemical reaction has occurred. Students use this previous knowledge and apply it to new phenomena to determine if the chemical processes they observe are, in fact, chemical reactions. Students may start to recognize chemical reactions as early as Lesson 1 while observing the MRE heater, which gives off hydrogen gas as a product. This is an indication that the MRE heater is undergoing a chemical reaction, which students should recognize from their prior experiences in *Bath Bombs Unit*.
- Make sure students have the necessary Common Core 6th-grade math concepts regarding ratios and proportions. For more details, see the following section about prerequisite math concepts necessary for the unit.

What are the prerequisite math concepts necessary for the unit?

In Lesson 3, students calculate the maximum temperature change for three different amounts of reactants. They report this change in temperature using positive and negative numbers to show the increase or decrease from the starting temperature. Prerequisite math concepts that may be helpful include the following:

- CCSS.MATH.CONTENT.6.NS.C.5 Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.

In Lesson 4, students determine the relative proportion of each reactant that showed the optimal temperature change by calculating the percentage of each reactant. Prerequisite math concepts that are needed include the following:

- CCSS.MATH.CONTENT.6.RP.A.3.C Find a percent of a quantity as a rate per 100 (e.g., 30% of a quantity means 30/100 times the quantity); solve problems involving finding the whole, given a part and the percent.

In Lesson 6 and Lesson 9, students will scale up the amount of reactants to use in their homemade heaters but maintain the same proportion of reactants they found to be most efficient in previous testing. Furthermore students then scale down amounts to test their prototypes. Prerequisite math concepts that may be helpful include the following:

- CCSS.MATH.CONTENT.6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double-number line diagrams, or equations.
- CCSS.MATH.CONTENT.6.RP.A.3.A Make tables of equivalent ratios relating quantities with whole-number measurements, find missing values in the tables, and plot the pairs of values on the coordinate plane. Use tables to compare ratios.

In Lesson 6 and Lesson 9, students will need to calculate the correct amounts of water beads and plain water to make "water bead soup" as a proxy for food in their prototype heaters. The ratio of water beads to plain water is 1:3 (1 part water beads to 3 parts water), and students will measure the beads and water in grams. Prerequisite math concepts that may be helpful include the following:

- CCSS.MATH.CONTENT.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote that candidate A received, candidate C received nearly three votes."*
- CCSS.MATH.CONTENT.6.RP.A.3.D Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

In Lesson 9, students may want to redesign their homemade heaters to increase the surface area of the reactant system that is in contact with the food system. While mathematical calculation of surface area will not be necessary for these design improvements, it may be helpful if students understand the concept of surface area. As such, the following standard may provide a connection point:

- CCSS.MATH.CONTENT.7.G.B.6 Solve real-world and mathematical problems involving area, volume, and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

How is this unit approaching the crosscutting concept of energy?

Many research studies of student learning have revealed that traditional approaches to teaching energy are ineffective and result in student difficulties in using energy to make sense of different phenomena (Nordine, Krajcik, & Fortus, 2011). *A Framework for K-12 Science Education* supports an updated approach to energy instruction that focuses students on the concept that there is a single quantity called energy and deemphasizes a focus on naming the forms of energy (National Research Council, 2012). In other words, energy is energy, regardless of the phenomena or form it's in. Research also shows that, when students focus their knowledge building on the concept of energy transfer, they have better energy-related learning outcomes (Fortus et al., 2019). As such, for this unit we adopted an approach to energy instruction based on energy transfers between systems, regardless of the phenomena or form of energy.

In this unit, students investigate different chemical reactions to help determine which will work best for their homemade heaters. They track energy transfers into or out of the various systems involved (the substances themselves, as well as the container holding them, the air, the thermometer, etc.) to help figure out that the energy from a chemical process could be transferred to heat up the food in our homemade Meal, Ready-to-Eat. We intentionally do not have students identify the different forms of energy in order to focus students' thinking around energy as a single quantity that transfers into and out of systems.

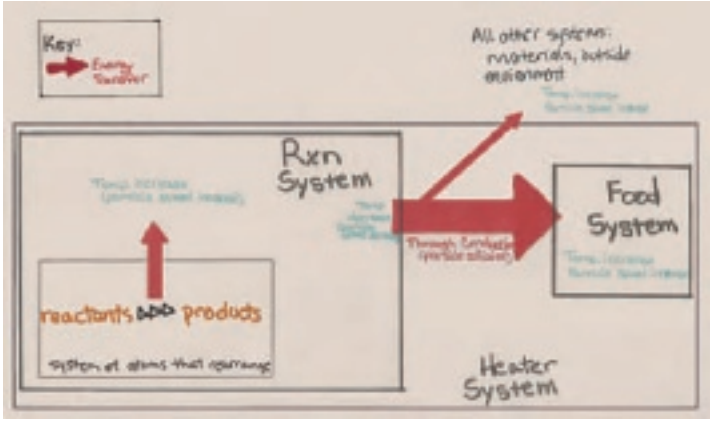
The crosscutting concept of energy is particularly important as students work in this unit to understand how they can design a device that uses a chemical reaction that transfers energy. Students will identify that, when the thermometer shows an increase in temperature, the thermometer is measuring an increase in energy of the surroundings. Since that energy was transferred from the system of substances they are testing, that system of substances has had an equivalent decrease in energy. Namely, the chemical reaction system transfers energy to the thermometer, its container, the outside environment, and the food. Therefore, the "reaction," or chemical reaction system, is decreasing in energy while the surroundings are increasing in energy, which is why those objects heat up and feel warmer. Similarly, when the thermometer shows a decrease in temperature, energy is being transferred from the surrounding system to the chemical reaction system. More specifically, when energy from the surrounding systems, like the thermometer, is transferred to the chemical reaction system, a decrease in temperature of the surroundings occurs. Therefore, in this case, the surroundings are decreasing in energy while the energy in the chemical reaction system is actually increasing, which might seem counterintuitive to students.

How does using Energy Transfer Models support this approach?

The Energy Transfer Models are visual representations used to track the flow of energy. As the molecules in a system of reactants are rearranged during a chemical process, there are energy transfers between the system of reactants and the surroundings. Any energy that is transferred to the environment or other systems comes from the relationship between the reactants, so the energy in the system of products is decreased by that same amount.

How can I help my students be successful in thinking about energy in this way?

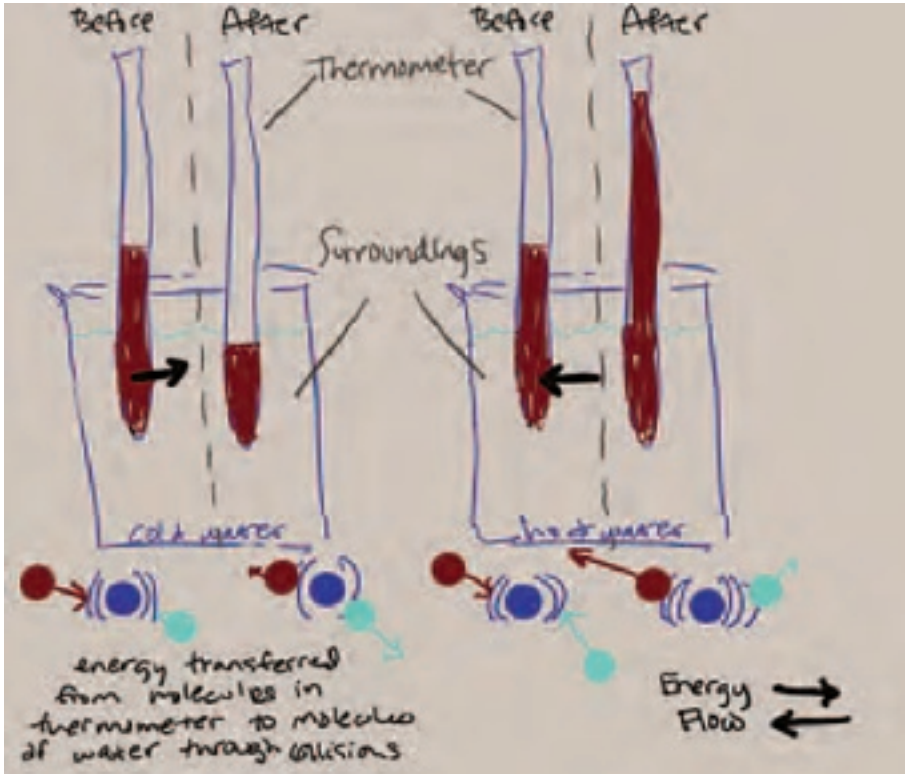
The crosscutting concept of systems and system models is critical to helping students think about energy transfers in chemical reactions. Supporting students in specifying system boundaries and making an explicit model of systems can greatly help their conceptual understanding of energy transfers in chemical reactions. For example, if students can identify the thermometer and the environment as separate systems from the molecules of the various substances in a chemical reaction, it supports reasoning about why an exothermic reaction transfers energy to the surroundings, leading to an increase in temperature of the thermometer. A systems approach supports similar reasoning for endothermic reactions. In these cases, energy is transferred away from the thermometer and environment, causing the thermometer to show a decrease in temperature and the environment around the chemical reaction system to feel cold.



However, if students think of the container, reactants, and thermometer as one system, then it seems illogical that an exothermic reaction could be showing an increase in temperature if it's actually giving away energy. Helping students to define the boundaries of the systems and carefully define the parts of systems that are involved supports their understanding of the energy transfer happening in these chemical reactions.

Why aren't students talking about bonds?

The full mechanism for patterns in energy transfer involves the bonds and bonding energies between atoms in the system of substances in a chemical reaction. However, students will figure out why these patterns occur in high school, as bonds between atoms are beyond the middle-school grade-band endpoint, according to *A Framework for K-12 Science Education* and NGSS (National Resource Council, 2012). Despite this grade-band boundary, students are still able to build a coherent explanation showing how energy is transferred to and from the chemical process system to other systems and why chemical reactions feel warmer or cooler based on those energy transfers.



References:

Fortus, D., Kubsch, M., Bielik, T., Krajcik, J., Lehavi, Y., Neumann, K., . . . Touitou, I. (2019). Systems, transfer, and fields: Evaluating a new approach to energy instruction. *Journal of Research in Science Teaching,* 56(10), 1341-1361.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Nordine, J. C., Krajcik, J. S., & Fortus, D. (2011). Transforming energy instruction in middle school to support integrated understanding and future learning. *Science Education,* 95(4), 670–699.

GUIDANCE FOR DEVELOPING YOUR WORD WALL

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have "earned" that word and can add the specific term to the class Word Wall. These "words we earn" should be recorded on the Word Wall using the students' own definition whenever possible. On the other hand, "words we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, words we encounter are helpful just in that lesson and need not be recorded on the Word Wall. However, if a word we encounter will be frequently referred to throughout the unit, it should be added to the Word Wall. As such, the Word Wall becomes an ongoing collection of words that we will continue to use, including all of the words we earn in the unit and possibly a few key words we encounter.

It is best for students if you create cards for the Word Wall in the moment, using definitions and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the posted meaning of the word, students "own" the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes creating Word Wall cards in the moment is a challenge. The teacher guide provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate. If you keep one Word Wall in your classroom for several sections of students, you might choose to record each class's definition separately, and then propose an "official" definition to post the next day that captures the collected meaning.

The words we earn and words we encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Words we earn	Words we encounter
L1	criteria, constraints (both recalled from *Cup Design Unit* and/or *Tsunami Unit*), chemical reaction (recalled from *Bath Bombs Unit*)	
L2	research	
L3	exothermic, endothermic	
L4	stakeholders	optimize
L5	trade-offs	
L6		prototype
L7		
L8	cascading consequences	
L9		
L10		

TEACHING SCIENCE LITERACY

How does the Core Knowledge Science Literacy routine integrate with the unit investigations?

The Core Knowledge Science Literacy Student Reader and the weekly Science Literacy routine layer varied reading opportunities into the science unit. In their lives after graduating from high school, most students will not become scientists. They will no longer routinely participate in guided investigations to figure out how phenomena work. They will, however, read text about science and scientific claims, day in and day out. The ability to learn and think about science through reading is a skill unto itself and is important in tandem with investigative learning. It is natural to primarily associate emerging literacy with reading and writing instruction at the elementary level, but middle school is an important time to hone literacy skills—specifically in science in the era of politicization of science topics, polarization among adults, and proliferation of misinformation on social media. Detection and construction of well-reasoned explanations are important not just in science, but throughout everyday life. Using claims and evidence in reasoning is the way that thoughtful people think about things, and writing is thinking in print. Students become voters as they emerge from high school, so it is important that they acquire skills for detection of faulty information and practice legitimate communication about scientific issues in the years leading up to that civic benchmark.

Throughout the course of the unit's investigative lessons, students write in their science notebooks in some fashion almost daily, and significant emphasis is placed on the speaking and listening communication threads of the CCSS. The instructional design of the investigations is deliberately light on having students access disciplinary core content through text. NGSS emphasis is on students investigating phenomena along the storyline, so students' interaction with text within lessons is minimal and in service to the unit's storyline. The Science Literacy routine is integrated to exercise students' ability to interact with text about science topics. The routine presents students with short reading selections in a variety of styles, all related to the unit in which students are engaged. Each reading selection is accompanied by a brief but thoughtful writing exercise.

The subject matter of the reading selections ties back to the unit, but the timing for the assigned readings is such that students do not read about specific facets of the subject before they have completed the lessons to investigate that content. In other words, the reading enhances and reinforces the knowledge that students have built in previous lessons; the reading does not reveal beforehand the key takeaways that students are intended to learn through lesson interactions.

When is it done within a unit?

The Core Knowledge Science Literacy Student Reader includes one reading collection per week for every week of the unit. A week's reading collection relates to the lessons completed in the previous week. The reading is assigned at the beginning of the week with the accompanying writing exercise due at the end of the week.

The reading and writing exercises are designed to be completed by students independently, with brief, supporting, teacher-facilitated discussions at the beginning, midpoint, and end of the week.

How do students typically represent their thinking as part of the routine?

Students generate a written product associated with each reading selection. The products are varied in form and include graphic organizers, concept maps, cartoons, memes, infographics, storyboards, outlines, and paragraphs. The complexity of the products increases from week to week, with the final product for the unit being a single, thoughtfully reasoned, and well-constructed paragraph.

Put Yourself in This Scene

Literacy Objectives

✓ Initiate thinking about the need to evaluate information in text and images.

Literacy Exercises

- Read a brief selection to pique interest, launch discussion, and begin to frame expectations.

Instructional Resources

Student Reader

Preface

Science Literacy Student Reader, Preface
"Put Yourself in This Scene"

No Prerequisite Investigation

The reading of the Preface is appropriate during the first week of unit instruction. The reading does not preemptively tell students facts about the topic that they are intended to learn throughout the course of their investigations.

Standards and Dimensions

NGSS

MS-PS1-2: (Building toward) **Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.**

Disciplinary Core Ideas

PS1.B: Chemical Reactions

Science and Engineering Practice: Analyzing and Interpreting Data

Crosscutting Concept: Cause and Effect; Patterns

CCSS: English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.8: Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. No Core Vocabulary terms are highlighted in the Preface.

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

science literacy **skepticism**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the Science Literacy Student Reader.
- Friday: Set aside time at the end of the week to facilitate a brief discussion about the reading.

You'll proceed with the in-class lesson investigations during this week.

2. Preview the assignment and set expectations. (Monday)

- Let students know that for the Science Literacy routine, they will read independently and then complete short writing assignments. The reading selections relate to topics they will be exploring in their Chemical Reactions and Energy unit science investigations.
- The reading and writing will typically be completed outside of class (unless you have available class time to allocate).
- The first week's reading is a short introductory segment in the book, and there is no accompanying writing exercise as the unit is getting started.
- The class will discuss the reading together at the end of the week.

SUPPORT—The Preface is written at approximately Lexile 1000–1150, which leans toward the high end of the expected text complexity band for middle school. You may wish to introduce a word identification and comprehension convention into your routine to support struggling readers. Hang an envelope near the door with the label, "When we talk about the next reading selection, I could use a little more help understanding the word(s) . . . " Encourage students, as they are reading, to jot words, phrases, or sentences that they are unclear about onto small scraps of paper and tuck them into the envelope at any time preceding the discussion of the reading. Whenever you facilitate class discussion about a reading selection, check the envelope first, and layer in added examples and repeat definitions to help students build comprehension and fluency for terms or complex sentences about which they have revealed they are uncertain.

3. Facilitate discussion. (Friday)

Facilitate a brief class discussion about the Science Literacy Student Reader Preface, entitled "Put Yourself in This Scene."

Pages 2–3 Suggested prompts	Sample student responses
How would you summarize the "scene" referred to in the title?	*While camping, you need to cook food. Instead of building a fire, you use a flameless heater, but you don't think it provided enough heat to cook your food thoroughly. Uncooked meat, or meat that is not cooked to the proper temperature, could make you sick.*
Why do you need to prepare food for a camping trip?	*You will need to eat because you will get hungry. If you don't eat, your body won't have enough energy to move or live.*
What do you know about flameless heaters?	*You can use them to produce heat. You can use them to warm your hands or cook food.*
Why do some foods need be cooked?	*If you don't cook some foods properly, like meat or eggs, they would not be appetizing and worse could make you sick. Cooking food kills harmful bacteria or germs.*
What advantages would a flameless heater have over a camp stove or building a fire?	*They are smaller and easier to carry than a camp stove. You don't need to collect firewood when you use a flameless heater. You also don't need to build and watch over a fire.*

Key Idea: Point out that we use chemical reactions every day. Treating stains on clothes with stain removers, lighting a match, cooking with baking soda, using batteries, and eating and digesting food all involve chemical reactions. Both the investigations and the reading selections in the unit ahead will help students advance to a place where they have more knowledge to apply to the scenario, and they will circle back at the end of the unit to the topic of chemical reactions.

Student Reader

Preface

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

EXTEND—Watch a video to show how to use a flameless heater.

SUPPORT—Make a class list of what students suspect are common chemical reactions. Refer back to the list periodically throughout this unit to add, change, or delete chemical reactions on the list.

LESSON 1

How can we heat up food when we don't have our typical methods available?

Previous Lesson

There is no previous lesson.

This Lesson

Anchoring Phenomenon

3 DAYS

In this lesson, we see that the flameless heater in a Meal, Ready-to-Eat (MRE) can provide hot food to people when typical cooking methods are not available. We develop an initial model to consider how a flameless heater works, but we also notice that MREs may not always be a viable solution. We decide to design a homemade flameless heater, and we list situations in which that could be useful. After brainstorming criteria and constraints, we create designs for a homemade flameless heater and compare our designs with other people's. We build a Design Questions Board and gather ideas for investigations that will guide our work as we continue designing.

Next Lesson

We will research existing solutions (flameless heaters and hand warmers) to determine whether we can incorporate either into our homemade heater design. We will use the results of our research and the Energy Transfer Model we create to help understand what the next step in our design process should be.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

1.A Ask questions that arise from careful observation of a flameless heater that is able to heat food (effect) using a chemical process (cause).

1.B Define a design problem that can be solved through the development of a homemade flameless heater with multiple criteria and constraints that uses a chemical process (system 1) to heat up food (system 2).

1.C Apply scientific ideas to design a solution for a flameless heater that heats food by a chemical process that transfers energy.

What Students Will Figure Out

- Prepackaged MREs are useful, but they are expensive, possibly confusing to use, and can be difficult to get to people.
- We want to design an effective, inexpensive, easy-to-use flameless heater that people can make at home and use to heat food when typical methods are not available.
- We need to gather more-detailed information from testing and data analysis to inform and improve further redesigns.
- We have a lot of questions and ideas for investigations that will continue to drive our design work.

Lesson 1 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**INTRODUCE AN INTERESTING PHENOMENON** Turn and talk about the ways in which people typically heat up food and show a few images of MREs, which provide hot food without those typical heating methods.	A-E	
2	12 min	**DEMONSTRATE USING AN MRE WITH THE WHOLE CLASS** Open an MRE and demonstrate how to use the flameless heater, watch a video of someone eating an MRE meal, and record and share noticings and wonderings.	F-H	chart paper, markers, MRE Flameless Heater Demonstration 7.2 Lesson 1 Person Eating an MRE (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
3	5 min	**DEVELOP AN INITIAL MODEL ON OUR OWN** Individually develop a model to explain how the flameless heater works to heat food just by adding room-temperature water.	I	*Initial Model*
4	5 min	**COMPARE INITIAL MODELS IN PARTNERS** Meet with a few different partners to find similarities and differences between models.	J	*Initial Model*
5	3 min	**REVIEW NORMS** Briefly consider class norms and choose one to focus on today.	K-L	Classroom Norms poster
6	12 min	**DEVELOP A CLASSROOM CONSENSUS MODEL** Co-construct an initial classroom consensus model, finding points of agreement and disagreement about how the flameless heater could work.	M	*Initial Model*, chart paper, markers

Part	Duration	Summary	Slide	Materials
7	3 min	**REFLECT ON NORMS AND ASSIGN HOME LEARNING** Reflect on the chosen focal norm and discuss how well the class did with following norms altogether.	N-O	Classroom Norms poster, projector Students Electronic Surveys, Why + How To (See the **Online Resources Guide** for a link to this item **www.coreknowledge.org/cksci-online-resources**)
				End of day 1
8	5 min	**REVIEW COMMUNITY SURVEY RESULTS** Record noticings and wonderings from reviewing the results of the survey.	P	projector
9	5 min	**BRAINSTORM RELATED SITUATIONS** Make a list of situations in which homemade flameless heaters could be useful.	Q	chart paper, markers
10	5 min	**NOTICE AND WONDER ABOUT SITUATIONS DURING WHICH MRES ARE TYPICALLY USED** Record noticings and wonderings from viewing photos of other situations where MREs were useful.	R-BB	chart paper, markers
11	7 min	**DEFINE OUR PROBLEM AND PROPOSE A SOLUTION** Identify problems with MREs. After collecting and sharing these problems as a class, propose a solution: designing a homemade flameless heater.	CC-HH	loose-leaf paper (6-8 sheets), chart paper, markers
12	6 min	**BEGIN PROGRESS TRACKERS** Set up Progress Trackers in science notebooks, including new column headings specific to the engineering work we will do in this unit.	II	chart paper, markers, 4" x 6" sticky notes
13	5 min	**DISCUSS CRITERIA AND CONSTRAINTS** Recall the meanings of *criteria* and *constraints* and record some of our criteria and constraints for a homemade flameless heater in our Progress Trackers.	JJ-LL	chart paper, markers
14	6 min	**DEVELOP INITIAL DESIGN** Individually create a design solution for a homemade flameless heater.	MM	1 sheet of blank paper (unlined), Initial Classroom Consensus Model, Criteria and Constraints chart
15	6 min	**COMPARE INITIAL DESIGNS IN SMALL GROUPS** Use the *Talking Sticks* protocol to share models of initial design solutions with a small group. Reflect on the designing and sharing process for home learning.	NN-OO	*Initial Model*, *Initial Design Reflection*
				End of day 2

Part	Duration	Summary	Slide	Materials
16	8 min	**REFLECT ON INITIAL DESIGN SOLUTIONS** Debrief last time's design work, including challenges, and collect ideas for how we could improve the process moving forward.	PP-QQ	*Initial Design Reflection*
17	5 min	**GENERATE QUESTIONS** Consider all the experiences in class so far and write questions that will help drive our next steps.	RR	a few sticky notes per student, Initial Classroom Consensus Model, Related Situations poster
18	18 min	**BUILD A DESIGN QUESTIONS BOARD** Share questions aloud and group them together with other similar questions to form a Design Questions Board that will guide the work of the class going forward.	SS	sticky notes with questions
19	7 min	**GENERATE IDEAS FOR INVESTIGATIONS** Brainstorm with a partner how we could find answers to our design questions.	TT	Design Questions Board
20	7 min	**SHARE IDEAS FOR INVESTIGATIONS** Compile a whole-class list of ideas for investigations to reference throughout the unit.	UU	chart paper, markers

End of day 3

Lesson 1 • Materials List

	per student	per group	per class
MRE Flameless Heater Demonstration materials			• 1 complete MRE package • 6 extra flameless heaters • 25 mL room-temperature water
Lesson materials **Student Procedure Guide** **Student Work Pages**	• Science Notebook • *Initial Model* • 1 sheet of blank paper (unlined) • *Initial Design Reflection* • a few sticky notes per student • sticky notes with questions		• chart paper • markers • 7.2 Lesson 1 Person Eating an MRE (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • Classroom Norms poster • *Student Electronic Surveys: Why + How-To* (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

	per student	per group	per class
			• projector • loose-leaf paper (6-8 sheets) • 4" x 6" sticky notes • Initial Classroom Consensus Model • Criteria and Constraints chart • Related Situations poster • Design Questions Board

Materials preparation (30 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

If you taught *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* immediately preceding this unit, keep the Word Wall words posted and the Key Model Ideas list in view as students will continue to refer to those in this unit. If you do not still have these available, post a photo of the Word Wall and Key Model Ideas from *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* for reference or re-post relevant words and ideas as needed throughout this unit.

Be sure to leave enough water out (you will need 25 mL per class) several hours before class begins so it can come to room temperature.

Test the video 7.2 Lesson 1 Person Eating an MRE to be sure it plays correctly (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Students will need to refer to the classroom norms you've already established, visible either on a poster in the room, in their science notebooks, or on **slide K**.

Prepare the electronic student survey for the class following the steps listed in *Student Electronic Surveys: Why + How-To*.

Be sure you have materials ready to add the following words to the Word Wall: *criteria*, *constraints*. Do not post these words on the wall until after your class has developed a shared understanding of their meanings.

Day 1: MRE Flameless Heater Demonstration

- **Group size:** whole class
- **Setup**
  - You'll want to use the same MRE package for each class you teach, so you'll open it with your first class of the day, then repack it, being sure to include a replacement flameless heater, to "reopen" for each subsequent class.
  - You'll need about 25 mL of water for each class—be sure to let the water sit out well before class begins to come to room temperature.

- For your reference, a video of opening and using the MRE is available at 7.2 Lesson 1 Person Eating an MRE (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

- **Notes for during the lab:** First check to make sure that the heater is not damaged, or it may not work. Then start the heater as directed on the package and continue passing around the other components of the MRE and spare flameless heater(s) for the class to observe while you're waiting for the food to heat up.
- **Safety:** Safety recommendations for teachers and students.
  - Never open and expose the contents of the heater. There is a risk for cross contamination.
  - Ensure that the lab has engineering controls (eyewash station and shower) available.
  - Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
  - Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
  - Follow your teacher's instructions for disposing of waste materials.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Wash your hands with soap and water immediately after completing this activity.
  - Never eat any food items used in a lab activity.
  - Never taste any substance or chemical in the lab.
  - Use caution when working with heated liquids—this can burn skin!
  - Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.
- **Disposal:** You can dispose of the *used* flameless heater in the regular trash but keep the other components of the MRE and repack them to reopen with your other classes. In Lesson 5, you will want to have the MRE available to find the total mass of everything inside an MRE, so repack it and save it for that lesson. However, check the food packages—if they are damaged, punctured, or opened, mass the whole package now and record the mass for students to use in Lesson 5. Then discreetly dispose of the damaged packages (after students have left the room).
- **Storage:** Store sealed components at room temperature as long as indicated on the package.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson (and this unit) builds directly on science ideas that students figured out in the *Bath Bombs Unit* unit. For instance, when students are observing and modeling the flameless heater in this lesson, they will suggest that some kind of chemical process is happening, possibly a chemical reaction. If they are convinced that this is a chemical reaction (it is, and the package states that hydrogen gas is produced), that is fine. If they are not convinced that it's a chemical reaction (because we don't yet know what substances the flameless heater contains to begin with, and they might be skeptical about a chemical process causing something to heat up), that is fine, too. Students will have an opportunity in Lesson 2 to investigate the reactants and confirm that this is a chemical reaction.

This lesson (and this unit) also builds directly on ideas that students figured out in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*. For instance, students will model the movement of molecules at different temperatures, indicating an increase in speed at higher temperatures.

In this lesson, students will take a first pass at designing their own flameless heater (on paper). The intent of this first-draft design is twofold: (1) to leverage students' excitement to "jump in" and try putting their ideas on paper after spending time discussing problems and listing criteria and constraints and (2) to motivate the need to gather more-detailed information from testing and data analysis to inform and improve further redesigns.

Where We Are NOT Going

While students will notice that this flameless heater causes food to heat up, they do not yet name this an *exothermic process*. That term is added to the Word Wall in Lesson 3, after students also have experience with exothermic and endothermic processes.

This unit will focus a great deal on energy transfer between systems, but in this lesson, students may or may not identify the heater and food as two distinct systems; and they may not yet name energy transfer as the cause of the food heating up. That thinking may begin here but will be further developed throughout the unit, beginning in Lesson 2.

LEARNING PLAN FOR LESSON 1

1. Introduce an interesting phenomenon.

5 MIN

Materials: None

Turn and talk about the ways people heat food.* Display **slide A**. Say, *I have a question to get us thinking about a new phenomenon we're going to explore. Think about all the ways in which people can heat up food inside and outside of their homes. Turn to an elbow partner and start listing ways you know of that we can heat our food.*

Share ideas about how people typically heat food. Briefly invite students to share what they said or what they heard from their partner about how people can heat their food. It is not necessary to record these ideas. Possible student responses include stovetop, oven, microwave, grill, toaster, campfire, and so forth.

Introduce our question.* Display **slide B**. Say, *You all came up with a lot of ways people typically heat their food. But what if people didn't have those methods available to them? I have some situations for us to consider in which people were not able to heat up their food in the usual ways. Everyone deserves not only enough food, but good, satisfying food—our physical and mental health depends on it. So, let's see how these people got hot food when they did not have their typical ways to heat up food. The photos of the situation we are about to see were taken after a natural disaster. In a previous unit, Tsunami Unit, we have thought a lot about unforeseen events that are devastating for those who live through them. I want to remind us that emergency situations can be hard to think and talk about, especially if we know someone who has experienced something like this. So, we will be thoughtful about what we say and how we say it and try to be mindful of keeping our focus on how people dealt with the problem of getting hot food without using the methods you all just mentioned.*

Additional Guidance

If you know that you have students or their family members who were affected by natural hazards, such as Superstorm Sandy in New York or Hurricane Maria in Puerto Rico, check in with them before you share the photos in this lesson. If it will make them uncomfortable to be in the whole-group setting while the class views these photos, you may want to offer an alternate setting for those students to consider how MREs have been used in disaster response or modify for your class how you frame the use of MREs (such as selecting different images or talking about rather than showing images).

Show a few images of MREs being distributed. Display **slide C**. Say, *Sometimes there are such big storms that whole cities don't have power. In this case, Superstorm Sandy knocked out power to New York City. In situations like these, helpers passed out something called Meals, Ready-to-Eat, or MREs.*

*** Attending to Equity**

This unit centers around Meals, Ready-to-Eat, which include a flameless heater because it can be comforting to have a warm meal, especially in the types of situations where MREs are often used (see Spence [2017] and Lawrence and Bargh [2008]). However, for students who do not have regular access to enough food, designing around how best to heat food might be especially difficult. Before beginning this unit, confirm what supports your school has in place for students who deal with food insecurity.

If you don't already know which students in your class experience food insecurity, you may want to find out so that you can check in with them (yourself or along with your school's social worker) to let them know a bit about what to expect in the unit and make sure they are connected with the supports available to them. If, during the course of this unit, a student shares with you that they are experiencing food insecurity, you want to be prepared to listen and refer them to supportive resources. It is important to provide space to normalize conversations about food insecurity. Note that this first lesson will be the only time that actual food is present

Alternate Activity

If time allows, you may want to provide more context about the development of MREs. The video explains how the US military's goal with MREs is to not only provide proper nutrition to the troops but to give them a sense of comfort and home with this food, as well. (See the **OnlineResources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Display **slide D**. Say, *Here are a few more photos of people getting cases of water and of these Meals, Ready-to-Eat in New York City after Superstorm Sandy.*

Display **slide E**. Say, *So in situations like after Superstorm Sandy, people were using these Meals, Ready-to-Eat. They include something called a "flameless heater" that is able to warm food without using electricity, gas, or fire. These photos show people eating warm food, and you can even see in one photo just how hot the food gets. But how does it do that without using the ways we're used to heating up our food? I have one here, so let's check it out!*

Additional Guidance

It's possible that some of your students have had experience with MREs and will be anxious to share what they know. In order to value these experiences while still allowing access for students who have not had experiences with an MRE, you may want to say something like, *We are going to silently and individually record our noticings and wonderings about this MRE so that everyone gets a chance to see it work and think about it for themselves. We will have several opportunities to share our thinking soon.*

in the classroom—in future lessons, water will be used as a proxy for food.

Spence, C. (2017). Comfort food: A review. *International Journal of Gastronomy and Food Science*, *9*, 105–109.

Williams, L. E., & Bargh, J. A. (2008). Experiencing Physical Warmth Promotes Interpersonal Warmth. *Science*, *322*(5901), 606–607.

(See the **OnlineResources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

* Attending to Equity

Supporting empathy and emotions: A unit where its phenomenon is connected to natural hazards is likely to elicit emotional stress from some students, either in terms of the empathy they feel for those affected or from experiencing a natural hazard directly or through the experiences of family and friends.

Emotional stress from a disaster can often be great in students who feel they do not understand the situation or that they have no control over the situation. While natural hazards often bring impacts that students cannot control, the aim of this unit is to help students consider how helping people build flameless heaters during and after natural hazard events can be good and to empower them to use what they learn during this unit to respond in ways that can help and comfort their loved ones in the event of a disaster.

If you have students who have traumatic experiences from natural hazards, consider some of the resources found in the *Tsunami Unit* unit.

2. Demonstrate using an MRE with the whole class. 12 MIN

Materials: MRE Flameless Heater Demonstration, science notebook, chart paper, markers, 7.2 Lesson 1 Person Eating an MRE (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Additional Guidance

Before opening the MRE package and again before watching the video of the person eating the MRE, remind your students to show empathy about the food they're seeing. It may not appear appetizing to everyone's different tastes, but it can be life-sustaining for people in difficult circumstances, such as after natural disasters or on tour with the military. We need to keep those situations in mind and avoid comments about the food that would be disrespectful.

Set up Notice and Wonder charts. Display **slide F**. Direct students to create a T-chart on the next clean page of their science notebook to record their noticings and wonderings as you open and demonstrate what's in the MRE package. Remind students that in a lab setting they should never eat or drink food prepared or brought into a lab, because there is a risk of cross contamination.

Science Notebook

If you haven't already set up science notebooks for this unit, direct your students to count off about 4 pages to use as a table of contents. They will also need to set aside 10–15 pages at the end of the notebook to use for their Progress Tracker (starting on day 2).

Observe the MRE's flameless heater. Open the MRE package and remove the flameless heater first. Say, *OK, so this is the part that actually does the heating up of the food, and I want us to get a good look at it. So, I have some extras of these to pass around. Be gentle with them and don't open them but take a look at one and record what you notice and wonder.*

Additional Guidance

The flameless heaters will not work correctly if they have been opened, torn, or punctured (such as with a pencil) before use, so be sure students pass them around carefully.

Be sure that all the supplies, including water, that you're using during this lesson and all future lessons are at thermal equilibrium. Since temperature change will be our indicator of energy transfer in this unit, it is important that all the substances and materials we use begin at the same temperature so our measurements of temperature change are reliable. You may want to get in the habit of setting out containers of water before you leave school each day so that they can come completely to room temperature before class the next day.

Pass around the extra flameless heaters for students to observe up close, keeping the one from the package near you. After a minute, let the extra heaters continue circulating among the group and say, *It says here we just need to add water, right? So let's try this!*

Heat the MRE's main entree using the flameless heater. Find the main entree pouch and cardboard sleeve in the MRE package (leave other items in the package for now). Narrate aloud the warning including the part about hydrogen

gas. Then narrate aloud the directions of the flameless heater as you follow them. Insert the food pouch, add room-temperature water up to the line, and fold the top over inside the cardboard sleeve. Prop the flameless heater on an angle as directed. Remind students to record in their notebooks their noticings and wonderings about this heating process.

Safety Precautions

- Wipe up any water spilled on the floor immediately—slip or fall hazard!
- Remind students to never eat or drink food prepared or brought into the lab. There is a risk of cross contamination.
- Never tear open and expose the contents of the heater. There is a risk of cross contamination.

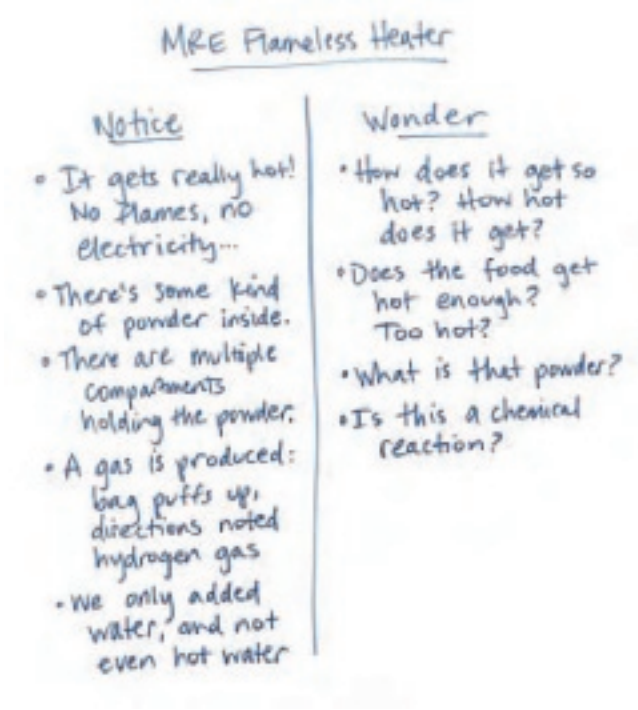
Briefly explore the other items in the MRE package. While you're waiting for the flameless heater to heat up and while the extra heater bags are still circulating around the classroom, remove the other components of the MRE package. Pass them around for students to observe. Remind the students not to open any of the items (because you need to have them available for later classes to observe and/or you cannot eat in the classroom).

Watch a video of a person eating an MRE. Display **slide G**. Say, *Our flameless heater here needs a few more minutes to heat up. Since we can't eat what's in the MRE here in our class, I have a video of someone who tried one so we can see what he has to say about it.*

Direct students to continue listing their noticings and wonderings in their notebooks while you watch the video of someone eating an MRE. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Remove heated food from the flameless heater. Carefully remove the heater bag from its cardboard sleeve so that the class can see that it has gotten puffy. Carefully tear off the top of the heater bag and remove the heated entree. Remind the class that we will not be eating the food in class (so don't open the food pouch). Walk around with the food pouch and/or heater bag so that students can observe them more closely. Remind students to record in their notebooks their noticings and wonderings about the heater.

Share noticings and wonderings about the flameless heater. Display **slide H**. Invite students to share what they noticed and wondered about the flameless heater while you record their ideas on chart paper. This sharing should be focused first on what we experienced in the classroom; if students have other experiences to share, ask them to hold onto those ideas until after the class has finished creating the list from the flameless heater observations. An example list with possible student responses is shown here.



Assessment Opportunity

Building towards 1.A.1 Ask questions that arise from careful observation of a flameless heater that is able to heat food (effect) using a chemical process (cause).

What to look and listen for: Students' wonderings should be based on their careful observations of the flameless heater used in class and as seen in the video and should show that they are curious about or want to predict the cause of the food being heated.

What to do: If students are struggling to connect their wonderings and questions to their observations of the flameless heater, you may wish to show them the video again or let them reinspect a new or used flameless heater. You can prompt them to consider specifically how the food is getting heated by asking, *What do you think is causing the food to heat up?*

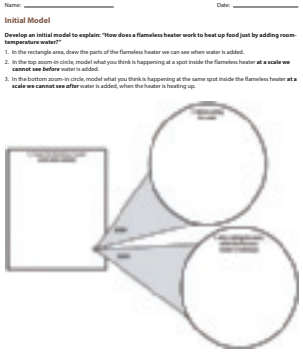
3. Develop an initial model on our own.

5 MIN

Materials: *Initial Model*, Science Notebook

Create initial models. Display **slide I**. Distribute the *Initial Model* handout. Direct students to develop an initial model to explain how they think a flameless heater works, including what they think is happening at a scale too small to see. Remind students to use pictures, words, symbols, labels, and so forth to explain their thinking. Allow students about 5 minutes of quiet, independent work time. If students think of more questions while they're working, encourage them to record those on the back of their handout or in their notebook.

You may instruct students to tape their initial model in their science notebook or you might want to collect the initial models as a pre-assessment. If initial models are collected, students can tape them in their science notebooks when they are returned.


Name: _____ Date: _____

Initial Model

Develop an initial model to explain: "How does a flameless heater work to heat up food just by adding room-temperature water?"

1. In the rectangle area, draw the parts of the flameless heater we can see when water is added.
2. In the top zoom-in circle, model what you think is happening at a spot inside the flameless heater **at a scale we cannot see before** water is added.
3. In the bottom zoom-in circle, model what you think is happening at the same spot inside the flameless heater **at a scale we cannot see after** water is added, when the heater is heating up.

4. Compare initial models in partners.

5 MIN

Materials: *Initial Model*, Science Notebook

Compare models with partners. Display **slide J** and direct students to make a T-chart in their science notebook to record similarities and differences between their models. Briefly explain the instructions for "Stand Up, Hand Up, Pair Up" and give students about 5 minutes to mingle, comparing models with a few different partners. Students should record similarities and differences in their T-chart while they are talking with different partners. If other questions come up during their conversations, students should record those questions in their science notebook, too.

Collaboration

"Stand Up, Hand Up, Pair Up" is a Kagan strategy that works like this: When you say "Go", students stand up with their hand up in the air (and handout, notebook, and pen in the other hand). They roam around the room to find another person whose hand is also up (the first person they make eye contact with) and go talk with that person. After they've recorded similarities and differences, they both put their hand up again to find new partners (with someone else whose hand is also up again). Students continue mingling to find partners as they're ready (no set signal from the teacher to rotate). (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

5. Review norms.

3 MIN

Materials: Classroom Norms poster

Remind students about classroom norms. Display **slide K** or refer to the Classroom Norms poster in your classroom or in students' science notebooks.

Say, *In a minute, we will gather in a Scientists Circle, and focusing on our norms will help us make that a meaningful time for everyone.*

Choose a focal norm for developing a classroom consensus model. Display **slide L**. Direct students to silently consider the norms and choose one that they will individually focus on for today. Have them give you a thumbs up when they have one in mind. Then, direct students to tell a partner which norm they've chosen, why it's important for them, and how they plan to improve in that area today.

Attending to Equity

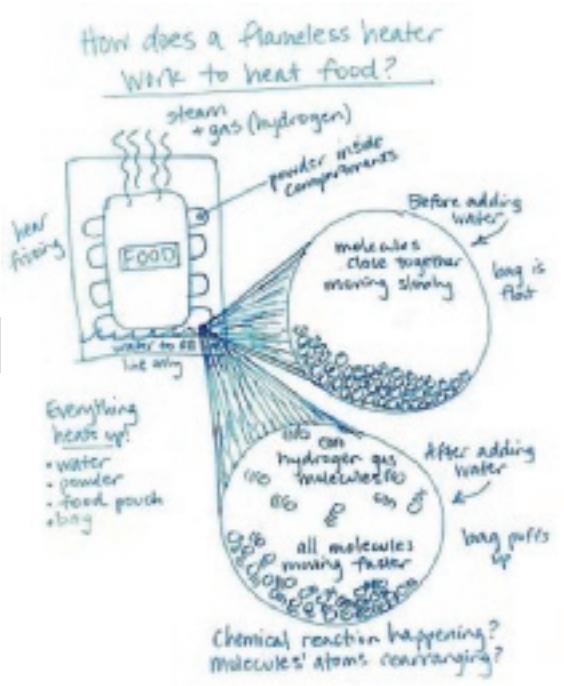
Universal Design for Learning: Use classroom norms to support *engagement* by fostering an equitable learning community that promotes trusting and caring relationships. Classroom norms will be especially crucial in this engineering-focused unit. The norms should reinforce to students the value of (1) the diversity of thought among all classroom community members in pushing our learning forward by sharing responsibility for conceptualizing design solutions, building prototypes, testing our designs, and sharing our data and (2) providing a safe learning environment that ensures fair participation. Students will be giving and receiving feedback that will include constructive criticism. In addition, classroom norms should interrupt cultural norms or stereotypes that could make science experiences feel uncomfortable for some students. If you haven't already established classroom norms to form this strong and safe classroom culture, take the time to do so here. You may wish to have students help you create the norms, or you may wish to create the norms yourself and then share them with students. If you create the norms yourself, spend some time discussing with students why each norm is important, what it might look and sound like when students are "demonstrating" the norm, and how not following the norm could affect how others feel and interact with the learning community. See the *Teacher Handbook* for more guidance on establishing classroom norms.

6. Develop a Classroom Consensus Model. 12 MIN

Materials: *Initial Model*, science notebook, chart paper, markers

Gather in a Scientists Circle and co-construct an initial consensus model. Display **slide M**. Direct students to form a Scientists Circle. Discuss and construct an initial consensus model representing areas of agreement and areas of disagreement in the model. It is unlikely that you will have complete consensus about what is happening in the flameless heater. The consensus model shown here is one example for how this consensus model may look.

Throughout the discussion and again toward the end, remind students to record in their science notebook any questions they have so that they do not lose track of those questions.



Key Ideas

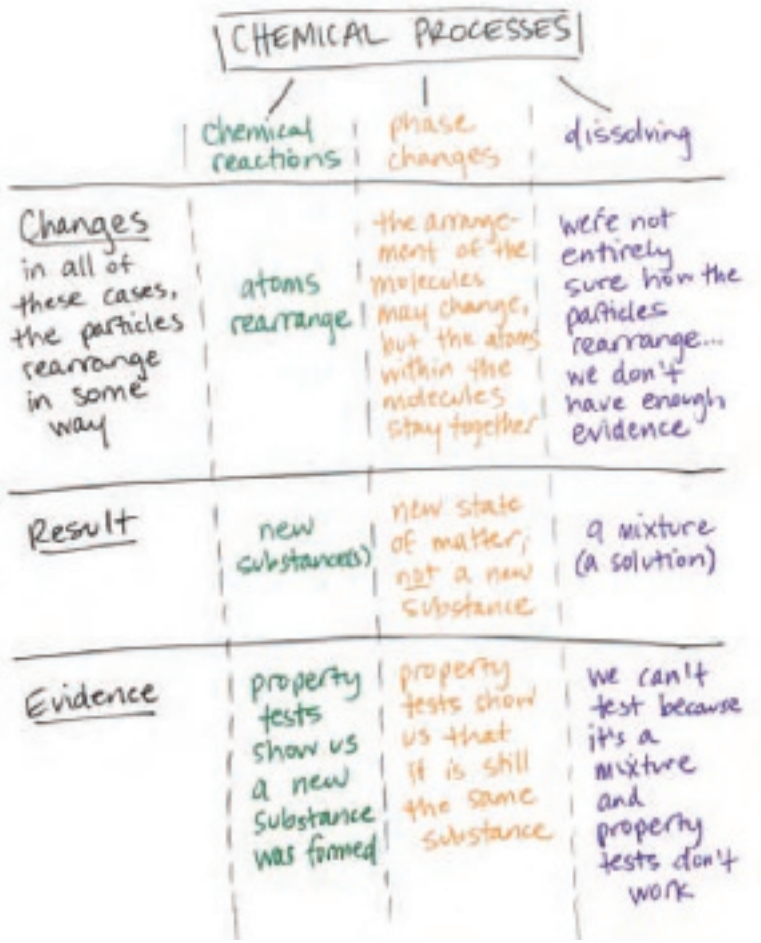
Purpose of this discussion: There are two goals of this discussion: (1) to generate a variety of initial ideas about what is going on in this flameless heater and (2) to scope out the territory of what the class does and does not understand in order to problematize what the group needs to figure out. As such, it is again important to accept all student responses and to encourage students to share their ideas. Furthermore, it is important to highlight areas of disagreement and help students clearly explain their thinking in these areas. Be careful not to respond favorably to any one idea over others so as not to "give away" what the class will investigate as the unit progresses.

Listen for these ideas:

- The temperature has increased—the particles have more kinetic energy now than before—and they are moving faster than when they started.
- There is no fire or electricity (battery, plug) involved.
- This seems to be some kind of chemical process and might be/is a chemical reaction (depending on your class).

Additional Guidance

During this Consensus Discussion, students will likely propose (if they haven't already) that some kind of chemical process is happening in the MRE flameless heater. Your class may or may not come to consensus about whether the heater is for sure using a chemical reaction. Use the Word Wall from *Bath Bombs Unit,* including the chart of chemical processes (see example shown here), for reference as the class recalls what they already know about chemical processes. If your class is convinced that the hydrogen gas is a new substance produced from what we started with in the flameless heater, you can add this idea to your initial consensus model. However, if not everyone is in agreement about this idea, add a question mark on the model about whether a chemical process or reaction is happening and move on. In Lesson 2, students will have an opportunity to investigate the substances inside the flameless heater and then confirm that this is a chemical reaction.



7. Reflect on norms and assign home learning.

3 MIN

Materials: science notebook, Classroom Norms poster, projector *Student Electronic Surveys: Why + How-To*. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Silently reflect on classroom norms. Display **slide N**. Say, *In the class consensus discussion, you each chose a focal norm to work on. Take a moment to think to yourself: How did you do with practicing the norm you selected to work on?*

Pause for about 30 seconds of individual think time, then ask, *How did the class do as a learning community? What did we do well? What could we improve on?*

After another pause to silently consider those questions, invite students to comment. Celebrate successes the class had in this lesson. Also, set a goal for a focal norm for the class to work on the next time you meet.

Assign home learning survey. Display **slide O**. Direct students to record additional questions in their science notebook about MREs and flameless heaters so that we don't forget them before the next class. Then suggest that we should survey our family and friends about what they know about MREs. Provide students with the link to the electronic survey and ask them to have their family and friends answer these questions before next class.

Say, *It seems like we have a lot of ideas and questions about MREs and flameless heaters. Often when experiencing something new we look at how others in society value and use them. Before next class let's survey our family and friends about what they know about MREs and look at how these results can help us understand more about them.*

Additional Guidance

Use *Student Electronic Surveys: Why + How-To* to help set up the electronic survey. Make sure that in the settings that students aren't limited to one response. This way students will be able to have multiple family and friends take this survey.

If this is the class's first time giving an electronic survey, use a projector to show students the survey questions and how to submit responses.

Home Learning Opportunity

Having students survey their family and friends about MREs, their accessibility, and related phenomena will be used to help connect students with the relevancy of MREs and will be used to help plant the need for a new design solution for flameless heaters.

End of day 1

8. Review community survey results.

5 MIN

Materials: science notebook, projector

Set up new Notice and Wonder charts. Display **slide P**. Direct students to create another T-chart on the next clean page of their science notebook to record their noticings and wonderings as you project and share the results from the survey.

Say, *Last class we decided to talk with and survey people we know about their knowledge and experiences with MREs. Let's look at our survey results to see what new ideas we can learn about MREs from talking to people in our community. Individually record what you notice and wonder in the T-chart you created in your notebook.*

Project the results for each question. Remind students what each of the questions was asking those that took the survey. Read some of the responses to the short-answer questions from the survey for students as they are recording their observations on their Notice and Wonder chart.

Survey Questions

1. Have you ever been in a temporary situation where you did not have access to the traditional ways of heating your food, like in an oven or microwave or over a flame (for example, during a power outage)?
2. Meals, Ready-to-Eat, also known as MREs, are self-contained food packages that can be used to provide people with warm food using a flameless heater when typical methods are unavailable. Have you ever used an MRE?
3. Do you know where you could get an MRE?
4. In what situations might an MRE be useful?
5. What are some other things that get hot without electricity or flame?
6. What questions do you have about MREs and flameless heaters?

9. Brainstorm related situations.

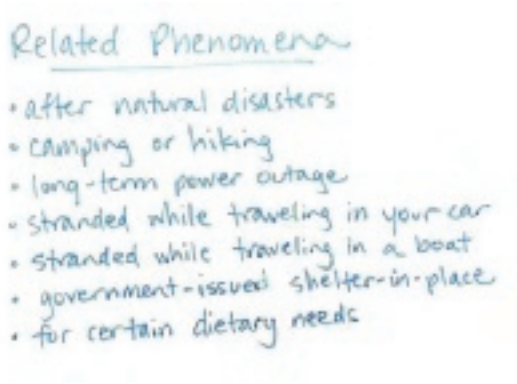
5 MIN

Materials: science notebook, chart paper, markers

Individually list related **situations where MREs would be useful.** Display **slide Q.** Say, *One of the survey questions asked, In what situations might an MRE be useful? So far in this lesson we have observed some different examples of MREs being used in different situations. It seems that there were some additional ideas and situations where MREs and flameless heaters might be useful. Use the next clean page in your science notebook to list any and all situations—related to the ones we've already seen or other situations—in which you think it would be helpful to have a homemade flameless heater.*

Give students about 2 minutes to write their ideas.

Share related situations where MREs would be useful. Use a new piece of chart paper to list related situations as students share their ideas.



10. Notice and wonder about situations during which MREs are typically used.

5 MIN

Materials: science notebook, chart paper, markers

Add to the Notice and Wonder chart. Display **slide R**. Direct students to draw a horizontal line below the writing in their Where Have MREs Been Used Notice and Wonder charts in their science notebook. Have students continue to add and record their noticings and wonderings as you share more information about how MREs are used.

Say, *By looking at and discussing our survey results we have identified and named a number of different situations in which MREs and flameless heaters could be useful. Let's look at some additional photos of people using MREs to see what ideas and observations can help us understand more about MREs and our survey results. Individually record what you notice and wonder, then draw connecting lines between these ideas and similar ideas from any noticings and wonderings you wrote based on the survey results.*

Show photos of other situations during which MREs have been used. Display **slides S-Z**, reading the captions and allowing students about 30 seconds per slide to record what they notice and wonder in their notebooks.

Observe prices of MREs. Display **slide AA**. Direct students to add to their chart what they notice and wonder about how the cost of a single MRE meal compares to other places at which we might purchase a meal. Students might use the "Wonder" side of their chart to make predictions about why the costs are so different.

Briefly share noticings and wonderings. Display **slide BB**. Invite students to quickly share some of the things they've noticed or questions they've wondered about while you record them. Have students also share how these ideas might connect to some of the survey results. It is not necessary to have an exhaustive list here, but keep collecting ideas until you have the following on your list (which will be helpful in the development of our design problem):

- MREs are expensive!
- MREs are not used every day but are helpful for certain situations, such as emergencies (natural disasters, stranded in a car, and so forth).
- Transporting MREs to people or places that need them can be difficult (helicopter drops, walking while carrying cases of them and water).

11. Define our problem and propose a solution.

7 MIN

Materials: science notebook, loose-leaf paper (6-8 sheets), chart paper, markers

Individually consider problems with MREs and flameless heaters. Display **slide CC**.

Say, *These flameless heaters and MREs are pretty useful, but they're not perfect. What problems or issues do you see with using MREs with flameless heaters to get hot food to people when they don't have their typical cooking methods available? Take a minute to jot down your ideas on the next clean page of your notebook.*

"Pass the Paper" to collect problem ideas. Display **slide DD**. Distribute a sheet of loose-leaf paper to each of 6-8 random students in the class. Explain the directions for this activity as follows:

- When you get a piece of paper, write one of your problems with getting hot food to people when they don't have their typical heating methods available.
- Also, if one of your ideas or a very similar one is already listed on a paper you get, put a check mark near it. We want to keep an informal tally of how many people thought of similar problems.
- If you think an idea that someone else has written is important, put a star near it, also.
- After you've written an idea and checked any others as needed, pass the paper along to someone else.

Additional Guidance

"Pass the Paper" is intended as a way to collect students' problem ideas quickly and informally—papers need not be passed in a certain direction or within a set time limit. After everyone has had a chance to write on at least one paper, you could collect them, but you'll get a better tally of how many students identified certain problems if you let them circulate a moment longer than that. As you collect the papers, start reading them to yourself to find the most commonly mentioned (or checked) problems that your class has identified.

Share and post frequently mentioned problem ideas. Display **slide EE**. Have students gather in a Scientists Circle. Skim through the papers as you collect them, then read aloud and list on chart paper the most commonly written or checked problems. The problems you'll want to call attention to (because they will be the most helpful in the upcoming steps) are the following:

- Cost: MREs are expensive!
- Availability: It can be difficult to get them or difficult to get them to people when needed.
- Ease of use: The directions are confusing.
- Lack of choice: Choice is limited to foods that come in the package.

Additional Guidance

The problems listed here are the ones that the unit focuses on designing around, but you may also choose to include other problems that your students suggest as you see fit. For example, students may point out problems with the MRE's packaging, such as that it's not reusable or easily recyclable. Depending on the time and materials available to them in later lessons, students may or may not be able to design solutions to all these problems. However, having other problems on the list can prompt other criteria or constraints that could add more challenge to the design, if needed.

Consider why MREs and having warm meals are important. Take a moment to discuss the value of including a heater in a Meal, Ready-to-Eat. Display **slide FF**.

Say, *Now that we've identified some problems with MREs, let's consider why warm food is important. Why do you think a heater is included with these meals? Why not just have people eat the food cold? Take a minute to consider these questions, then we can share our ideas with the rest of the class.*

After a minute of individual time to think, invite students to share their ideas about why MREs would be heated before eating.

Suggested prompt	Sample student responses
So why do you think a heater is included with these meals? Why not just have people eat the food cold?	*Some food tastes better when it's warm.* *If you're in a situation, like a storm or military operation, having warm food might make you feel less worried—it's comforting.* *Does the food need to be hot enough to be safe? Like, kill any germs (bacteria)?*

Say, *Yes, all of these are reasons why we would want to heat food. MRE flameless heaters do not get the food hot enough to kill bacteria, that's done when they're packaged, but researchers have found that warm food can help people feel "warmer" psychologically, not just physically. So including flameless heaters can be important in providing comfort to people as well as providing them with a warm meal.*

Turn and talk to consider how we might be able to solve these problems. Display **slide GG**. Direct students to talk with a neighbor about the following questions:

1. What if, during an emergency situation, all the MREs and flameless heaters were sold out? How could people be prepared if that happened?
2. What if people couldn't buy the premade MREs and flameless heaters? What could they do?

Consider a solution to these problems. Display **slide HH**. Say, *These flameless heaters can be pretty useful in a lot of different situations. But what if people couldn't get access to them because they are too expensive or sold out? What could we do to help people be prepared in advance to heat up food when they don't have their typical methods available?*

Come to consensus about how we could solve the problems we found with purchased MREs: Say, *We can design a homemade flameless heater that is easier to use, has a lower cost, and doesn't need to be transported to people for them to use it.*

If needed to elicit the homemade idea, you might also ask, *How have people accomplished a project like this on their own in other circumstances?*

Post the design solution. Write the class's proposed solution on chart paper. *How can we design a homemade flameless heater to help people heat up food when typical methods are not available?*

Say, *This is interesting. Last time we were in our circle we were working as scientists trying to figure out how the MREs work, but our goal this time seems different. Now we are identifying some problems with MREs, and we want to know how we can solve these problems. This shift in focus shows us that we are now taking on the role of engineers by attempting to use the science ideas to help design solutions to problems.*

So let's call this an Engineers Circle. Scientists and engineers have a lot in common, especially in our ways of thinking, our habits of mind: both scientists and engineers value new ideas, are open to hearing questions and comments from others, and are respectfully skeptical when they're trying to figure something out. So we will keep that mindset while we discuss problems and solutions in our Engineers Circle. Then, as we continue our work on this unit, we will figure out more about what it means to be an engineer.

12. Begin Progress Trackers.

6 MIN

Materials: science notebook, chart paper, markers, 4" x 6" sticky notes

Start Progress Trackers in science notebooks. Display **slide II**. Direct students to find the section of their science notebook that they've set aside for this unit's Progress Tracker. Say, *Like in past units, our Progress Tracker will be a tool in our science notebooks to keep track of ideas we figure out to work on answering a question. However, in this unit, our question is about solving a problem: How can we design a homemade flameless heater? To help us keep track of what we've figured out about this designing-solutions work (called engineering), we will use different column headings than we have had in other units.*

Tell students, *The left-side column heading is "What did we do as engineers?" and the right-side column heading is "What did we figure out that can help us with our designs?" Go ahead and set this T-chart up in your notebook.*

Depending on the task on which they are reflecting, sometimes students will complete the tracker independently and sometimes with more scaffolding as a class. Use questions, such as those that follow, to guide students as they make their first entries in this new tracker.

Suggested prompts	Sample student responses
Let's think about what we just did. Who can summarize what our discussion was focused on just now?	*We were talking about the problems with MREs and how we could solve them by making our own heating devices.*
OK, so what we did there was what engineers do at the very beginning of designing something—we defined our problem. Let's write that on the left side of our Progress Trackers.	*Our problem is that it's hard for people to get hot food in situations when they don't have access to the usual ways they heat food.*
Then let's record what that means for us. What is the problem we've identified here?	*Prepackaged MREs can be helpful, but they* • *are expensive,* • *can be confusing to use,* • *include limited food choices, and* • *can be hard to get to people who need them.*
After we defined our problem, we did something else that engineers do; so draw a horizontal line in your tracker under what we just wrote about our problem. What did we do once we had defined the problem?	*We said how we could solve it!* *We started thinking about how we want to fix those problems.*
Great. So on the left side again, let's write that we proposed a solution. *And on the right side, what does that mean for our design?*	*Our solution is to make a homemade flameless heater to help people heat up food when typical methods are not available.*

See the example Progress Tracker here, including possible student responses.

What did we do as engineers?	What did we figure out that can help us with our designs?
We defined our problem.	Our problem is that it is hard for people to get hot food in situations when they do not have access to the usual ways they heat food. Prepackaged MREs are • expensive, • might be confusing to use, • include limited food choices, and • can be hard to get to people who need them.
We proposed a design solution.	We want to make a homemade flameless heater to help people be prepared to heat up food when they cannot use typical cooking methods.

Assessment Opportunity

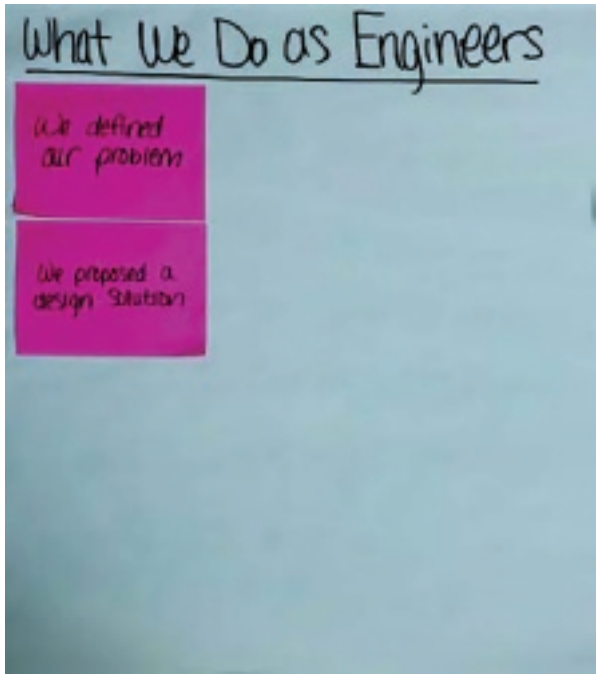
Building toward 1.B Define a design problem that can be solved through the development of a homemade flameless heater with multiple criteria and constraints that uses a chemical process (system 1) to heat up food (system 2).

What to look and listen for: Take note of which students are able to contribute to the class discussion about what to record in their Progress Trackers. As students add entries to their Progress Trackers, look to see that they are able to explain in their own words how they have defined the problems with prepackaged MREs, proposed the solution of a homemade flameless heater that could help solve those problems, and listed initial criteria and constraints.

What to do: Students will have more-explicit scaffolding for systems thinking in regard to their flameless heater designs during Lesson 4. So, if you notice that students have not yet connected the criterion of heating the food to two systems interacting, make note of who specifically will need support during Lesson 4 and come back to the idea then. However, you may set the stage for systems thinking by asking, *What is the most important criterion for our heater? What must it be able to do to be successful?* It has to heat the food. You can point out that the heater system must cause the food system to heat up.

Create a space to record what we're doing as engineers. Designate a part of the classroom whiteboard or chalkboard or new chart paper to be the class-level What We Do as Engineers board and title it that way. Tell students, *I want us to have a class record of what we're doing as engineers so we can keep adding to this list and work to figure out what engineers do. So, when we're working on our Progress Trackers, I'm going to record some ideas on big sticky notes, too.*

Write and post large sticky notes that say "We defined our problem" and "We proposed a design solution." Right now, these could be placed anywhere on the board or chart paper, but as we come back to this list in future lessons, we will reorganize these sticky notes to represent how engineering involves revisiting the same steps or ideas as we revise our thinking, redesign our solution, and work to optimize our design. See the example shown here.



13. Discuss criteria and constraints.

5 MIN

Materials: science notebook, chart paper, markers

Recall the terms *criteria* and *constraints*. Display **slide JJ**. Say, *In the Unit 6.5: Where do natural hazards happen and how do we prepare for them? (Tsunami Unit) we learned that whenever we want to solve a problem, we need to first define the criteria and constraints of the solution. Let's remember what those words "criteria" and "constraints" mean. Take a moment to turn and talk with a partner about those words.*

After about a minute of partner talk time, invite students to share what they know about criteria and constraints. Add these words to the Word Wall using a definition and icon or image that your class agrees upon. Examples are shown here.

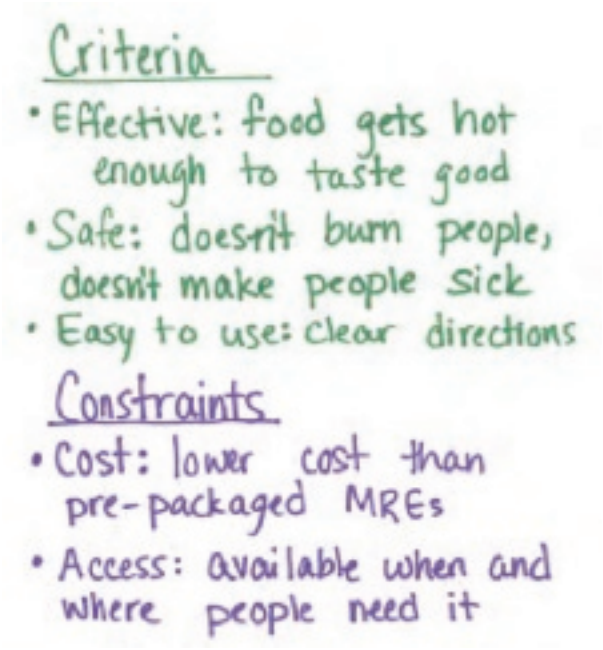
Turn and talk about criteria and constraints for our homemade flameless heater. Display **slide KK**. Say, *OK, so what criteria do we have for our homemade flameless heater? What does it need to be able to do? And what limitations will we have for our design? What constraints should we have? Turn and talk with a partner about that.*

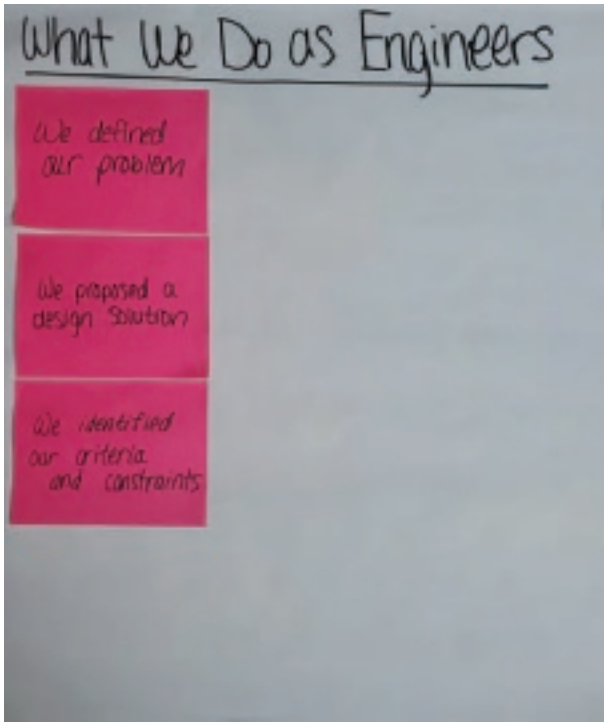
After about a minute of partner talk time, quickly have a few students share some of the criteria and constraints they mentioned or heard from their partner. Since you won't have time for everyone to share, encourage students to signal with a raised hand or similar gesture if they also mentioned or heard a similar idea.

Post a public record of possible criteria and constraints. It will be helpful to students when they create their initial designs if they can refer to these criteria and constraints. So, if you do not have time to jot these on chart paper while students share them, do so while students are adding to their Progress Trackers. An example list is shown here.

Add to our Progress Trackers. Display **slide LL**. Say, *We just remembered something else that engineers do—they have to define the criteria and constraints for their solution. But what does that mean for our design? What did you and your partner talk about? Take a moment to add another entry to your Progress Tracker, and use the right column to list the criteria and constraints that our homemade flameless heater should have.*

See example Criteria and Constraints chart and updated What We Do as Engineers board.





See the example Progress Tracker, including possible student responses.

What did we do as engineers?	What did we figure out that can help us with our designs?
We identified our criteria and constraints.	Criteria for our homemade flameless heater • Effective - gets the food hot enough to taste good but not so hot that it burns • Easy to use - clear directions Constraints for our homemade flameless heater • Lower cost than prepackaged MREs • Available when and where people need it

Additional Guidance

At this point, the criteria and constraints that students list will be general and need not be categorized in the same way as is shown in this example (i.e., some students may deem the time it takes to heat the food to be a criterion rather than a constraint). The class will revisit their criteria and constraints in Lesson 4 and refine them so that they are more specific.

14. Develop initial design.

6 MIN

Materials: 1 sheet of blank paper (unlined), Initial Classroom Consensus Model, Criteria and Constraints chart

Individually create a design solution. Display **slide MM**. Have students refer to the classroom consensus model and the Criteria and Constraints chart as they model a design solution.

Say, *We've been considering what our solution needs to be able to do and the limitations we'll have. So how can we design a homemade flameless heater to help people prepare for different situations? Well, engineers don't just guess and check to see if a design solution works; they base their designs around their prior knowledge about science ideas. We already began thinking about what science ideas might be at play when we constructed our classroom consensus model. While we might not know everything yet about how flameless heaters work, we can still refer to the classroom consensus model along with our Criteria and Constraints chart to help inform us in modeling a design solution. I'll give you a blank piece of paper where you can plan your design—use words and drawings to help get your ideas onto paper. Be sure that your design shows how your heater will cause food to be heated up. We'll work for about five minutes before we share our design in small groups.*

Distribute blank paper and circulate the room while students work.

Additional Guidance

If you have students who are stuck or overwhelmed by a completely blank page, prompt them to begin by considering just one problem to try to solve (such as making their design easier to use than a prepackaged MRE's heater). You could also encourage them to begin by listing the materials they might want to use, then transition to drawing how they might put those materials together.

Assessment Opportunity

Building toward 1.C Apply scientific ideas to design a solution for a flameless heater that heats food by a chemical process that transfers energy.

What to look and listen for: Since this is the first lesson in the unit, this is a pre-Assessment Opportunity to how students are designing a solution and whether they are beginning to incorporate systems thinking along with knowledge about energy flow from chemical processes into their design models. Student designs may represent how their proposed heater system interacts with the food system (by using arrows or showing molecules moving at different speeds), and/or they may propose some kind of chemical process to cause the food to heat up. However, at this point, it is OK that students may not have included these details in their designs.

What to do: If students' designs do not indicate how their heater will cause the food to heat up, ask them to go back and add that thinking. Even if they're not sure what, specifically, they need to put in the heater (such as reactants), they could attempt to show in their design how the heater causes the food to heat up. If students have designed a heater that uses traditional heating methods (such as flames or electricity), remind them that we want our homemade heater to be usable in many circumstances, such as after a flood or inside a car, where those traditional methods may not be available.

15. Compare initial designs in small groups. 6 MIN

Materials: *Initial Model, Initial Design Reflection*

Give directions for the *Talking Sticks* protocol. Display **slide NN**. Say, *In a moment, we will gather in small groups and share our designs. In order to be sure everyone gets a chance to speak, we will use our writing utensils as "talking sticks." To begin round 1, everyone in the group will put their writing utensil into the center of the group. As each person takes a turn to tell the group about their design, they pick up their writing utensil. No one gets to respond to the person explaining their design during round 1—each person is only telling about their design. After all the writing utensils have been picked up, place them in the middle again to begin round 2. In round 2, each person will have a chance to comment on similarities and differences between their design and others or they can ask clarifying questions about others designs. As each person shares they are to pick up their writing utensil when they do so. If a person responds to a question during round 2, that does not count as their comment and they do not pick up their writing utensil until they have initiated a question or comment themselves.*

Direct students into small groups (3-4 students each) with their initial design paper and writing utensil and circulate to listen in as groups share.

Assessment Opportunity

If you did not get to see every student's initial design while they were working to create them, listen in while groups are talking to check out the designs you haven't seen yet. The goal is to gather formative pre-assessment data about where students are right now with the practice of modeling and see whether they have included systems thinking or ideas about chemical processes in their design models. The next several lessons will focus specifically on these ideas, so having this pre-assessment data will help you prepare to best meet your students where they are.

Assign home learning. Display **slide OO**. Distribute *Initial Design Reflection*. Direct students to answer these questions on the *Initial Design Reflection* handout before class meets again.

- What went well when creating or sharing your initial design?
- What was difficult about creating or sharing your initial design?

Home Learning Opportunity

Answering these questions while the experience is fresh in their minds will help students prepare for the discussion at the beginning of the next class, which will surface the need for a systematic process of planning, testing, comparing, and revising designs.

End of day 2

16. Reflect on initial design solutions. 8 MIN

Materials: *Initial Design Reflection*

Gather in an Engineers Circle. Display **slide PP**. As students enter the classroom, have them bring their *Initial Design Reflection* and form an Engineers Circle.

Debrief our work from last time. Display **slide QQ**. Lead a discussion to reflect on the work of designing a solution and sharing those designs, starting briefly with positives and then moving into how we can improve the process.

Key Ideas

Purpose of this discussion: Reflect on this round of design work and think about what we need to do next.

Listen for these ideas:

- It's overwhelming to try to meet all the criteria and constraints in one try.
- The criteria and constraints were helpful for planning and comparing our designs with those of others.
- We didn't have enough information about how we might be able to make a flameless heater work (we're used to cooking with typical methods!).
- We want to test some ideas out because we can't really help each other move forward until we know what actually works.

Suggested prompts	Sample student responses
First of all, who can remind us of the problems we wanted our flameless heater to solve? Why did we want to design a different homemade one?	*Prepackaged MREs are expensive!* *It can be hard to get MREs to people when they're needed.* *MREs are sometimes confusing to use.* *There are limited food choices with prepackaged MREs.*
What went well about creating or sharing your initial design?	*The criteria and constraints helped me plan and check my design and compare with others.* *I could think of any ideas I wanted—I liked the freedom to be creative.* *It was cool to see other people's ideas—I would like to try some of those in my design now.*

Suggested prompts	Sample student responses
What problems did you encounter while you were creating your initial design?	*It was hard to get started because we have so many criteria and constraints to wrap into one design.* *It was hard to plan how we would heat up food without a fire or electricity since we're not sure exactly what's going on with the materials inside that heater.* *It was hard to think of something new after seeing the prepackaged MRE.*
You mentioned using the criteria and constraints as you designed. What was helpful or challenging about using those criteria and constraints?	*We said the materials had to be cheap and easy to get, but I don't know which materials will work and how much they cost.* *We said the food has to get hot enough, but how hot is that?* *When we compared designs, we could use the criteria and constraints to focus on one part of a design to compare them or ask questions.*
When you shared your designs, could you tell which design would work to solve our problem?	*We saw a lot of interesting ideas, but we don't know if they work until we test them.*

Say, *So it sounds like we have a lot more we need to figure out about what our designs need to do and how they might work. Let's use this thinking to generate some questions we need to figure out.*

17. Generate questions.

5 MIN

Materials: science notebook, a few sticky notes per student, Initial Classroom Consensus Model, Related Situations poster

Generate questions that will drive our design work. Display **slide RR**. Refer students to the initial classroom consensus model.

Say, *So we think we're going to be able to tackle this problem and design a solution: We can design an effective, inexpensive flameless heater that people can make themselves to use when they need it. And we're starting to plan how we might be able to work together to accomplish this goal. But I know we still have questions. There's a lot we need to figure out about the science of flameless heaters in addition to how to make a successful homemade flameless heater. Let's take a couple of minutes to write our questions so that they'll be clear to others when we want to get them organized. Look back at the questions you have in your Notice and Wonder chart, the questions you recorded during our modeling, and your initial design.*

- *What questions do you have about flameless heaters?*

- *What will we need to investigate in order to solve this problem?*
- *What else do we need to know to refine our criteria and constraints?*

Remember to write one question per sticky note, write in marker—big and bold, and put your initials on the back in pencil.

Give students a minute or two to generate their questions and record them on sticky notes.

Assessment Opportunity

Building toward 1.A.2 Ask questions that arise from careful observation of a flameless heater that is able to heat food (effect) using a chemical process (cause).

What to look and listen for: Students' questions for the DQB should be connected to the observations that they had previously made but be more directed at seeking additional information about how they could design a device that will heat food without electricity or flame (possibly using a chemical process).

What to do: If students are struggling to generate questions connected to their previous observations, direct them to their Notice and Wonder chart and related situations list. If students are struggling to seek information that could inform their design, point them to specific places in their initial design and ask, *What would you need to know more about to figure this out?*

18. Build a Design Questions Board. 18 MIN

Materials: sticky notes with questions

Gather in an Engineers Circle to construct the DQB. Display **slide SS**. Direct students to bring their questions on sticky notes to the circle.

Say, *We have a lot of really helpful questions that will direct our work. It is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions. We are going to create a Design Questions Board (yes, you heard me right—it's still a DQB, but a little different for this unit since we're focused on this design work). We want to group and organize our questions so that they can help guide our investigations and keep track of what we want to figure out.*

Instruct students to share their questions, one by one, with the whole group. Explain to students how you will create the DQB:

- The first student reads his or her question aloud to the class, then posts it on the DQB.
- Other students raise their hand if they have a question that relates to the question that was just read aloud.
- The first student selects the next student whose hand is raised.
- The second student reads his or her question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.

*** Attending to Equity**
The first priority during the formation of the DQB is reinforcing a classroom community wherein all ideas are valued. As such, everyone should have a question on the board. Use your judgement on how to press students to form "how" and "why" questions. If students struggle with sharing, encourage them to go public with question(s) as they are, rather than focusing specifically on forming a "how" or "why" question.

- Continue until everyone has at least one question on the DQB.
- If a question doesn't fit with any questions that are already on the board, students should create a new cluster.

Some of the questions students have might include the following:*

- How can this heater work without flames or electricity? How does it get hot?
- What substances are in the heater "compartments"?
- How hot should our food get? At what temperature is food comfortable to eat?
- Is a flameless heater reusable? (Could we make it reusable?)
- What materials will we need to make our own flameless heater? Where can we get those materials?
- How much will our materials cost? Do we need a budget?
- Are these materials or substances harmful or toxic? What safety precautions do we need to take?
- How can we make our flameless heaters easier to use? Would fewer steps be helpful? How can we clearly communicate our directions to people who will use them?

Label the questions. After all students have shared their questions, you will have several different clusters of questions on the DQB. As a class, decide on "umbrella" questions or topics for the clusters of questions and label them. Then, if you haven't already done so, post our overarching design question at the top of the DQB: *How can we help people build flameless heaters?* See the photo of one classroom's DQB shown here.

19. Generate ideas for investigations.

7 MIN

Materials: science notebook, Design Questions Board

Generate ideas for investigations. Display **slide TT**. Say, *We have so many questions to explore! How could we start to investigate the answers to some of these questions? Title the next page in your science notebook "Ideas for Investigations." Choose one question or category of questions from our Design Questions Board* and talk with one or two people near you to consider how we might find the answer—what investigation could we design, what data should we gather, and how could we figure this out in our classroom? Keep track of your ideas in your notebook. After you've discussed one question, move on to another. We'll work for about five minutes.*

*** Attending to Equity**

Universal Design for Learning: It will be helpful to students if they can clearly see the question(s) or category of questions they are focused on for generating ideas for investigations. So, you may have students temporarily disassemble the DQB and take sticky note questions or groups of questions to their partnership or trio for reference while they generate ideas. Or, if possible, you might take photos of sections of the DQB and share those digitally with students to look at while they brainstorm.

20. Share ideas for investigations.

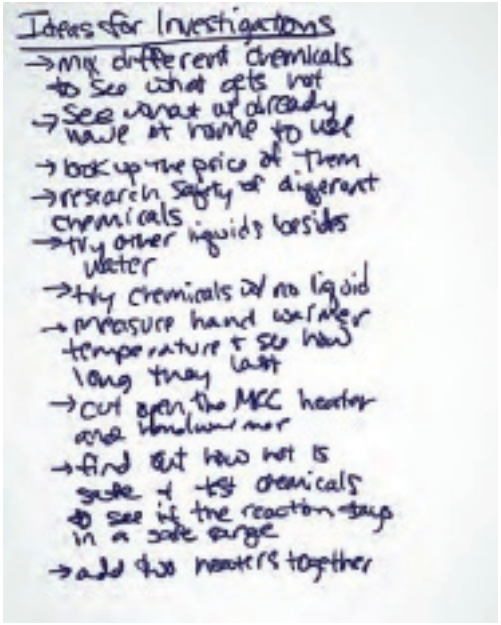
7 MIN

Materials: science notebook, chart paper, markers

Share ideas for investigations. Display **slide UU**.

Title a new piece of chart paper "Ideas for Investigations". Ask student pairs or trios to share one of their investigation ideas with the whole class. Then continue soliciting ideas from each pair or trio. Record these ideas on the chart paper for the whole class to keep as a reference. The goal is to hear a variety of ideas that we may be able to investigate over the course of the whole unit.

See an example Ideas for Investigations poster shown here.



Additional Guidance

This Ideas for Investigations list can be revisited throughout the unit just like the Design Questions Board. When a future lesson involves an investigation like one the class has suggested, take the time to point that out. If your students suggest ideas that are not planned in the unit but that you feel would be productive to pursue, use your discretion and your knowledge of the storyline to decide where these additional investigations would best fit so that the unit's punchlines continue to build on one another.

Say, *We have so many great ideas to investigate! We have great ideas for finding the data we need a little bit at a time. That will help make our work manageable and successful. And remember, when we make progress on one question, that progress usually helps us answer others. I'm excited to get started on this work next time!*

ADDITIONAL LESSON 1 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.7.1: Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 7 topics, texts, and issues, building on others' ideas and expressing their own clearly.

CCSS.ELA-LITERACY.SL.7.1.C: Pose questions that elicit elaboration and respond to others' questions and comments with relevant observations and ideas that bring the discussion back on topic as needed.

During this lesson, students have several opportunities to talk—expressing their own ideas clearly and building on the ideas of others—with their classmates, from partner sharing to whole-group discussions. However, round 2 of the Talking Sticks activity used for sharing initial design models is a key moment to look for students to pose questions and comments to their peers and respond with relevant responses and observations.

LESSON 2

How do heaters get warm without a flame?

Previous Lesson

We developed an initial model to consider how the flameless heater in an MRE works, but we also noticed that MREs may not always be a viable solution. After brainstorming criteria and constraints for a homemade flameless heater, we created those designs. We built a Design Questions Board and gathered ideas for investigations.

This Lesson

Investigation

2 DAYS

We revise an investigation initially designed to see how hot flameless heaters and air-activated hand warmers get to collect additional data that could serve as evidence to support the idea that a chemical reaction is happening when the devices heat up. We research the different ingredients in each device and observe changes in the substances in the devices as they warm up to confirm new substances are made. We create an Energy Transfer Model using what we learn from these investigations. The class decides that while neither of the reactions we tested would be appropriate for our homemade heater, we should investigate other reactions.

Next Lesson

We want to test different chemical reactions to determine if any of them cause an increase in temperature for use in our homemade flameless heater designs. Once we identify a reaction with which to move forward, we will investigate energy transfer from that system to the food system using an Energy Transfer Model.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

2.A Conduct an investigation to serve as the basis for evidence to confirm that the devices are undergoing a chemical reaction when the temperature increases as energy is transferred from the substances in the devices to its surroundings (what the thermometer measures).

2.B Develop a model to describe how energy is transferred between different parts of our reaction system to inform the next steps of the design process.

What Students Will Figure Out

- Energy transfers from the system of atoms that rearrange during the chemical reaction to surrounding systems (which includes the water and air inside the heater device, the material the device is made out of, the thermometer, the container the food is in, the food, and the environment outside of the MRE).

- In our homemade heater designs we need to maximize energy transfer to the food and minimize transfer to the outside environment.
- Our research helped us figure out that the substances that are in each device we investigated are not good candidates for our homemade heater. We need to find another chemical process.

Lesson 2 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Consider the questions the class left off with last time and decide to investigate the flameless heater as well as another device that gets warm without fire or electricity (a hand warmer) to learn if chemical reactions are happening in each of these devices.	A	Design Questions Board from Lesson 1, Ideas for Investigations chart from Lesson 1
2	15 min	**PREPARE FOR FLAMELESS HEATER AND HAND WARMER INVESTIGATIONS** Review ideas from *Cup Design Unit* and create an initial model of energy transfer between a thermometer and its surroundings to prepare for further investigation of a flameless heater.	B-C	chart paper, markers
3	25 min	**PLAN AND CARRY OUT THE FLAMELESS HEATER INVESTIGATION AS A CLASS** Revise the temperature investigation to include investigations that will provide additional data that could serve as evidence to support the idea that there is a chemical reaction happening as the devices are warming up. Conduct the investigations and collect data.	D-J	*Ingredient List for MRE Heater*, 7.2 Lesson 2 Contents of the MRE Heater video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), Ideas for Investigations chart from Lesson 1, sticky notes (optional), Flameless Heater Demonstration *End of day 1*
4	20 min	**CARRY OUT THE HAND WARMER INVESTIGATION IN SMALL GROUPS** Activate the hand warmers and record the temperature of each experimental setup at specific time intervals keeping track of any other observed changes (odor, visual changes, sounds, and so forth).	K-Q	*Ingredient List for MRE Heater*, 7.2 Lesson 2 Contents of the Hand Warmer video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), Hand Warmer Investigation

Part	Duration	Summary	Slide	Materials
5	8 min	**HAVE A BUILDING UNDERSTANDINGS DISCUSSION ABOUT OUR RESULTS** Use evidence from our investigations to identify that a chemical reaction is occurring in the flameless heater and the hand warmer.	R	3-4 sticky notes (optional), chart paper, markers
6	15 min	**HAVE A BUILDING UNDERSTANDINGS DISCUSSION ABOUT OUR RESULTS** Use evidence from our investigations to identify that a chemical reaction is occurring in the flameless heater and the hand warmer.	S	chart paper, markers, What We Do as Engineers board, 1 sticky note
7	2 min	**NAVIGATION** Consider based on this lesson's work what we should investigate next time.	T	
				End of day 2
		SCIENCE LITERACY ROUTINE		Student Reader Collection 1: *A Hot Meal on the Go*

Lesson 2 • Materials List

	per student	per group	per class
Flameless Heater Demonstration materials	• indirectly vented chemical splash goggles • nonlatex apron • heat-resistant gloves		• 1 8-oz. Styrofoam coffee cup with lid • 1 flameless heater trimmed to be a similar mass as the hand warmer you will be using inside the Styrofoam cup • 1 digital thermometer • 1 digital scale • 1 timer or clock • 10 mL room-temperature water in a separate container
Hand Warmer Investigation materials	• indirectly vented chemical splash goggles • nonlatex apron • heat resistant gloves	• 1 8-oz. Styrofoam coffee cup with lid • 1 digital thermometer • 1 digital scale • 1 timer or clock • 1 pair of unopened hand warmers	

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• Science Notebook • *Ingredient List for MRE Heater* • 3-4 sticky notes (optional)		• Design Questions Board from Lesson 1 • Ideas for Investigations chart from Lesson 1 • chart paper • markers • Lesson 2 Contents of the MRE Heater video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • sticky notes (optional) • 7.2 Lesson 2 Contents of the Hand Warmer video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • What We Do as Engineers board • 1 sticky note

Materials preparation (20 minutes)

Online Resources

Watch 7.2 Lesson 2 Timelapse of MRE Heater Set-Up, 7.2 Lesson 2 Timelapse of Handwarmer Set-Up, 7.2 Lesson 2 Contents of the MRE Heater, and 7.2 Lesson 2 Contents of the Hand Warmer to anticipate the kinds of questions students may have while planning and doing their investigations (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**).

Make sure the lab has engineering controls—eyewash station and shower—available.

Flameless Heater Demonstration and Hand Warmer Investigation

- **Setup**
  - Gather materials for the demonstration and student investigations. You will be showing how the mass and the temperature change over time when a flameless heater is activated, and students will investigate how the mass and temperature change over time when they activate hand warmers.
  - Set out a container of ~50 mL of water the day before so it equilibrates to room temperature.

- 1 unopened flameless heater. Be very careful to not tear open the heater contents. When the powder is not contained in the device the temperature will get dangerously hot (approximately 90°C). If you mistakenly cut a section of the flameless heater so the powder escapes, put that heater aside in a safe container to react with excess water later (100 mL or more) and use another MRE heater for the demonstration.
- 1 pair of hand warmers per group.
- **Notes for during the demonstration:** Set up the Flameless Heater Demonstration in a way that allows students to see the temperature changes over time and to make any other observations according to their data collection plan. **Alternate Activity:** 7.2 Lesson 2 Timelapse of MRE Heater Set-Up video and 7.2 Lesson 2 Timelapse of Handwarmer Set-Up are available if you are unable to carry out these investigations in your classroom video (See the **Online Resources Guide** for links to these items. **www.coreknowledge.org/cksci-online-resources**).

- **Safety:** Safety recommendations for students and teacher(s)

Ensure that the lab has engineering controls (eyewash station and shower) available.

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Follow your teacher's instructions for disposing of waste materials.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

- **Disposal:** The used and cooled flameless heater and hand warmers can be disposed of in the garbage.
- **Storage:** Other parts of the MRE can be saved or recycled. Store them in a cool dry place until they can be used.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In this lesson we collect evidence to support the idea that a chemical reaction can lead to a change in temperature. The change in temperature is due to energy being transferred to other systems from the chemical reaction system. For instance, the chemical reaction system transfers energy to the surrounding molecules, thermometer, its container, the outside environment, and the food. That results in those objects feeling warmer. We use the idea that chemical reactions are involved in energy transfer to inform our homemade heater design. We gather evidence comparing the chemical reactions of two common devices (the flameless heater and an air-activated hand warmer) and realize

that neither of these reactions will be appropriate to use in our design. We identify "research" as something we do as engineers in our homemade flameless heater designs and add this to our What We Do as Engineers board.

We recall from *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* how thermometers work to help set the stage for energy transfer diagrams within the larger MRE system. Thermometer readings allow us to observe and measure energy flow from one place to another. The temperature reading on a thermometer changes when the amount of energy transferred to or from the thermometer changes. If more energy is transferred to the thermometer, the temperature reading increases, and if less energy is transferred to the thermometer, the temperature reading decreases. This recall is a helpful step to begin building models that will show how energy is transferred between parts of the MRE system.

We begin building a model of energy transfer between parts of the MRE system. It is critical to carefully define system boundaries here and throughout this unit. If students are unclear when they communicate about where energy is transferring to and from, ask clarifying questions to stress the importance of having clearly defined system boundaries.

By the end of this lesson students will uncover the idea that the system of reactants (atoms that are rearranging to form products) is a system that is within, but separate and different from, the entire system of particles the thermometer is measuring. The surroundings of the thermometer contain atoms that are rearranging, but also (depending on the reaction we examine) water, salt, and all the other particles also in the immediate area. Energy *is* being transferred to the total reaction system (all the particles that are measured by the thermometer) from a part of that system (the system of atoms that are rearranging during the chemical reaction) rather than from a source outside of the system.

Where We Are NOT Going

A common partial understanding students may have is that during an exothermic reaction (when the thermometer detects a temperature increase), energy is being put into the chemical reaction (the system of atoms that are rearranging) in order for it to feel warmer. This seems logical because in *Cup Design Unit* students learned that when objects heat up, energy is being transferred to them, for example, how energy from sunlight transfers into a clear cup, increasing the temperature of the liquid in the cup. The key to understanding why we measure a temperature increase is to focus on the system the thermometer is actually measuring.

While we will eventually tie this back to *Bath Bombs Unit* and show the atoms in each of the substances rearranging, we will not be zooming in to that scale in this lesson. We will broadly discuss that atoms are rearranging in a chemical reaction, but we won't add the specific products and reactants to our model until the next lesson.

Additionally, it is out of grade band for students to explain *why* energy is transferred to or from the system of reactants (the atoms that are rearranging to form products). This unit will only acknowledge that energy transfer coincides with atoms rearranging and use this idea to inform our designs.

LEARNING PLAN FOR LESSON 2

1. Navigation

5 MIN

Materials: Design Questions Board from Lesson 1, Ideas for Investigations chart from Lesson 1

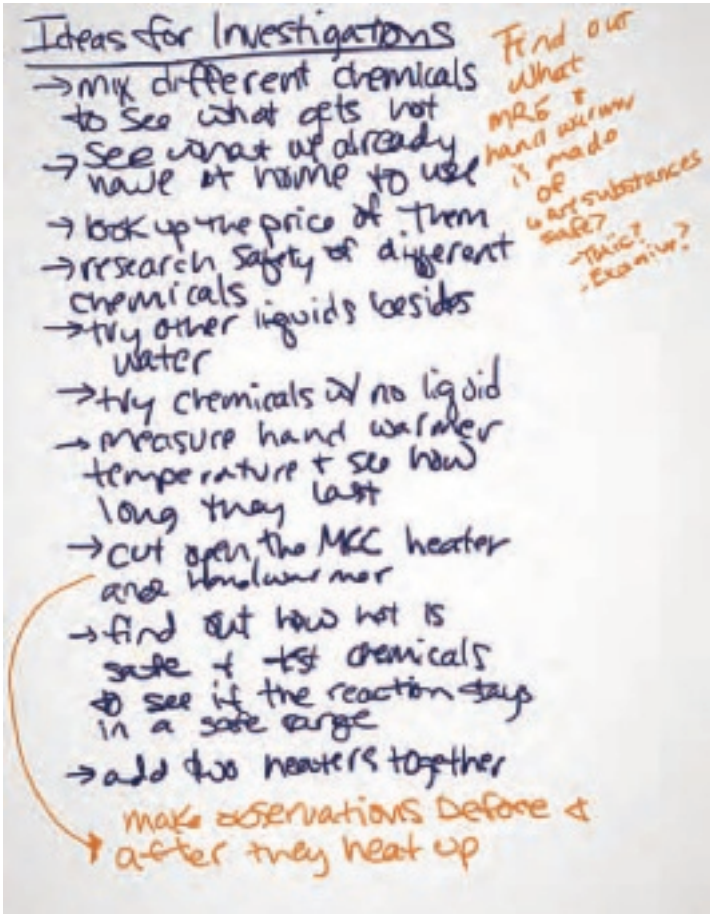
Navigate to today's work. Display **slide A**. Say, *We ended up with a lot of questions and ideas to investigate last class! Let's prioritize where it makes sense to go next. To help us with that, let's recall what we accomplished last time.*

Use the Design Questions Board and Ideas for Investigations chart from Lesson 1 during this discussion to remind students of ideas they had and to add any new ideas. As ideas that are already listed on the Ideas for Investigations chart are talked about, note them, and as new ideas or more-specific ideas are surfaced, add those to the chart as well.

Suggested prompts	Sample student responses
Last lesson we explored a flameless heater that could heat up food. What did we have to do to get the device to start warming up?	*We had to add water to the bag and let it sit for a while, and then it got really hot and heated up the food inside.*
Do we know why adding water to the flameless heater bag would make it change temperature?	*No. We think it's a chemical reaction since we thought we saw a gas produced with the flameless heater. That is how we knew we had a new kind of matter with the bath bombs.* *When there is a new kind of matter that wasn't there before, we know a chemical reaction happened.*
What were some of the ideas we had to investigate the flameless heater in order to help us confirm if a chemical reaction is causing it to get hot?	*We could look at the ingredients in the flameless heater to see if there are things that could react with water.* *We could also compare it to other things that get hot without using fire or electricity to see if they work the same way.*
OK great, you think there is a chemical reaction happening in the flameless heater and that is what is making it warm up. What other devices can we think of that get warm without using fire or electricity?	*Hand warmers, glow sticks, hot packs like at hospitals.*
Do you think these other things are also getting hot because of a chemical reaction? How could we figure that out?	*We could look at what they are made of and compare the ingredients.*

Suggested prompts	Sample student responses
If these other devices are also chemical reactions, do you think they will get as hot as the flameless heater?	*Maybe. But wait, we don't know how hot the flameless heater even gets.*
Right, so we didn't think to collect that data last time. We should probably do that now. I also have some hand warmers we can investigate, but I think it makes the most sense to go back and collect the necessary information about the flameless heater first. Are there any other investigations we should do that might be important? For example, what else could we do to find evidence that supports our idea about these devices undergoing a chemical reaction as they get warm?	*We also need to find out what the heater is made out of.* *We can look at the ingredient list to see if we think anything in there would get hot if we added water to it.* *We can also make observations before and after the reaction to see if there is new stuff made.*

Summarize for the class. Say, *OK, so we think that some of these other things might also be getting warmer because of a chemical reaction, and we have some hand warmers that we can investigate and compare to the flameless heater. But to be able to compare the hand warmer to the flameless heater, we first need to collect some data about the MRE heater, like how hot it gets.*



2. Prepare for flameless heater and hand warmer investigations. 15 MIN

Materials: science notebook, chart paper, markers

Plan to collect temperature data for a working flameless heater as a class. Say, *We have this extra flameless heater right here. We can activate it like we did in the last lesson, but this time we will keep track of the temperature as well. Let's set up a data table in our science notebooks so we have a place to record our data. It's probably important to keep track of how fast these warm up too, so we will make a table that gives us space to record the temperature a few different times.* Display **slide B** and give students time to get their notebooks ready to collect data.

Say, *We will investigate the hand warmer after the flameless heater. Would it make sense to have that data organized in the same way to make it easy to compare? To save time later, let's also build our data collection table for the hand warmer now.* Show **slide C** and give students a moment to finish setting up their science notebooks.

Review how energy is related to the temperature change we see on a thermometer. Say, *As we plan to collect these temperature data, I think it is important to do a quick review to make sure we all agree how thermometers work. We know they measure temperature changes, but let's make sure we can explain how they actually detect the change in temperature.*

As you review these ideas as a class, facilitate the construction of a Thermometer Model to explain energy transfer through particle collisions. Start with a clean sheet of chart paper and have a few different colors of chart markers ready to draw components of the model as students surface ideas. This model will be an important artifact to look back to as the class begins to model the energy transfer in the MRE system later in this lesson.

Key Ideas

Purpose of this discussion: Students developed ideas about energy transfer through particle collision in *Cup Design Unit*. It is important to review these ideas to ensure all students have access to this explanation so they can use these ideas to build on when developing the Energy Transfer Model for the MRE system.

Look for/listen for:

Energy is transferred when particles collide.

Substances that have faster-moving particles have more energy and will transfer some of their energy to the particles with less energy (in the case of the thermometer this results in a higher temperature reading when measuring a substance that is hot as energy flows to the thermometer from the surroundings and a lower temperature when measuring a substance that is cold as energy flows to the surroundings from the thermometer).

Systems can interact with the surroundings—in this case energy is transferred to and from the system (the particles that make up the thermometer) and its surroundings (the particles of the substance that are being measured).

Supporting Students in Three-Dimensional Learning

Students create this model to connect and use the ideas about energy transfer at the scale of particle collisions they developed previously to develop a more-simplified way to show energy transfer between different parts of a system. Creating this model here using elements of CCCs and DCIs with which students are already familiar will allow students to focus their energy on thinking more about the new ideas related to energy transfer and chemical reactions that we will add to this model later in the lesson.

*** Supporting Students in Developing and Using Systems and System Models**

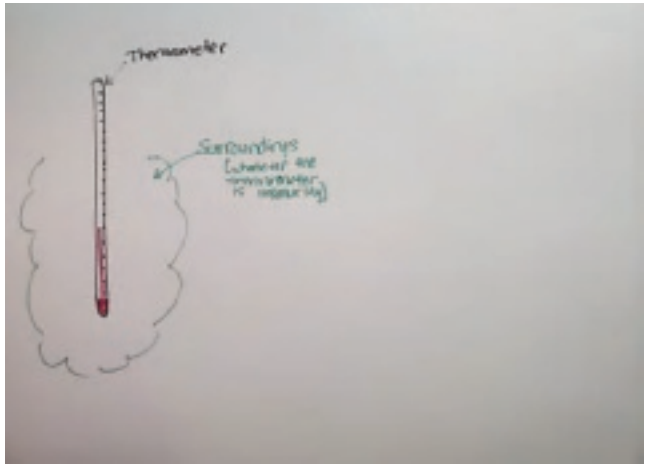
Beginning to develop systems thinking and identifying that energy flows to and from the system and the surrounding systems is important here. In Lesson 3, we investigate exothermic and endothermic reactions. The idea that exothermic reactions release energy from a system of rearranging atoms yet result in a temperature increase (and vice versa for endothermic reactions) is counterintuitive. Carefully defining the system boundaries and defining the parts of the MRE system will

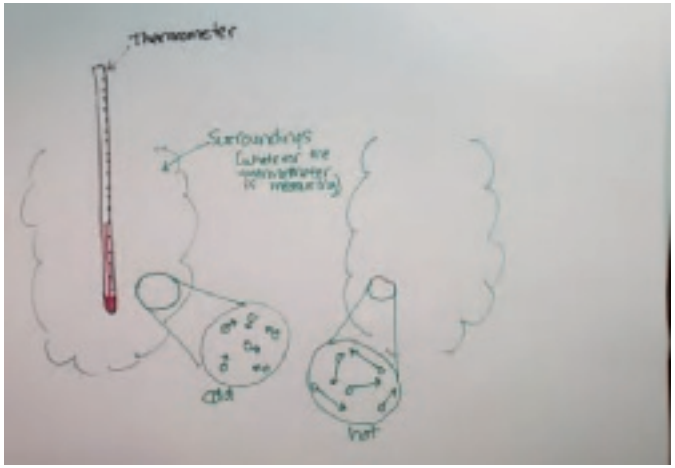
Suggested prompts	Sample student responses
Let's think back to Cup Design Unit, where we figured out how thermometers work. Let's show what we learned by creating a quick model. What are thermometers actually measuring?	*Thermometers measure the temperature of a substance. Thermometers can show us when the temperature of a substance changes.*
How do we know what a thermometer is measuring? If I grab the thermometer in my hand, what am I measuring? What if I just hold it out in the room? What if I put it in the flameless heater solution?	*The thermometer measures whatever its surroundings are. If your hand is around it, it measures that; if it is in air in the room or the liquid of a solution like in the MRE, it measures that.* *****
OK, so we have a thermometer, and it is measuring the temperature of whatever substance makes up its surroundings, but what exactly is temperature? How could we show on a model that two substances have different temperatures?	*When particles that make up a substance are warmer, we can show the particles are moving faster. A substance that is colder has slower-moving particles.*
Great! So if particles move at different speeds, how is the speed of these particles related to energy?	*The faster particles have more energy.* *So if the particles in a substance are moving faster, that substance will have a higher temperature and that also means it has a high amount of energy,*
How can we show that particles have different amounts of energy on a model like this?	*We can show particles with short arrows or long arrows. The longer the arrows, the faster the particle is moving, showing it has more energy and a higher temperature or vice versa.* *We can show more or less parentheses around the particles to show if it is vibrating faster or slower. The more parentheses around a particle, the faster the vibration, showing it has more energy and a higher temperature or vice versa.*

motivate students to think about what (in the MRE system) the thermometer is measuring. With system boundaries clearly defined, students see that energy is transferred from the system of rearranging atoms to the surroundings in the case of an exothermic reaction and from the surroundings to the system of rearranging atoms in the case of an endothermic reaction; linking the idea of the thermometer measuring the surroundings will help students make sense of these ideas when they surface in Lesson 3.

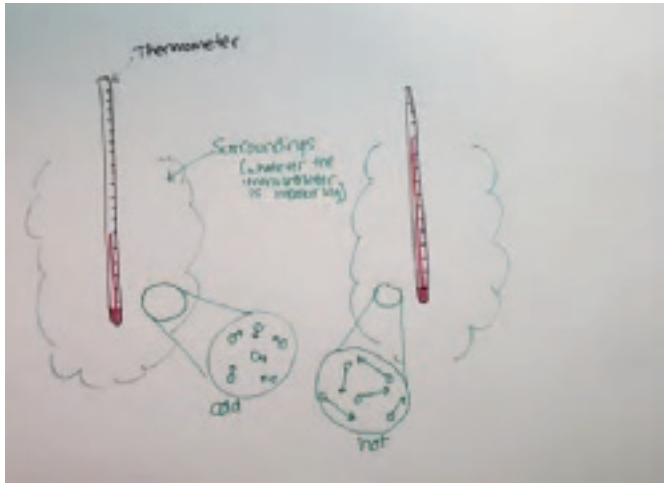
*** Supporting Students in Developing and Using Energy and Matter**

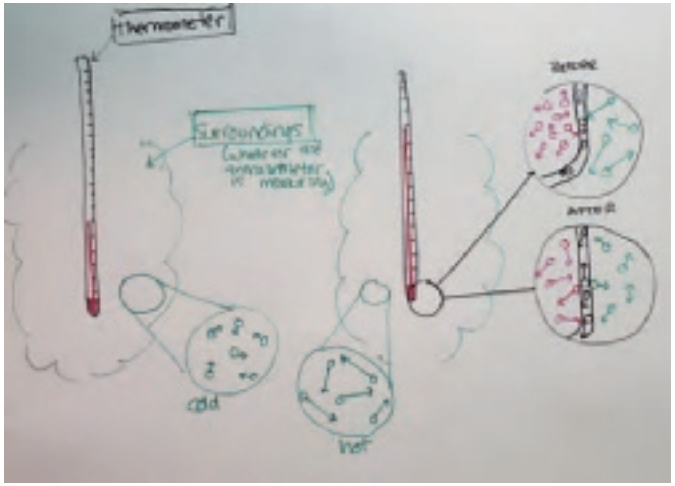
Reviewing how thermometers work is a key piece to scaffold the crosscutting concept of energy transfer in chemical reactions. Later in this lesson, students will further develop these concepts when modeling the energy transfer and track the energy as it flows between parts of the MRE system.



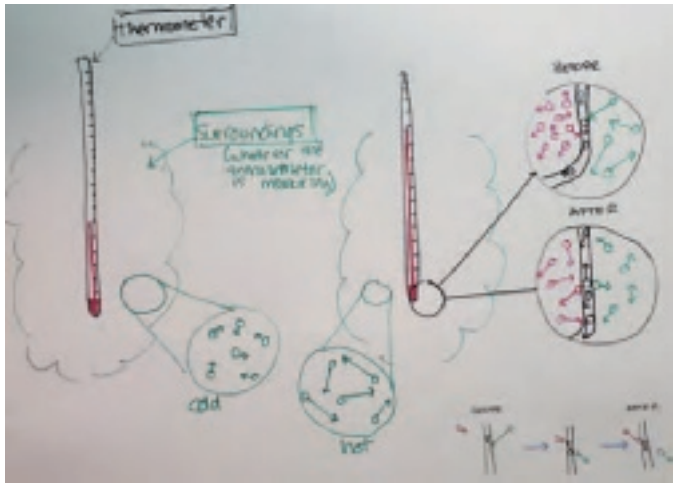


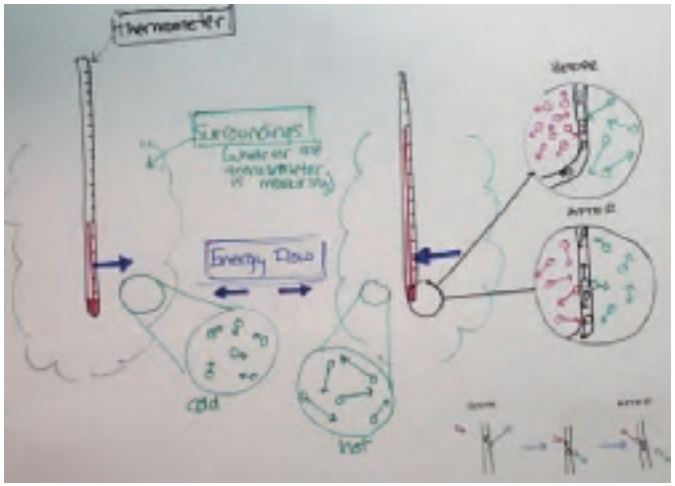
Suggested prompts	Sample student responses
OK, then what is happening that causes us to see a temperature change on a thermometer?	*If the substance being measured is warmer than the thermometer, energy is transferred from the particles in the surroundings to the particles of the thermometer.* *If the substance being measured is colder, the energy is transferred from the particles in the thermometer to the particles of the surroundings.*
How does the transfer of energy between these substances that make up the thermometer and the surroundings happen?	*When particles collide with each other energy is transferred from one to the other.*





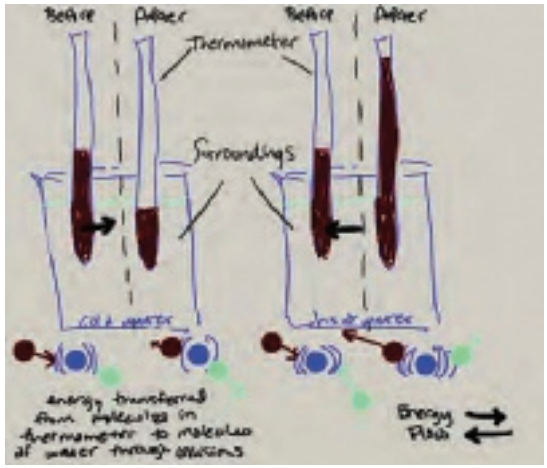
Suggested prompts	Sample student responses
How would we show this transfer of energy on our model?	*We could use a step-by-step diagram or before-and-after versions showing how the energy in the particles changes after they hit each other.* *We could show particles of two different amounts of energy before they collide.* *Then after they collide we can show the faster particle gets slower and the slower particle gets faster.*
So, if energy is flowing to the thermometer from its surroundings, the particles of the substance in the thermometer get faster than before. Will the temperature go up or down?	*The temperature should go up.*
So then what direction must energy be flowing when the temperature of the substance we are measuring goes down?	*Energy must be flowing from the thermometer to the surroundings.* *
OK, that makes sense. But it takes a long time to draw all these particles. Do we need to have this much detail in every energy flow diagram we make? Can we decide on a simplified way to show the direction of energy flow?	*Maybe you can just show a few of the particles in each substance instead of all of them.* *We could just use arrows—whichever way the energy is flowing, the arrow can show the direction.*

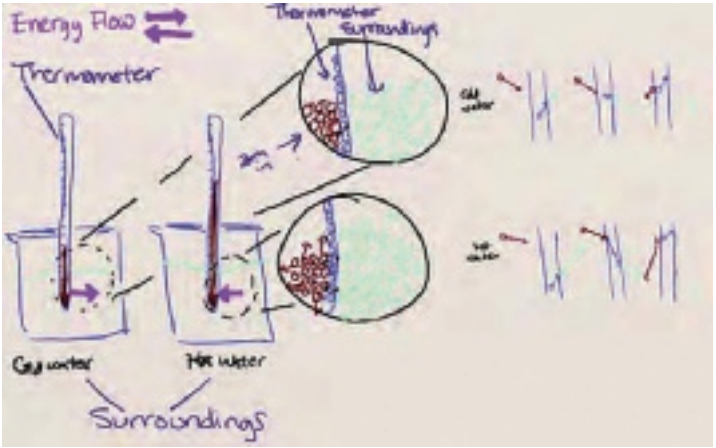




Additional Guidance

The prompt-response section above is an example of one way to facilitate the class discussion as students construct this model together. There are example images within the discussion prompts and another example of a finished model provided below. The models do not need to look exactly like any of these, but it is important that they have a way to show key ideas that the class recalls from *Cup Design Unit*. Keep this class representation posted where all students can see so they can build on these ideas as we construct an Energy Transfer class consensus model later in the lesson that focuses on energy flow in the MRE system.





Alternate examples of final models that convey these ideas.

Suggested prompts	Sample student responses
What parts of the MRE system are we most interested in? What parts do you think we need to keep track of with regard to energy flow?	*The flameless heater.* *The food.*
OK, so our goal is to heat up our food. How could we show that with our energy flow arrows?	*We could show an arrow from the flameless heater to the food.*

3. Plan and carry out the flameless heater investigation as a class. 25 MIN

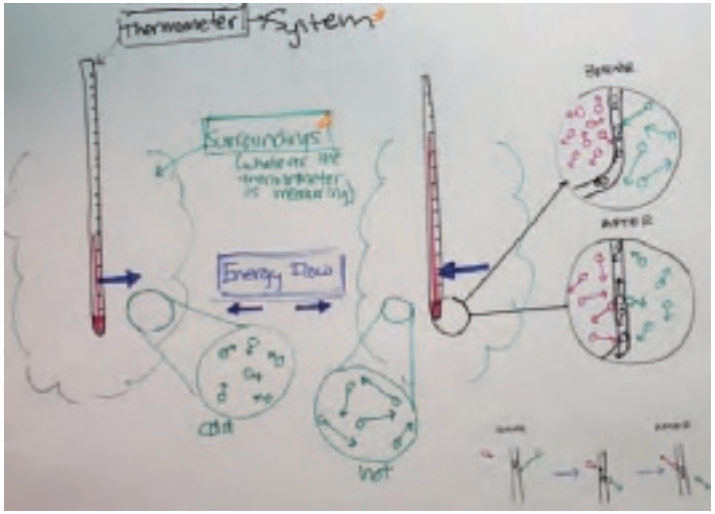
Materials: Flameless Heater Demonstration, science notebook, *Ingredient List for MRE Heater*, Ideas for Investigations chart from Lesson 1, sticky notes (optional) 7.2 Lesson 2 Contents of the MRE Heater. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Investigate the flameless heater reaction. Set out the materials for this demonstration in a place where students can make observations. Show **slide D** and say, *OK, so let's get ready to activate this flameless heater. We have the flameless heater in a Styrofoam cup that we can cover with a lid, and we have some room-temperature water in a separate container that has been sitting out overnight. Once we add the water, it should start warming up immediately. We will call this combination of substances our reaction system.* Refer to the Energy Transfer Model you just created to map the setup of this investigation to the energy flow ideas.

Suggested prompts	Sample student responses	Follow-up questions
If we want to measure how warm this system gets, where should we put the thermometer?	*We should put it inside the cup.*	*Great, so you're saying that the thermometer will measure the temperature of the reaction system, is that right?*
But wait... didn't we show in our model that the thermometer is measuring the energy flow from its surroundings?	*Yes, but the thermometer's surroundings will be whatever it is measuring.* *When we put the thermometer in the system, the system becomes the surroundings for the thermometer.*	*So are you saying that what we call the system and what we call the surroundings is relative, depending on what system we are talking about? That is really interesting.*

Say, *So it is probably really important for our explanations to carefully define what we are considering to be the system we are studying.* If you haven't already added the terms "system" and "surroundings" to the Thermometer Model, take a moment to do that now.

Say, *OK, I think we are almost ready to begin the investigation. Be ready to collect data in your notebook.*



Attending to Equity

Multiple students in the class may ask to see the video again after watching it once. If this is the case, then ask them why they want to watch the video again. What are they wanting to see or look for? Through asking these questions and making students verbalize and identify why they want to watch it again, you are increasing access and engagement with the investigation. If students can't verbalize a reason they want to rewatch beyond just to see it again, then use your discretion as to whether you have time in your class period for this. You may also suggest they see the next slide with before and after photos first and then return to replay the video if still needed.

Suggested prompts	Sample student responses
At what time do we need to be ready to collect the first temperature measurement? I will set a timer for us.	*The table says zero minutes.*
Hmmm, once we add water to the flameless heater in this cup, it will start to warm up immediately. I think zero minutes means before the reaction has started, so how can we get the temperature at zero minutes?	*Since all these things have been sitting out in the same place, they are probably the same temperature, so we could take the temperature of the water before you pour it into the cup with the flameless heater.*

Say, *That sounds like a good idea, but it also made me think of something else. If we are going to be collecting the temperature of this activated flameless heater, we should get as much information from this investigation as possible, since we only have one of these.*

Plan other types of data we need to collect from these investigations. Lead a class discussion to plan the data you will collect in this investigation. The purpose of the investigation is to figure out if the substances in the flameless heater and the hand warmer are undergoing a chemical reaction.

Key Ideas

Purpose of this discussion: Plan an investigation to figure out that the devices that get warm (the flameless heater and the hand warmer) have substances that are undergoing a chemical reaction.

Listen for these ideas:

- We need to look for evidence that there is new matter.
  - There is a change in mass (if gas escapes, like with the bath bomb).
  - Other observations show a gas being produced.
  - There is a change of color.
  - We can hear fizzing or other bubbling noises.
  - There are new smells or odors that were not there before.
- How can we measure and record these data?
  - Weigh the setup before and after the device warms up.
  - Write down our observations about what we see, hear, or smell before, during, and after the investigations.

Assessment Opportunity

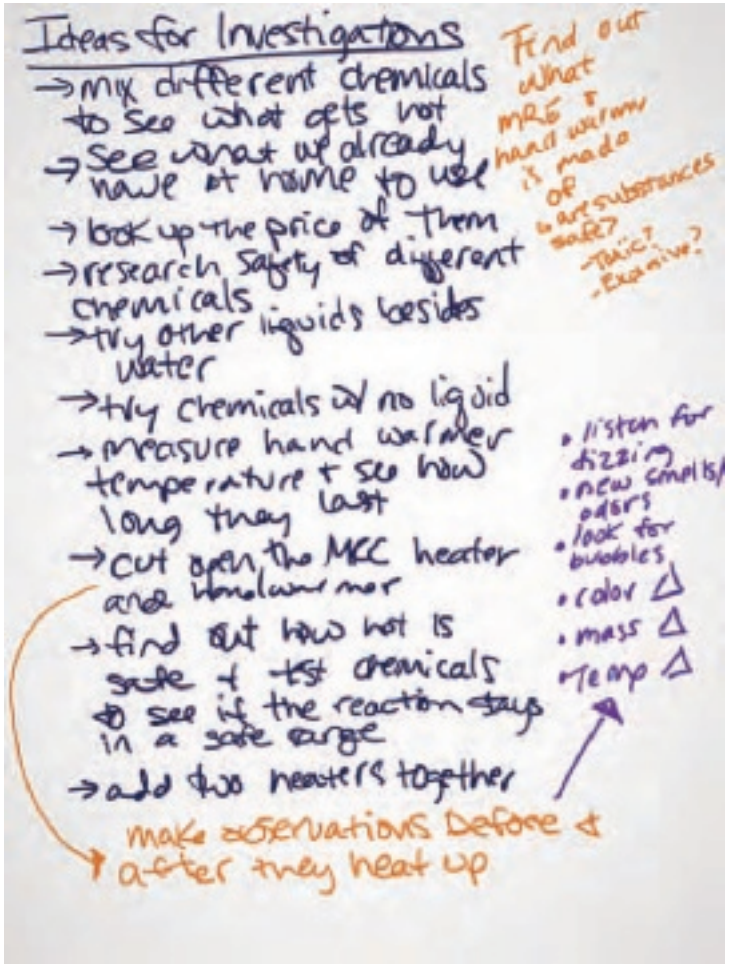
Building towards: 2.A.1 Conduct an investigation to serve as the basis for evidence to confirm that the devices are undergoing a chemical reaction when the temperature increases as energy is transferred from the substances in the devices to its surroundings (what the thermometer measures).

What to look for and listen for: See Key Ideas above.

What to do: Throughout the lesson, try to elicit responses from everyone in the class so that you can formatively assess which students may need more support and guidance when planning future investigations. If students are not raising the idea of looking for changes before, during, and after the devices warm up, ask them to think back to their experiences from *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* that could help them generate ideas for this investigation. Consider using a discussion map or seating chart to track which students contribute ideas and the extent they are demonstrating security in each of the elements.

Refer to the Ideas for Investigations chart you updated at the start of the lesson. Display **slide E**. Say, *When we are measuring how hot the flameless heater gets, we should probably try to collect as much evidence as we can. In addition to getting the temperature data, what else do we think we should be recording*? *What specific data do we want to collect during these investigations that could serve as evidence that a chemical reaction is happening?* As students list specific types of data, make notes updating the Ideas for Investigations chart, either directly on the chart or on sticky notes if there is not enough room on the chart.

Suggested prompts	Sample student responses
What specific things might we try to observe if we wanted to know if a chemical reaction was happening?	*We want to see if there is new matter that wasn't there before.*
What would we record as evidence that there was new matter?	*Since we thought a gas was escaping, we could get the mass of the heater before and after.* *We could look for any color changes.* *We could describe if there are any new odors that weren't there before.*



Update our notebooks for data collection. Say, *These are great ideas, let's add them to our data tables so we can be organized about our observations and measurements*. Show **slide F** and give students a moment to update in their notebooks to account for change in mass and other observations.

Find the starting mass of the device. Say, *We need to get the mass of the substances, but we don't want them to actually start warming up yet because we can't start taking the temperature at the same time as we record the mass.*

Suggested prompts	Sample student responses
How can we get the total starting mass without actually adding water and starting the reaction?	*We can weigh the water separately and add it to the starting mass of the flameless heater.*
It is really hard to get a measurable difference in mass when we are working in such small amounts. We could easily drip a little water from the cup and that would make it so we wouldn't be able to see results because that would be a loss of mass we couldn't account for. Should we be separating these things to weigh them at the end?	*No, we will need to weigh everything all together. We even need to weigh the thermometer at the start and finish because we could easily lose a drop of water that would be attached to the thermometer.*
We will run into a similar issue with our hand warmer investigation, except as soon as we open the bag it starts to warm up. We will need to weigh the hand warmer when it is still in the bag. What do we need to think about when we weigh it again at the end of the investigation?	*We need to make sure we weigh the bag with it again at the end. We need to weigh the entire setup at the start and at the end to be safe.*

Show **slide G** and allow students to update their data collection table.

Weigh components and activate the flameless heater. Weigh the flameless heater setup and either call out the mass or choose a student to report the reading to the class. Then do the same for the container of water. Measure the temperature of the water in the container and share that information with the class as well.

Additional Guidance

At this point in their learning, students are not expected to differentiate between *weight* and *mass*. They will begin to do that during *Unit 8.1: Why do things sometimes get damaged when they hit each other? (Collisions Unit)*. The *Teacher Guide* and other materials in this unit will refer to *mass*, but if your students talk about *weight* instead, you do not need to take time now to explore the difference between them.

Activate the flameless heater and set a timer. Be ready to set a timer or set an alarm on your phone to go off every 5 minutes. Add the water to the cup with the flameless heater and place the lid on the cup in a way to be sure the system is vented, either by not snapping the lid down or by creating a gap in the lid where you add the thermometer. Start the timer and give students some time to share and record any initial observations. Then say, *We have a lot of time between temperature readings, and there were some other things you suggested we find out about these devices*. Refer to the Ideas for Investigations chart and say, *While this investigation is running let's collect some more data that could serve as evidence that a chemical reaction is happening*.

Additional Guidance

Students will be collecting data from several different sources during this step (the ongoing investigation, video and images of the contents of the heater, and a description of the ingredients). Set a timer to go off every 5 minutes for

15 minutes so students (and you) will remember to collect temperature data and other observations at those time intervals. Circulate around the class during this time to make sure students have collected information for each of the other sources. Use questions to help students think about what characteristics are important to record and how to describe them in a way to give them the most information.

Make observations about the substances inside the flameless heater as they are warming up. Refer to the Ideas for Investigations chart and say, *We said we wanted to collect some observations about whether the substances are changing when they warmed up. One piece of evidence that would support the idea of a new substance being made is if we can see a color change. Our setup doesn't really allow us to see that while we collect temperature change, and we wouldn't have time to separate the substance from the water and dry it out before class ended anyway, so we have video and photos showing the substances in the flameless heater before and after they warm up.* Show the video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), on **slide H** and the photos on **slide I**. Give students time to record the observations about the substances inside the flameless heater before and after it warms up.

Make observations about the ingredients in the flameless heater. Refer to the Ideas for Investigations chart and say, *Another idea you had was to find out what substances were inside the devices.* Show **slide J** and give each student a copy of *Ingredient List for MRE Heater.* Say, *This reference has information about the ingredients for both the flameless heater and the hand warmer. For now, let's only look at the flameless heater list.* Ask students to work with a partner to look at the ingredient list for the flameless heater. They should annotate the ingredient list and write in the "Other Observations" section of the data table anything they think may be important.

Continue collecting data and observations for 15 minutes. After the final temperature measurement is recorded, collect the mass of the entire setup and the container the water was initially in so students can add the total final mass to their data table. Make sure all students have the data recorded in their student notebook. They will use these data as evidence to support whether the substances in the flameless heater were undergoing a chemical change.

End of day 1

4. Carry out the hand warmer investigation in small groups.

20 MIN

Materials: Hand Warmer Investigation, science notebook, *Ingredient List for MRE Heater*, 7.2 Lesson 2 Contents of the Hand Warmer video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Online Resources

Collaboration

In Lessons 2, 3, and 5, students will be doing experiments in small groups. It may be helpful to mix up students for each of these investigation groups in order to see who works well with one another. Then you can use those observations to inform intentional groupings when you are creating design teams (which begin working together in Lesson 6 and will continue together for the remainder of the unit). Consider grouping students of different genders, math abilities, and personalities.

Supporting Emergent Multilinguals

It is helpful to intentionally group emerging multilingual students with certain peers. Sometimes this could be peers who know the same languages as them, while other times it could be peers whose English language development is slightly more advanced. It is important that this grouping be thoughtful and that it varies throughout the course of a unit where practical so that students benefit from working with different peers.

Discuss safety protocols. Show **slide K**. Remind students that they should not open the contents of the hand warmers. If, while preparing the investigation, the hand warmer should rip open, let students know they should not attempt to fix it or clean up the remains. It is dangerous to ingest or inhale the contents of the hand warmers, and the substances inside should not be touched with bare hands should the hand warmer break open. Say, *If your hand warmer rips open, get my attention immediately. I will give you a new hand warmer or ask you to join another group, and I will take care of the broken hand warmer for you.*

Ask your students what other safety guidelines we should use when working with dangerous or unknown substances. You may already have lab safety guidelines in place and can review them now. **Slide L** also lists these sample safety guidelines:

- Do not cut or tear open your hand warmer. Notify an adult immediately if your hand warmer is torn or breaks open.
- Wear indirectly vented chemical splash goggles, heat-resistant gloves, and a nonlatex apron during setup, investigation, and cleanup.
- Secure loose clothing, remove loose jewelry, tie back long hair, and wear closed-toe shoes.
- Avoid touching your face (so substances don't get near your nose or mouth); never taste any substance in the lab.
- Move carefully so that we do not spill anything. Immediately wipe up any spills that do happen.
- Follow instructions for cleanup and wash your hands with soap and water after cleanup is complete.
- Use caution when working with heated liquids—they can burn skin.

Discuss how to modify the setup for the Hand Warmer Investigation. Show **slide M** and say, *We will be using a very similar setup that we used for the flameless heater to collect temperature data. However, we don't need to add any water to the hand warmer; it will be activated as soon as you open it.*

Discuss in small groups the data collection for the Hand Warmer Investigation. Show **slide N**. Ask students to open their science notebook to where they created the data table for this investigation. Give them 1 minute to discuss with their group what the first step of this investigation will be and whether they have any questions before they get started. Bring the class together to share ideas.

Suggested prompts	Sample student responses
OK, the very first step of this investigation will be to collect the materials we will be using and to put on your gloves, apron, and safety goggles. However, what data do we need to collect first?	*We need to collect the temperature at time zero. We also need to get the starting mass.*
These hand warmers are activated when they are exposed to air, so as soon as you open them, they will begin to warm up. What can we record as the starting temperature?	*Since the hand warmers have been sitting in the room, we can record the temperature in the cup before we add the hand warmer as the starting temperature.*
What about the mass?	*We can take the mass of the whole setup before and after it warms up like we did with the flameless heater.* *We need to take the mass before we open the hand warmer, and we need to make sure we also include the hand warmer wrapper each time we take the mass.* *Once we open the hand warmers, we can put the wrapper in the cup with the hand warmers.*

Begin the Hand Warmer Investigation. Say, *While we were collecting temperature data for the flameless heater we had time to make observations and look at some other data we were interested in collecting. We will do the same for the hand warmers. I will keep a timer for the class to remind us all when we need to take our temperature readings*. Pass out a pair of hand warmers to each small group (giving a final reminder not to open them yet). Remind students that since you are keeping time for the whole class, it is important that we all open the hand warmers at the same time. Give them time to record the starting temperature and mass of the unopened hand warmers combined with the rest of the setup. Then instruct students to open their hand warmers, shake both hand warmers to fully activate them, place both the hand warmers and the wrapper in the cup, and cover them with the vented lid. Announce that you have started your timer.

Make observations about the substances inside the hand warmer as they are warming up. Once all groups have their hand warmers out of the package and in the cup setup to begin the investigation, show **slide O** and ask students to collect observations while you play video (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**). Move to **slide P** and leave the images on the screen to give time for students to record any other observations.

Make observations about the ingredients in the hand warmer and compare them to the ingredients in the flameless heater. Show **slide Q**. Ask students to examine the hand warmer ingredients they find listed on *Ingredient List for MRE Heater*. They should discuss with their small group what they notice and then record any important observations on their data table.

When the timer alerts that 15 minutes has passed, students will record the final temperature measurement and record the mass of the entire setup. Circulate to make sure students are remembering to also weigh the package the hand warmer was in when they initially weighed it.

5. Have a Building Understandings discussion about our results. 8 MIN

Materials: science notebook, 3-4 sticky notes (optional), chart paper, markers

Identify the maximum temperature change recorded in each of the investigations. See the key located in the teacher reference section—*Example observations for investigations*—for sample maximum temperature changes. Ask students to take a moment to compare the other observations for each investigation to decide what data they can use as evidence to support their ideas and specifically how the data serve as evidence that chemical reactions are happening when these devices warm up. Encourage them to underline or make other annotations on their data tables or provide sticky notes for students to highlight the data that can work as evidence to support the idea that a chemical reaction happened.*

Lead a Building Understandings Discussion about our test results. Display **slide R**. Use questions, such as those that follow, to help the class make sense of this lesson's investigations.

Key Ideas

Purpose of this discussion: (1) Use evidence to support the idea that a chemical reaction is occurring when the devices warm up and (2) determine whether either of these chemical reactions would work for our heater design.

Listen for these ideas:

- Students use data they collected as evidence to support the idea that the flameless heater and the hand warmer both use a chemical reaction.
  - Students observe gas being produced in the flameless heater.
  - Both devices showed a color change, indicating something new was made in each instance.
  - The flameless heater lost mass, and the hand warmer actually gained mass after it warmed up.
- Chemical reactions can cause a temperature change.
- Energy is transferred from these substances to the surroundings when they are undergoing a chemical reaction.
  - More energy is transferred from the substances in the flameless heater compared to the hand warmer.

Assessment Opportunity

Building towards: 2.A.2 Conduct an investigation to serve as the basis for evidence to confirm that the devices are undergoing a chemical reaction when the temperature increases as energy is transferred from the substances in the devices to its surroundings (what the thermometer measures).

What to look and listen for: See Key Ideas above.

What to do: Students should see that, while both devices changed in temperature, the substances in the flameless heater caused a larger increase in temperature. Both devices were observed for the same amount of time, and there was a smaller change in temperature in the Hand Warmer Investigation. Additionally there are two other key pieces of evidence (change in mass and change in color) that students should be using to support their claims. If students are missing these, be sure to

*** Attending to Equity**

Universal Design for Learning: Students may benefit from sentence starters to help them express what they see. Consider providing some sentence or question starters such as these:

- The evidence that supports that a chemical reaction (was or was not) happening in the (flameless heater or hand warmer) was _____.
- _____ supports the idea that a chemical reaction (did or did not) happen in the (flameless heater or hand warmer) because _____.
- What data did you look for to support the idea that a chemical reaction was or was not happening in the device?

Supporting Students in Engaging in Using Mathematics and Computational Thinking

Students collect temperature data in a way that allows them to calculate and discuss rates. To highlight this practice push on ideas around the data we actually collect. Did we collect the highest possible temperature? Would that matter? Why is the rate of temperature change more important than the maximum possible temperature change given an unlimited time frame?

prompt them to check the data they collected in their science notebooks or direct them to the before-and-after photos of the substances in each device as they are warming (slides I and P).

Suggested prompts	Sample student responses
What data did your group collect from the flameless heater investigation?	*The temperature of the system went up _____ degrees in 15 minutes.*
What about the hand warmers?	*The temperature of the system went up _____ degrees in 15 minutes. The temperature did not change as much in the 15 minutes we observed.*
Did other groups find similar data?	*Yes, we all saw the temperature increase.*
We saw that a gas was produced during the investigation, and there was a warning about it on the MRE heater package. Additionally we noticed that there was a loss in mass from when we started heating it and after it was warming for 15 minutes. Based on what we figured out with the bath bombs, what claim do we now have evidence for about what is making the flameless heater work?	*This is a chemical reaction. The package told us that the gas is hydrogen, which is not one of the original ingredients; so the molecules of those reactants must have split apart, and the atoms rearranged to form that new product.* *We also know that the gas was part of the MRE before because after the reaction it weighs less.*
What about the hand warmer? We didn't really see or hear any gas escaping. Were you able to collect any evidence to support the claim that this device is also undergoing a chemical reaction?	*We collected data that showed the heater actually got heavier, and when we observed photos of the stuff inside, there was a color change.* *This is also a chemical reaction; so the molecules of those reactants in the ingredient list must have split apart, and the atoms rearranged with something in the air to form that new product.* *We also think the extra mass came from a new substance that was a different color, and it probably came from molecules that came from the air.* *This substance wasn't part of the hand warmer before because after the reaction it weighed more.*
OK, so we saw the temperature increase for both devices, and we are in agreement that each of these devices had substances that were undergoing a chemical reaction. What can we say about energy flow as a result of this reaction?	*When the chemical reaction happens, energy is flowing from the chemical reaction to its surroundings.*

Suggested prompt	Sample student responses
Let's think back to the Energy Transfer Model we created. How could we represent energy flow for these investigations?	*We could show an arrow leaving the substances that were reacting and going to the surroundings.* *We could have an arrow from the surroundings to the thermometer (making the temperature increase).*

6. Have a Building Understandings discussion about our results. 15 MIN

Materials: science notebook, chart paper, markers, What We Do as Engineers board, 1 sticky note

Create a class consensus model. Use the Energy Transfer Model you created as reference and say, *We could draw our cups around this thermometer and add our substance inside the cup and some arrows to show energy transfer, but that would be really messy. Instead, let's start a new model to make sure we can track the energy flow and see if we can use this to help with our homemade heater designs.* Post a new piece of chart paper to begin the consensus model.

Key Ideas

Purpose of this discussion: (1) Use what we recalled from *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* combined with *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* and the investigations we completed in this lesson to create a model that describes energy flow in an MRE system and (2) use the model we created and the information we learned from our investigations in this lesson to decide on our next design steps.

Listen for these ideas:

Energy is transferred from these substances to the surroundings when they are undergoing a chemical reaction.

- Specifically, we need to define what we are measuring (It is not possible for us to measure only the reactants or products. There are many other particles in the immediate surroundings of the products and reactants that our thermometer is also measuring, so we need to show that on our Energy Transfer Model).
- More energy is transferred from the substances in the flameless heater compared to the substances in the hand warmer.

Energy is transferred from the surroundings to the thermometer, the food, the materials the container is made out of, and the outside environment.

- We want to maximize energy transfer between our reaction system and the food and minimize transfer between our reaction system and the other things.

The matter in the system changes (we know from *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* that when chemical reactions happen the atoms in the reactants rearrange into products).

- We want to design our system to maximize energy transfer between the chemical reaction system and our food while also ensuring matter from the chemical reaction does not mix with our food.

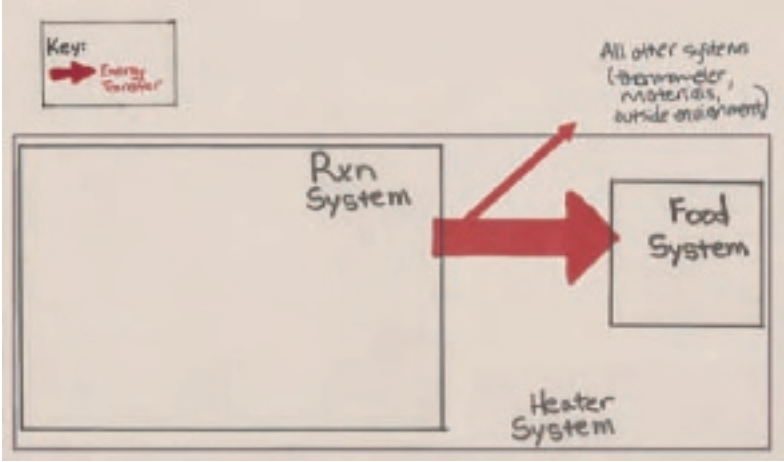
Assessment Opportunity

Building towards: 2.B.1 Develop a model to describe how energy is transferred between different parts of our reaction system to inform the next steps of the design process.

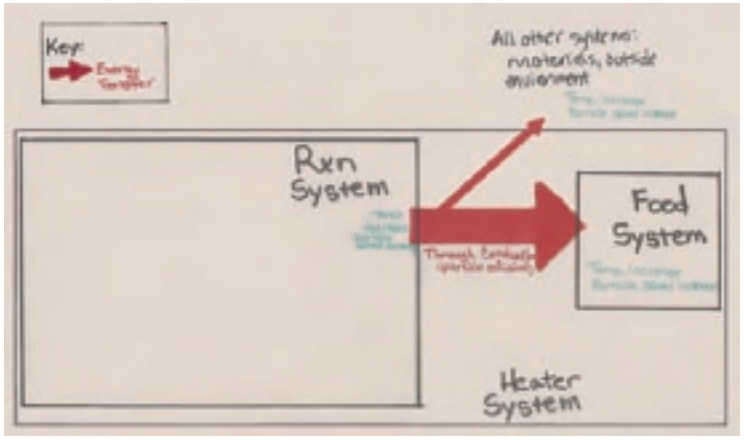
What to look and listen for: See Key Ideas above.

What to do: Students may still want to use the flameless heaters in their designs. Ask questions about what they found out about the substances in the MRE heater to help them use that information to motivate the need to find a different chemical reaction. If students are having trouble tracking the energy flow, refer them to the arrows we added to the Thermometer Model and work backwards from there to find the place the energy was transferring from. An important part of the discussion that may not come naturally is the definition of the system containing only the atoms that are rearranging as part of the chemical reaction. Refer to your temperature investigation setups and problematize the idea of figuring out what particles we were measuring the temperature of. Can we measure *only* the products and/or reactants? No, but we do have evidence that their immediate surroundings changed temperature so energy must have been transferred from somewhere. What is the only system that makes sense?

Suggested prompts	Sample student responses	Follow-up questions
What parts do we need to include in our homemade heater design?	*Substances that will undergo a chemical reaction.* *Container to keep the food separate from the substances used to heat it up.* *A container or something to hold it all together so energy doesn't just transfer to the environment.*	*Great, how should we label these parts?*
We have several different parts of our system, what else do you think might be important to show?	*We can show how the temperature changed.* *We need to show energy flow.*	*How do we want to show that on our model?* *Should we have a key to help us keep track of the symbols we are using?*
Where are all the places on our model we should show these arrows?	*From the reaction system to the food. From the reaction system to the packaging. From the reaction system to the outside environment.*	*What directions should those arrows be going?*
Do we want as much energy going to these other systems as to our food?	*No, we want most of the energy to go from the reaction system to the food system.*	*Is there a way we could use the arrows to show more and less energy transfer?*

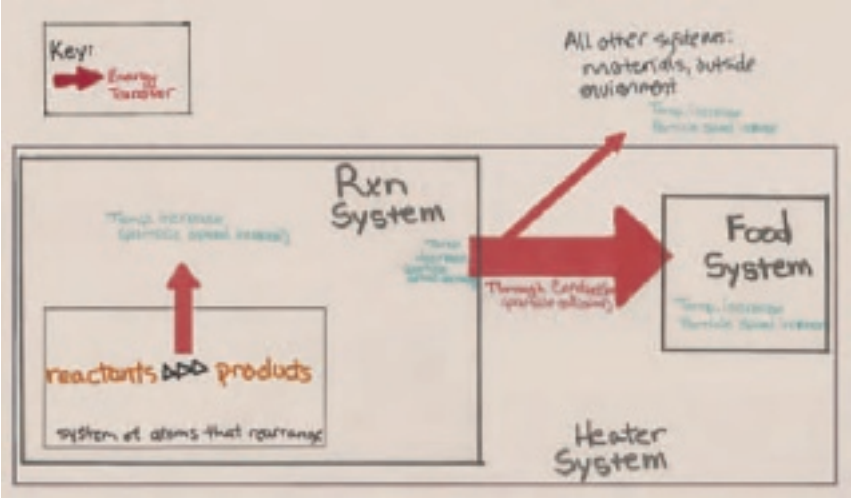


Suggested prompts	Sample student responses	Follow-up questions
So far this model is tracking energy flow between these systems in our potential homemade heater. Let's also keep track of what is actually happening as a result of that energy transfer.	*When the energy goes from one system to the next, the temperature changes.*	*Look back at the Energy Transfer Model.* *What was actually going on with the particles when we saw the temperature change?*
So where on the model should I write that particles are moving faster or slower?	*The end of the arrow in the direction of energy flow should have particles moving faster.* *The other end should have them moving slower.*	*Should we add the mechanism too? How did some particles get faster and others get slower?*



Suggested prompts	Sample student responses	Follow-up questions
OK, so it looks like we have the reaction system with particles moving slower. But wait, I thought we said the temperature increased when the reaction happened.	*It did get warmer.*	*Great, but how would they just start moving faster?*
What do we need to note about the particles to show the temperature increase?	*We need to show the particles get faster.*	
When particles move faster, we said we must have an arrow showing the flow of energy into that system, right? Where would this arrow come from?	*It's coming from the chemical reaction.*	*So do you think this is all the same system?*
When our thermometer was in the investigation setup, what particles was it measuring?	*We were measuring the reaction system.*	*Is the reaction system the same as the chemical reaction?* *Were all the particles in the cup involved in the reaction?* *Think about physically where the thermometer was.*
We remember from Bath Bombs Unit that a chemical reaction is when the atoms in a substance rearrange to form a new substance, right?	*Yes, we need to show that.*	*Do you think we were directly measuring the reactants and products only?* *Is it even possible to only measure the reactants and products?*
Do you think it is important that we show that this rearrangement of atoms is happening?	*We need to show that reactants are transformed to products.*	*How can we show that we are not directly measuring only the atoms that are rearranging on our model?*
Do you think the energy would transfer if this rearrangement of atoms didn't happen?	*I don't think there would be energy transfer if there wasn't a reaction because we didn't see a temperature change until we activated each heater.*	

Use the model to help us decide what our next steps should be. Say, *Creating this model really helped me understand what is happening with energy flow in our system. Do you think this could help us think about what part of this system we should focus our engineering efforts on?* Refer to the model you just created as the students narrow their focus.



Suggested prompts	Sample student responses
Where are the places we notice important energy transfers?	*Between the reaction system and the food.* *Between the reaction system and surrounding systems (packaging or container keeping the food separate from the reaction, packaging keeping all of these parts separate from the outside, and so forth).* *Between the system of atoms that are rearranging and the rest of the reaction system.*
Which of these arrows do we want to maximize and which do we want to minimize?	*Maximize energy flow between the reaction system and the food system.* *Maximize energy flow between the system of atoms that are rearranging and the rest of the reaction system.* *Minimize any energy flow that does not lead to the food.*
Aside from getting our food hot, are there any other things we need to consider with regard to our design? Are there any safety considerations our model helps us think about?	*We probably need to be careful about having too much energy transferred from the reaction system—we don't want people to burn themselves.* *We want a material that lets us transfer a lot of energy to the food, but we need to keep the food in a separate system because we don't want the substances undergoing the reaction to mix with our food.*

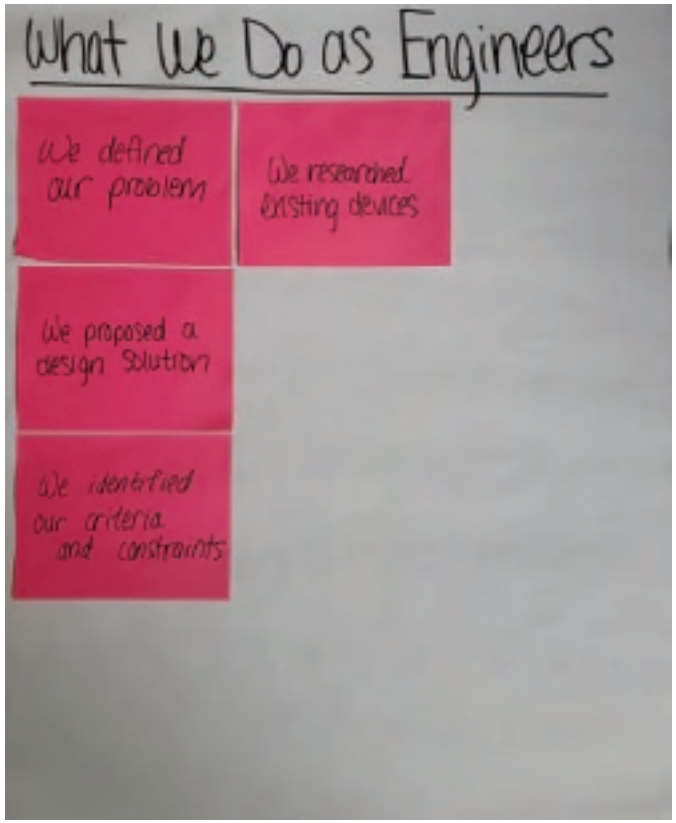
Suggested prompts	Sample student responses
We already figured out what we need to consider with regard to some of these arrows, right? What did we learn in Cup Design Unit?	*We can change materials to minimize or maximize energy flow between systems.*
What do we need to learn more about?	*We don't really know how to maximize the amount of energy transferred from the system of atoms that are rearranging.* *We need to figure out how to get more energy to come from the system of atoms that are rearranging.*

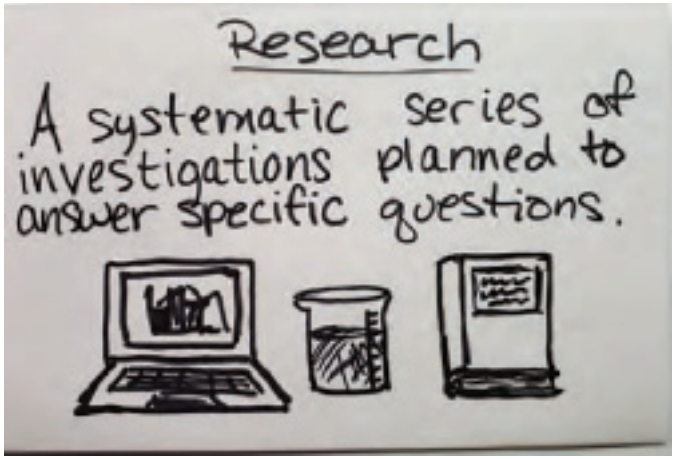
Update Progress Trackers. Display **slide S**. Direct students to the Progress Tracker section of their science notebook. Use questions similar to the following to help students process the lesson's work and record their thinking.

Suggested prompts	Sample student responses
Who can summarize what we did last time and today in this lesson?	*We observed and took temperatures of the MRE flameless heater and a hand warmer as they warmed up and noticed new substances were formed. This indicates that chemical reactions took place.*
When engineers study other existing solutions to determine how they might use this information to inform their own design, that is called "research". Why do you think that's a good name for what we did in this lesson?	*Well, instead of us trying to randomly guess about what we could do, we are learning about some already-existing solutions so we can think about what direction we need to take or what ideas are dead ends.*

Add "research" to the What We Do as Engineers board and Progress Tracker. Say, *we researched existing devices to learn that a chemical reaction was happening when the temperature of the devices increased. We can use this to look for other chemical reactions that might work better for our homemade heater.* Write a large sticky note that says, "We researched existing devices" and add it to your class What We Do as Engineers board.

Also, add *research* to the Word Wall (an example image is shown here).





Have students record in the right column of their Progress Tracker how researching existing heater solutions helped them with their designs. See sample entry.

What did we do as engineers?	What did we figure out that can help us with our designs?
We researched existing devices by planning investigations that collect specific data to help confirm that a chemical reaction is happening when they are heating up.	We planned investigations and decided what kind of data we needed to collect to help us confirm that chemical reactions are happening when the devices warm up. We learned the reactions we studied are not appropriate for our homemade heater, but now we know that we need to look for other chemical reactions that will be safe and effective to use in our homemade heater designs.

Assessment Opportunity

Building towards: 2.B.2 Develop a model to describe how energy is transferred between different parts of our reaction system to inform the next steps of the design process.

What to look and listen for

- Data we collected from investigating possible solutions served as evidence that chemical reactions were happening when both devices we tested warmed up.
- Chemical reactions can cause an increase in temperature; different reactions cause different temperature changes.
- We should test other chemical reactions to see if they could work in our homemade heater design.
- Researching existing solutions helped us figure out our next steps in the design process.

What to do: If students are struggling, you can have them update their Progress Trackers with a partner or do a think-pair-share to brainstorm ideas before writing an individual entry. Ask them about what they learned in this lesson and how they were planning to use what they learned.

Update the table of contents. As a reminder, have students periodically update the table of contents in their science notebook.

7. Navigation

2 MIN

Materials: None

Navigate to next time's work. Display **slide T**. Say, *So unfortunately, we saw MRE flameless heaters are expensive and could be difficult to get in an emergency. It also is not safe to work with the substances inside them because magnesium is highly flammable and hazardous. So, the MRE flameless heater won't fit our criteria and constraints for a homemade flameless heater. The substances that make up the hand warmers seem to be safer, but they don't get hot enough, at least not in a reasonable amount of time.*

Suggested prompt	Sample student response
What are we wondering now?	*Is there another chemical reaction that might work better? Do other chemical reactions heat up, too?*

SCIENCE LITERACY: READING COLLECTION 1

A Hot Meal on the Go

1 **What's Cooking?**
2 **Food for Thought**
3 **Military Memoir: MREs**
4 **Winter Ritual**
5 **Hot Hands for Sale!**

Literacy Objectives

- ✓ Read to find out how chemical reactions produce heat.
- ✓ Read to learn practical uses of chemical reactions.
- ✓ Use reading to describe how chemical reactions preserve food.
- ✓ Use reading to explain how chemical reactions are used in hand warmers.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 1–2.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Prepare a food plan for a weekend trip in response to the reading.

Instructional Resources

Student Reader

Collection 1

Science Literacy Student Reader, Collection 1
"A Hot Meal on the Go"

Exercise Page

EP 1

Science Literacy Exercise Page
EP 1

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 1: How can we heat up food when we don't have our typical methods available?
- Lesson 2: How do heaters get warm without a flame?

Standards and Dimensions

NGSS

MS-PS2-3: (Building toward) Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Disciplinary Core Ideas

PS1.B: Chemical Reactions

Science and Engineering Practice(s): SEP; Analyzing and Interpreting Data

Crosscutting Concept(s):

CCSS Cause and Effect

English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

CCSS.ELA-LITERACY.W.7.2

Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

chemical reaction

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

flameless heater **reconstitute**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Exercise Page

EP 1

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

2. Preview the assignment and set expectations. (Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Chemical Reactions and Energy unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *In "What's Cooking?" you will find out how people use chemical reactions to prepare hot and tasty food without a stove or fire.*
  - *In the second selection, you'll read about different ways chemical reactions and other processes have been used to preserve food throughout history.*
  - *"Military Memoir: MREs" explores the benefits of using chemical reactions to prepare ready-to-eat meals on the go.*
  - *In "Winter Ritual," you'll find how to use chemical reactions to keep your hands and feet warm in cold weather.*
  - *The final selection will help you figure out the true story behind hand warmers that use chemical reactions to generate heat.*

- Distribute Exercise Page 1. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a food plan for a weekend camping trip.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
- *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What is an MRE?	*It's a Meal, Ready-to-Eat. It has vacuum-sealed food inside of its package or pouch. The food often needs to be heated, so MREs come with a flameless heater.*
What is a chemical reaction?	*A chemical reaction is what happens when two different substances interact and form a new substance that has new properties that are different from the ones of the original substances.*
What makes a meal good?	*It tastes good so you enjoy eating it, and it is good for you (nutritious) so your body can stay healthy and strong.*
If you were going on an overnight hiking trip, what kinds of food would you take with you to eat?	*lightweight foods that taste good and provide energy; foods that will not spoil or get smashed in a backpack*
How do you keep your hands and feet warm in cold weather?	*I wear gloves and heavy socks and boots. I rub my hands together. I blow hot air from my breath into my cupped hands.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
How could you heat up food if no stove or fire were available?	*On a sunny day, you could set the food in a container in the sun. Or you could buy or make a flameless heater.*
What ingredients are in this type of flameless heater?	*powdered magnesium, iron, salt*
How do flameless heaters work?	*They work by creating a chemical reaction.* *A chemical reaction releases heat.* *They work because of a process called oxidation.* *To create the chemical reaction that releases heat, water is added to certain metal and salt mixtures, which makes the metal rust quickly to release heat.*

SUPPORT—Have students watch a video to show how flameless heaters work.

- Refer students to the Exercise Page 1. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to create a food plan for a two-day hiking trip.*
  - *In the selections, you learn about preserving food and heating food using chemical reactions. This lets you know that you can plan hot meals during your trip.*
  - *Think about what you read as you make a list of foods you really like that you can have for breakfast, lunch, and dinner.*
  - *Make sure your foods are lightweight, portable, nutritious, easy to eat, and delicious. A great menu will include foods that would make others want to join you or have the same foods for their own trip.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 1

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise.

The five reading selections help to explain how some chemical reactions can preserve food or generate heat to cook meals or warm your hands and feet.

Student Reader

Collection 1

Pages 4–5 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "What's Cooking?"	*It explains how you can have hot food even when you don't have a stove or fire.*
Why might you want to use a flameless heater?	*You might want to use a flameless heater in these scenarios:* *if you are hiking and don't want to build a fire* *if there is no electricity* *if you are in a situation, such as outer space, where you can't make a fire*
Why might certain foods not be good to take on a hiking trip?	*Fresh foods, like grapes, rot quicky and could get smashed.* *Heavy foods, like potatoes, would be hard to carry.* *Raw meats and perishable products like dairy foods will spoil if they are not refrigerated.*

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

SUPPORT—Reinforce the concept of *chemical reaction* by having students describe common chemical reactions that involve two different substances interacting to create a new substance, for example, mixing colors, baking a cake, mold growing, wood rotting.

Pages 6–7 Suggested prompts	Sample student responses
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first selection was about foods you can eat without having a refrigerator or stove. This selection reviews ways that foods have been preserved throughout history when there were no refrigerators or stoves.*
Why is it necessary to find ways to preserve food?	*You might have a lot of food that you can't eat right away, and you can preserve it so it doesn't go bad.* *Preserving food can help you ensure you have enough food to eat in the future, in case you are unable to get more food.*
What are the ways you and your family preserve food?	*freezing, refrigerating, drying, canning, pickling*
What types of preserved foods do you eat?	*pickles, canned tomatoes, ice cream, potato chips, nuts, milk*

CHALLENGE—Have interested students research and then demonstrate to the class how vermiculite expands when heated. Ask other students to demonstrate how foods like powdered milk can be reconstituted by adding water.

Pages 8–9 Suggested prompts	Sample student responses
What is the general purpose of the third article, "Military Memoir: MREs"?	*It explains the benefit of MREs.*
What are the benefits of using MREs in the military?	*You don't have to make a fire that other people could see.* *MREs are lightweight, so they are easy to carry.* *MREs take a lot less time to heat food than building a fire.* *MREs are easy to clean up.*
What are some disadvantages to using MREs?	*They don't stay hot for long and might be hard to use in the dark.*

Pages 10–11 Suggested prompts	Sample student responses
What is the general purpose of the fourth article, "Winter Ritual"?	*It describes how hand warmers use chemical reactions to warm your hands and feet on a cold day.*
What are the advantages to using hand warmers?	*They are lightweight.* *You don't have to build a fire.* *You can apply them directly to the parts of your body that are cold.*
What are the uses of the ingredients of a hand warmer?	*salt and iron to create the chemical reaction* *charcoal to provide water* *vermiculite for insulation so you don't burn yourself*

Pages 12–13 Suggested prompts	Sample student responses
How does the last selection relate to the other selections in this collection?	*It helps you think about how chemical reactions that release heat do and do not work.*
Which claims are questionable in the first ad for handwarmers?	*They stay hot for up to 24 hours.* *You can stop and start the warming process.* *Hand warmers do not expire.*

EXTEND—Have students watch a video that describes dehydrating food that can be reconstituted during a camping trip.

Pages 12–13 Suggested prompts	Sample student responses
What do you know about hand warmers that makes you realize that the second ad is telling the truth?	*Once the chemical reaction has occurred, it is over, so you can't start and stop it.* *The chemical reaction happens over a couple hours, not 24 hours.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 1, students should create a menu for a two-day hiking trip. The foods should be nutritious and delicious and should be easy to carry and prepare for eating.

Use the rubric provided on the Exercise Page to supply feedback to each student.

LESSON 3

What other chemical reactions could we use to heat up food?

Previous Lesson

We conducted investigations to learn that chemical reactions are happening in the flameless heater and hand warmer when they warm up. We created an Energy Transfer Model and used this model, combined with our research, to help us decide that neither reaction we tested would be appropriate for our homemade heater and that we should investigate other chemical reactions.

This Lesson

Investigation

3 DAYS

In this lesson, we test different chemical reactions to determine if any of them cause an increase in temperature for use in our homemade flameless heater designs. We figure out that root killer and aluminum foil cause the largest increase in temperature, and we think it may work to heat up our homemade flameless heater. We model the chemical reaction as particles and the transfer of energy out of the reaction system to the food system and investigate varying the weight of each system.

Next Lesson

We will plan and conduct an investigation to determine which proportion of reactants will work best to heat up our food. Then, we will reflect on what makes good instructions and identify our stakeholders. Finally, we will administer a survey to our potential stakeholders to figure out what aspects they find most important.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

3.A Collect data that support choosing the chemical reaction that can transfer the most energy to the food system.

3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

What Students Will Figure Out

- Root killer and aluminum foil mixed together in saltwater caused a large increase in temperature.
- Exothermic reactions transfer energy to the surroundings; these reactions feel warm. Energy transfers from the surroundings to an endothermic chemical reaction; these reactions feel cold.
- Chemical reactions can transfer energy to other systems.
- The more reactants we use in a chemical reaction, the more energy is being transferred into or out of the system. The evidence of this is a greater temperature change.
- To raise the temperature of a larger amount of food, more reactants are required.

Lesson 3 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Consider questions that the class had at the end of Lesson 2 and revisit the Ideas for Investigations chart to motivate looking at other chemical reactions.	A-E	What We Do as Engineers board, class-level Criteria and Constraints chart, Ideas for Investigations class chart from Lesson 1
2	10 min	**PREPARE TO INVESTIGATE WHICH REACTION IS THE BEST CANDIDATE TO TRY IN OUR HOMEMADE FLAMELESS HEATER** Prepare to investigate other chemical reactions to determine which one is the best candidate to try in our homemade flameless heaters by measuring the temperature changes of each one.	F-H	transparent tape, *Data Table for Chemical Reactions Lab*, chart paper, markers
3	25 min	**CONDUCT THE CHEMICAL REACTIONS LAB** Small groups measure temperature changes caused by different chemical reactions.	I-K	*Data Table for Chemical Reactions Lab*, *Chemical Reactions Lab Instructions*, *Class Data for Chemical Reactions Lab*, *Some Common Gases* (optional), *Sample Temperature vs. Time Data*, chart paper (optional), markers (optional), Chemical Reactions Lab
4	5 min	**FIND PATTERNS IN THE DATA AND TRACK ENERGY FLOW FROM OUR INVESTIGATION** Use our class lab data to find patterns in the temperature changes and track energy flow in the different investigations by answering the sensemaking questions.	L	*Class Data for Chemical Reactions Lab*, whole-class data table
				End of day 1
5	20 min	**BUILDING UNDERSTANDINGS DISCUSSION ABOUT OUR CLASS RESULTS** Use our class data and patterns analysis about temperature change to figure out which reaction heats up the most.	M-O	*Class Data for Chemical Reactions Lab*, whole-class data table, cards for the Word Wall (exothermic and endothermic), What We Do as Engineers poster, chart paper (optional), markers (optional)
6	15 min	**CO-CONSTRUCT PARTICLE-LEVEL MODELS OF THE REACTION** Co-construct particle-level Energy Transfer Models to track energy transfers and help explain why more reactants led to a greater temperature change.	P-Q	chart paper, markers, classroom consensus model from end of Lesson 2, Key Model Ideas poster from *Bath Bombs Unit* (optional)

Part	Duration	Summary	Slide	Materials
7	10 min	**ADD ENERGY TO THE PARTICLE-LEVEL REACTION MODEL**	R	chart paper, markers
				End of day 2
8	5 min	**NAVIGATION AND ENERGY TRANSFER MODELS** Shift focus from particle models to an Energy Transfer Model only. Consider the 1- and 2-gram systems of the copper sulfate and aluminum reaction.	S	pencil, *Energy Transfer Models*, chart paper, markers, class Energy Transfer Model from previous class
9	8 min	**CREATE A NEW ENERGY TRANSFER MODEL FOR A DIFFERENT AMOUNT OF REACTANTS** Work in small groups to model the energy transfer for a different amount of reactants.	T-U	pencil, partially completed *Energy Transfer Models*, chart paper, markers
10	7 min	**PRESENT NEW ENERGY TRANSFER MODELS TO THE CLASS** Share one or two small groups' Energy Transfer Models with the class.	V	partially completed *Energy Transfer Models*, whole-class Energy Transfer Model, document camera (optional)
11	7 min	**SET UP DOUBLING SYSTEMS INVESTIGATION** Motivate the need to increase the amount of food and do more tests. Set up the Doubling Systems Investigation.	W	*Energy Transfer Models*, chart paper, markers
12	5 min	**VIDEO OF DOUBLING SYSTEMS INVESTIGATION** Watch a video of the tests described in the Doubling Systems Investigation.	X	Doubling Systems Investigation
13	7 min	**REVISITING MODELS AND COMPLETING CAPTIONS** Revise class models and models on the handout. Add an explanation in words as a caption to each model.	Y	*Energy Transfer Models*, chart paper, markers
14	5 min	**UPDATING PROGRESS TRACKERS** Update Progress Trackers with what engineers do and tape completed *Energy Transfer Models* below the Progress Tracker.	Z	transparent tape, completed *Energy Transfer Models*, What We Do as Engineers poster
15	1 min	**NAVIGATION** Discuss big ideas from the lesson and navigate to Lesson 4.	AA	
				End of day 3

Lesson 3 • Materials List

	per student	per group	per class
Chemical Reactions Lab materials **Student Procedure Guide** **Student Work Pages**	• nitrile gloves • nonlatex apron • indirectly vented chemical splash goggles	• 3 8-oz. Styrofoam cups with lids • 1 digital thermometer • 1 rubber band • 1 digital scale • 1 tray	• 110 mL of room-temperature water • 340 mL of room-temperature vinegar • 360 mL of room-temperature saltwater • 40 mL of room-temperature cabbage juice solution • pieces of 1.75 steel wool pads soaking in room-temperature vinegar • 40 g baking soda • 16 g shredded aluminum foil • 14 g root killer • 2 additional 8-oz. Styrofoam cups for measuring vinegar and cabbage juice • 18 10 × 10 cm squares of folded parchment paper • 6 plastic spoons • paper towels
Doubling Systems Investigation materials	• *Energy Transfer Models*		• 7.2 Lesson 3 Doubling Reactants or Food (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
Lesson materials	• Science Notebook • transparent tape • *Data Table for Chemical Reactions Lab* • *Chemical Reactions Lab Instructions* • *Class Data for Chemical Reactions Lab* • *Some Common Gases* (optional) • pencil		• What We Do as Engineers board • class-level Criteria and Constraints chart • Ideas for Investigations class chart from Lesson 1 • chart paper • markers • *Sample Temperature vs. Time Data* • chart paper (optional) • markers (optional) • whole-class data table • cards for the Word Wall (exothermic and endothermic)

	per student	per group	per class
	• *Energy Transfer Models* • partially completed *Energy Transfer Models* • completed *Energy Transfer Models*		• What We Do as Engineers poster • classroom consensus model from end of Lesson 2 • Key Model Ideas poster from *Bath Bombs Unit* (optional) • class Energy Transfer Model from previous class • whole-class Energy Transfer Model • document camera (optional)

Materials preparation (90 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make one copy each of *Data Table for Chemical Reactions Lab*, *Class Data for Chemical Reactions Lab*, and *Energy Transfer Models* for each student. Trim *Data Table for Chemical Reactions Lab* and *Energy Transfer Models* to fit science notebooks. If you do the flammability test Alternate Activity during the lab, print one copy of *Some Common Gases* for each student.

Be sure you have materials ready to add the following words to the Word Wall: *endothermic*, *exothermic*. Do not post these words on the wall until after your class has developed a shared understanding of their meaning, which will happen throughout day 2.

Watch two videos on the website:

1. This video shows demonstrations of the lab procedures that students will follow on day 1 to measure the temperature changes caused by different chemical reactions (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).
2. This is the video that students watch on day 3 to investigate the temperature changes when the amount of reactants or the amount of food doubles (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Make sure the lab has engineering controls—eyewash station and shower—available.

Day 1: Chemical Reactions Lab

- **Group size:** form 6 groups of students. Adjust group size so that you have 6 groups of students.
- **Setup**
  - Since students will be measuring the temperature changes caused by each chemical reaction, it is critical that all substances and solutions (including water and vinegar) have fully come to room temperature. All substances and solutions should be prepared at least a day before students conduct their investigations and allowed to come to room temperature overnight. Likewise, avoid storing substances and solutions near windows and other HVAC equipment that may be hotter or colder than the rest of the room.

- Place one steel wool pad into a container of vinegar labeled "High." Tear another steel wool pad in half. Place one half into a second container of vinegar labeled "Medium." Tear the other half in two so that you now have two quarter pads. Place one quarter pad into a third container of vinegar labeled "Low." Make sure that the pieces of steel wool are submerged as much as possible. These only need to soak for 5-10 minutes before use but can be soaked longer. Do not seal the container tightly, as some hydrogen gas will be generated and can build up pressure. Watch these videos for a demonstration (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).
- ***Please note that the steel wool needs to be kept in the vinegar until students are ready to monitor temperature changes for each individual piece. Once the steel wool is exposed to air, the reaction will begin.***
- Prepare 100 mL of cabbage juice by adding 0.1 g of powdered cabbage juice extract to a container. Add 100 mL of water to the container and stir to make sure all the powdered extract dissolves. Watch this video for a demonstration (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).
- Prepare 400 mL of saltwater by adding 2.4 g of table salt to a container. Add 400 mL of water to the container and stir to make sure all the table salt dissolves. Watch the video for a demonstration (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).
- Prepare 16 g of shredded aluminum foil by running ~8" × 11" pieces of aluminum foil through a paper shredder. A crosscut paper shredder is preferred since it cuts the aluminum into small pieces (~2 cm × 0.5 cm), whereas strip-cut paper shredders produce long strips that will then need to be cut into smaller pieces. You may need to run a few pieces of aluminum foil through the shredder to remove any paper bits before you collect foil to use in class. Note: You will need an additional ~115 grams of shredded foil per class for each of Lessons 4, 6, and 9, if it would be easier to prepare it all at once now. Watch this video for a demonstration (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).
- Obtain 18 8-oz. Styrofoam cups with lids to make 6 sets of 3 cups and 3 lids. Use tape to label cups so they can be reused later. Label the sets with the groups' letter IDs (A through F), which correspond to the different chemical reactions found in *Chemical Reactions Lab Instructions*. Label the 3 cups for each group with "Low," "Medium," or "High" (or "L", "M", or "H").
- For groups A and B, pour 50 mL of room-temperature vinegar into each cup. Place the lids securely on the cups.
- For group C, place the lids securely on the empty cups.
- For groups D and E, pour 60 mL of saltwater into each cup. Place the lids securely on the cups.
- For group F, add the following volumes of water to the different cups then place the lids securely on the cups:
  - Low: 50 mL
  - Medium: 40 mL
  - High: 20 mL

- Prepare trays of supplies for groups to use in their investigation. Place each set of 3 cups and 3 lids onto a different tray and label the trays A-F to correspond with the cup labels. Place 1 digital thermometer, 1 digital scale, 1 rubber band, and some paper towels on each tray. Make sure students have access to a timer or clock. Add the following to the specified trays:
  - Trays A and B: a container of ~7.0 g baking soda, 3 10 × 10 cm squares of folded pieces of parchment paper, and 1 plastic spoon
  - Tray C: the 3 containers of steel wool pieces submerged in vinegar, 2 plastic spoons, and 3 extra paper towels
  - Trays D and E: a container of at least 6.5 g of root killer (copper sulfate), a baggie with 8.0 g of small pieces of aluminum foil, 6 10 × 10 cm squares of folded pieces of parchment paper, and 1 plastic spoon
  - Tray F: a container of at least 40.0 g of prepared cabbage juice, a container of at least 40.0 g of vinegar, 2 additional Styrofoam cups for weighing liquids into, 2 disposable pipettes (optional)
  - Print out 6 copies of the procedures for each chemical reaction in *Chemical Reactions Lab Instructions* and add them to the trays for easy reference by students.

Safety

Ensure that the lab has engineering controls (eyewash station and shower) available.

1. Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
2. Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
3. Follow your teacher's instructions for disposing of waste materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.
8. Use caution when working with heated liquids—this can burn skin!
9. Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

Be sure to remind students to firmly place lids and gently swirl the Styrofoam cups to avoid the escape of liquid from the cups.

Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.

- **Notes for during the lab:** Students working with the vinegar-dipped steel wool in air may notice some rotten-egg-like smells when they extract the steel wool from the vinegar and remove the cup lid after monitoring temperature. The cabbage juice is also rather fragrant. The aluminum foil and root killer reaction and the resulting copper in the

products have noticeable metallic smells. These smells are not hazardous in the quantities with which students work; however, some students may be extra sensitive. Safety Note: You need to have appropriate lab ventilation—some students may have respiratory issues if exposed to these vapors.

- **Storage and Disposal:** Save any extra saltwater solution for upcoming labs. All root killer and aluminum reaction materials will be used in future labs, so make a point not to dispose of any *unused* substances. Any remaining water or cabbage juice as well as the liquids in the Styrofoam cups can be washed down the drain with cold or warm water. Solid wastes (pieces of steel wool, copper, and aluminum from the root killer and aluminum reaction) can be disposed of in the garbage. Rinse out all Styrofoam cups and save for future lessons; although the Styrofoam cups from the reactions involving metals will be stained, this should not interfere with the experiments.

Unused root killer and cut-up aluminum foil can be retained for future lessons. Vinegar, unused steel wool, powdered cabbage juice extract, and baking soda can be stored on the shelf for next year.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In this lesson students investigate different chemical reactions to help determine which will work best for their homemade heaters. They will track the energy transfer into or out of the various systems involved (the substances themselves as well as the cup holding them, the air, the thermometer, and so forth) to help figure out that the energy from a chemical reaction could be transferred to heat up the food in our homemade flameless heater. After choosing the best reaction to move forward to heat food, students build particle models using what they figured out from *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* to explain what is going on with the chemical reaction and energy transfer.

Students will identify that when the thermometer shows an increase in temperature, energy is transferred to other systems from the system of substances they're testing. In other words, energy is being released from that system. For instance, the chemical reaction system transfers energy to the thermometer, its container, the outside environment, and the food. That's why those objects heat up and feel warmer. When the thermometer shows a decrease in temperature, energy is being transferred from the surrounding system to the chemical reaction system. When energy from the surrounding systems, like the thermometer, is transferred to the chemical reaction system, a decrease in temperature of the surroundings occurs. Therefore, energy is actually absorbed into the chemical reaction system, which might seem counterintuitive to students.

Students develop and use Energy Transfer Models to predict temperature changes when increasing the amount of food and/or increasing the amounts of reactants.

Where We Are NOT Going

The mechanism for *why* energy transfer occurs in the patterns that it does involves the bonds and bonding energies between atoms in the system of substances that we're testing. Students will figure out in high school why these patterns occur because bonds between atoms are beyond the middle-school grade-band goal.

Also, there is no need in this unit to label energy in the chemical reaction system as "potential energy". Thinking about energy as energy without labeling the forms of energy at first has been shown to be helpful for students' sensemaking around this crosscutting concept. In 8th grade, students will have opportunities to think about potential and kinetic energy within various systems.

In the root killer and aluminum reaction, there are two additional reactions going on besides the $3CuSO_4 + 2Al \rightarrow 3Cu + Al_2(SO_4)_3$ This lesson does not get into these side reactions, but here are the explanations for these reactions in case students are curious about why saltwater is needed or are trying to account for the hydrogen gas. The saltwater is needed to remove an outer layer of aluminium oxide on the aluminum foil to expose pure aluminium so that the main reaction with the $CuSO_4$ can begin. Also, it can be observed that hydrogen gas is simultaneously released from the reaction when aluminum metal foil is added to the $CuSO_4$ solution. If the pH of the solution is measured, it is found to be slightly acidic. Therefore, there are free hydrogen ions in solution, which cause the side reaction of hydrogen ions with the aluminum surface to form hydrogen gas and aluminum ions. Due to the limited concentration of hydrogen ions, this reaction consumes only a small amount of the aluminum.

This lesson presents the balanced equation for the copper sulfate (root killer) and aluminum reaction because students may want to account for the amount of matter in both the reactants and products. They should have figured out from *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* that matter is conserved during chemical reactions. However, the details of moles and how we balance equations are not covered in this unit.

As students conduct the investigation on day 1, the group working with cabbage juice and vinegar will notice a dramatic color change. In a neutral water solution, the cabbage juice will be a bluish-purple color but will turn bright pink when the vinegar is poured in. From *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)* they will be familiar with color as a property used to identify a substance and may conclude that the observed color change indicates the formation of a new substance; however, a mechanistic explanation for why this color change occurs is beyond the scope of this unit.

Other reactions have reactants dissolved in water. We are not trying to show the mechanism for dissolving. As in *Bath Bombs Unit* we do not distinguish between molecular substances and ionic lattice structures and the different processes they undergo during dissolving. This is above grade level, and students will have the opportunity to figure out that content in high school. It is sufficient here that students show single units of a compound separating from other units of the compound as they dissolve. Students are not expected to show dissociation as separate ionic particles.

LEARNING PLAN FOR LESSON 3

1. Navigation

5 MIN

Materials: science notebook, What We Do as Engineers board, class-level Criteria and Constraints chart, Ideas for Investigations class chart from Lesson 1

Recap where we left off in Lesson 2. Have the What We Do as Engineers board, the class-level Criteria and Constraints chart, and the Ideas for Investigations class chart from Lesson 1 posted and visible to the class. Display **slide A**. Use the following prompt-response box to navigate to the investigation of different chemical reactions. If students are struggling to answer the prompts, have them refer to their Progress Tracker.

Suggested prompts	Sample student responses
What did we figure out last time about using the materials in the MRE flameless heater or the hand warmer in our own designs?	*They won't work because they're either too expensive, not hot enough, or not safe.*
For our homemade heater, what do we need the chemical reaction to do? What are our criteria for it?	*To make a homemade flameless heater we need a reaction that will heat the food, works fast, doesn't cost a lot, is safe to use, and is available when people need it.*
I gathered some things from local places, like the grocery store and the hardware store. How can we figure out if some of these might work for our homemade flameless heater?	*Let's test them like we did last time and see if any of them get hot.*

Share images of substances that we are going to use in our investigations. Display **slide B**.

Say, *One combination of substances we will test is baking soda and vinegar. How many of you have mixed these two substances? These are often found in the kitchen and are used for cooking and cleaning.*

Display **slide C**. Say, *The next combination is root killer and aluminum foil in saltwater. Root killer is something that can be flushed down toilets when external sewer pipes have been clogged by tree roots. It kills the roots that have gotten into the pipes but doesn't get absorbed far enough into the root system to kill the whole plant. We are going to combine root killer with aluminum foil and saltwater. How many of you have used aluminum foil before? How about saltwater? These are common items or easy to make at home.*

Display **slide D**. Say, *Another combination that we will test is cabbage juice and vinegar. The cabbage juice is made from red cabbage that has been boiled in water. Vinegar is another household substance that you probably have in your kitchen or maybe even in your cleaning supplies.*

Finally, we will test (**slide E**) *steel wool that has been soaked in vinegar and then exposed to air. Steel wool is another substance that you may find in your cleaning supplies; it's used as a scrubber for removing stuff that might be stuck on objects.*

2. Prepare to investigate which reaction is the best candidate to try in our homemade flameless heater.

10 MIN

Materials: science notebook, transparent tape, *Data Table for Chemical Reactions Lab*, chart paper, markers

Review safety protocols. Solicit ideas from students for being safe when combining substances. Then display **slide F**. Recall the following list of safety ideas we used in Lesson 2 and ask students if they would like to add anything to the list. Clarify details as needed for your classroom.

1. Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
2. Immediately wipe up any spilled water on the floor—this a slip and fall hazard.
3. Follow your teacher's instructions for disposing of waste materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.
8. Use caution when working with heated liquids—this can burn skin!
9. Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames.

The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

Additional consideration: Only combine substances and amounts our teacher tells us to so that we don't accidentally create harmful reactions, explosions, vapors, and so forth.

Motivate students' thinking about how to conduct the investigation and what data to collect.* Say, *Let's think about how to conduct this investigation.* Be sure to gather differing opinions about how the amounts of substances used will affect the temperature change. Accept all answers.

Suggested prompts	Sample student responses
What question are we trying to answer with this investigation?	*Which reaction do we think is the best one for trying in our homemade flameless heater?*
So, we are trying to find the reaction that will work for our heater. Does the amount of the substance we use matter?	*It depends on what we are using.* *No, I think certain reactions just get hot the same—no matter how much you use.* *Yes! More is better.*

Give students a minute to turn and talk with a partner and then go public with the following question.

*** Supporting Students in Engaging in Planning and Carrying Out Investigations**

The focus of this investigation is for students to collect data to understand that you can measure temperature increases (exothermic) or decreases (endothermic) in chemical reactions. And some chemical reactions have no measurable temperature change. They are testing these reactions so that they can use an optimal reaction for their homemade flameless heater design. The planning portion of the investigation should flow quickly so that students have time to conduct all the trials. Many variables don't need to be decided by students but simply recalled from previous labs.

*** Attending to Equity**

Universal Design for Learning: Remember that you will be creating design teams in Lesson 6 that will work together for the remainder of the unit. It may be helpful in this lesson to group students differently than in Lesson 2 to gain additional insight on who works well together. Then you can use those observations to inform intentional groupings when you are creating design teams. To support student engagement, consider grouping students of different genders, math abilities, and personalities.

Suggested prompt	Sample student responses
So how could we test our ideas in our investigations?	*We could try different amounts of the substances to see if adding more or less makes a difference.* *We could add more and more reactants to see what happens.* *We have to measure the temperature to make sure our reaction gets hot.*

Supporting Emerging Multilinguals

You might also intentionally group emerging multilingual students with certain peers who know the same languages or with peers whose English language development is slightly more advanced.

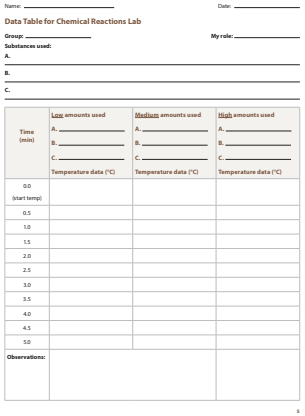
Make a prediction in their science notebook. Show **slide G**. Say, *For a reaction that heats up, if we used more substances, would we get more heat, less heat, or the same amount of heat? What makes you think this? What related phenomena from your own experiences help you think this?* Give students a minute to write their predictions in their notebooks.

Co-create a public record of the data we want to collect. Say, *So we've decided we want to investigate all of these chemical reactions. We've got a lot of things we want to test, so why don't we divide and conquer these tests? We want to share our results, so we need to follow the same protocols. What types of data should we collect in our investigations?*

Record the data on chart paper as students suggest them. The minimum data that should be collected are as follows:

- amount of each substance (grams)
- starting temperature of substances (°C)
- temperature every 30 seconds for 5 minutes (°C)
- temperature change from starting to maximum or minimum temp (Δ°C)
- observations, such as any color changes, odors, how it feels when you touch the container, sounds

Prepare science notebooks to collect small-group data and assign chemical reactions to groups.* Show **slide H**. Hand out *Data Table for Chemical Reactions Lab* and have students tape their data table into their science notebook. Use the slide to help students navigate how to fill in the data table. As they conduct the investigation, students will collaborate on this data table as they collect *temperature* data over *time* for different amounts of substances (Low, Medium, High). Point out to students that they will need to collect data every 30 seconds for 5 minutes for each amount of substances, so they will need to work together efficiently.



Name: _____ Date: _____

Data Table for Chemical Reactions Lab

Group: _____ **My role:** _____

Substances used:

A. _____

B. _____

C. _____

Time (min)	Low amounts used A. _____ B. _____ C. _____ Temperature data (°C)	Medium amounts used A. _____ B. _____ C. _____ Temperature data (°C)	High amounts used A. _____ B. _____ C. _____ Temperature data (°C)
0.0 (start temp)			
0.5			
1.0			
1.5			
2.0			
2.5			
3.0			
3.5			
4.0			
4.5			
5.0			
Observations:			

Additional Guidance

The lesson is written as having six groups of students investigate four different chemical reactions (see **slide H**). If you have fewer students and fewer groups, be sure to have at least two groups investigate root killer and aluminum foil in saltwater, since this is the reaction that students will use in their designs, and we want to be sure we have accurate data to justify moving forward.

Give other management directions and reminders as needed, specific to your classroom.

3. Conduct the chemical reactions lab. 25 MIN

Materials: Chemical Reactions Lab, science notebook, *Data Table for Chemical Reactions Lab*, *Chemical Reactions Lab Instructions*, *Class Data for Chemical Reactions Lab*, *Some Common Gases* (optional), *Sample Temperature vs. Time Data*, chart paper (optional), markers (optional)

Share instructions for the Chemical Reactions Lab and discuss placement of the thermometer in liquids. Pass out *Chemical Reactions Lab Instructions* and ask students to refer to it for procedures to follow for their assigned group. Explain to students that all groups will use the same lab equipment. Display **slide I** and ask students to refer to these photos in the instructions as you point out the Styrofoam cups with lids and digital thermometers they will be using. Specifically point out that groups with chemical reactions involving liquids (all but the steel wool group) should pay special attention to where the thermometer tip sits in the liquid, as shown on **slide I**. Instructions about the placement of the thermometer in the liquids are also included in the procedures for those chemical reactions. If you are using the digital thermometers, make sure students switch them to C.

Point out the different experimental procedures and the roles. Tell students that there are different procedures to follow in *Chemical Reactions Lab Instructions* for the different chemical reactions. Ask them to turn to the section for their group's reaction as they conduct the investigation. Display **slide J**, point out the table of roles for group members in each reaction's procedure, and emphasize that each role is responsible for a task at different times. Say, *If you don't have a task at any given moment, you can record the data in your own notebook and help clean up.* Let students know that different reactions have slightly different roles and that each group member should choose a role and record it on *Data Table for Chemical Reactions Lab* in their science notebook.*

Review material retrieval, weighing, and cleanup procedures for your classroom. Say, *Each group's tray contains all the equipment and substances that your group will need.* Provide instruction specific to your classroom around using the digital scales to weigh out substances. Give other management directions and reminders as needed, specific to your classroom.

Carry out the investigation. Allow about 20 minutes for students to conduct their investigations. Circulate to hear what students are noticing and take note of how students work together to inform the creation of design teams in Lesson 6. Make sure that students are using any free time to copy into their own science notebook the temperature data collected by the Data Recorder onto *Data Table for Chemical Reactions Lab*. Sample data are provided in *Sample Temperature vs. Time Data* for your reference. As you monitor groups, ask questions to help students focus on what they are trying to figure out rather than just focusing on the procedures. Here are example questions you might ask:

- What are you noticing about the temperature change?
- How do you think energy is transferring in this reaction?
- If you think about two systems involved, the reaction system and the thermometer, what direction is the energy transferred to make the temperature increase or decrease?

Alternate Activity

Students may notice that there are a lot of bubbles on the steel wool when it is submerged in vinegar. Vinegar is used to clean the surface of the steel wool by removing oils left on it after manufacturing. Iron in the freshly cleaned steel

*** Attending to Equity**

Universal Design for Learning: Having roles allows for clear, tangible ways to actively participate and can lead to more-equal participation for all students, which supports student engagement. Roles can be assigned with special attention to student learning styles or strengths to increase student confidence. Roles should be clearly defined and include meaningful responsibilities essential to the task.

In this part of the lesson the suggested roles are responsibilities to ensure the lab gets completed with reliable data and within the allotted amount of time. There are three different amounts of substances each group will be testing and only one thermometer and scale per group. For this reason, the suggested roles at this moment are to help the group manage their work flow, rather than intellectual roles such as Idea Connector or Evidence Wrangler. However, using intellectual roles is encouraged during sensemaking sections of the lesson and throughout the unit.

surface slowly starts to react with vinegar to produce hydrogen. As an extension activity, students can collect some of the gas and conduct a flammability test as in *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*.

The root killer and aluminum foil in saltwater reaction also produces small hydrogen bubbles due to the sodium chloride disrupting the oxide layer on the foil; though, this may not be noticeable since it will occur inside of the closed cup. Therefore, this reaction could also be subject to a flammability test.

The bubbles produced by the reaction of baking soda and vinegar contain carbon dioxide gas that will extinguish a flame and therefore is not flammable.

The student reference *Some Common Gases* can be used with students to help facilitate the flammability tests.

Safety Precautions

Have a discussion with students about the safety guidelines that we should have in place for the hydrogen gas that is generated by these reactions. Guidelines should include the use of vented containers to avoid the buildup of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Safety Note: You need to have appropriate lab ventilation—some students may have respiratory issues if exposed to these vapors.

Additional Guidance

When students take the lid off of the cup containing the vinegar-soaked steel wool exposed to air, they will probably notice a sulfury odor like rotten eggs. Steel wool can contain sulfur as an impurity, and vinegar often has sulfur-containing substances as preservatives. These substances can react to generate low levels of hydrogen sulfide gas, which can be detected by our noses at very low levels. Safety Note: You need to have appropriate lab ventilation—some students may have respiratory issues if exposed to these vapors.

Assessment Opportunity

Building towards: 3.A Collect data that support choosing the chemical reaction that has the ability to transfer the most energy to the food system.

What to look for and listen for

- Students work effectively as a team to measure and record temperature data vs. time by staying focused on their roles.
- Students calculate the maximum temperature change for each amount of substances in their group's chemical reaction and report the appropriate sign (+ or – to indicate that the reaction caused an increase in temperature or a decrease).
- All groups, except those with cabbage juice and vinegar, identify that the magnitude of the temperature change increases as the amount of substances increases. The cabbage juice and vinegar group identifies that very little temperature change occurred regardless of the amounts of substances.

Supporting Students in Engaging in Planning and Carrying Out Investigations

The data produced in carrying out this investigation serves as evidence for students to choose the best reaction to use in their homemade flameless heaters. As students are conducting this investigation, remind them of this purpose and emphasize this important practice of science and engineering to use in our engineering design process.

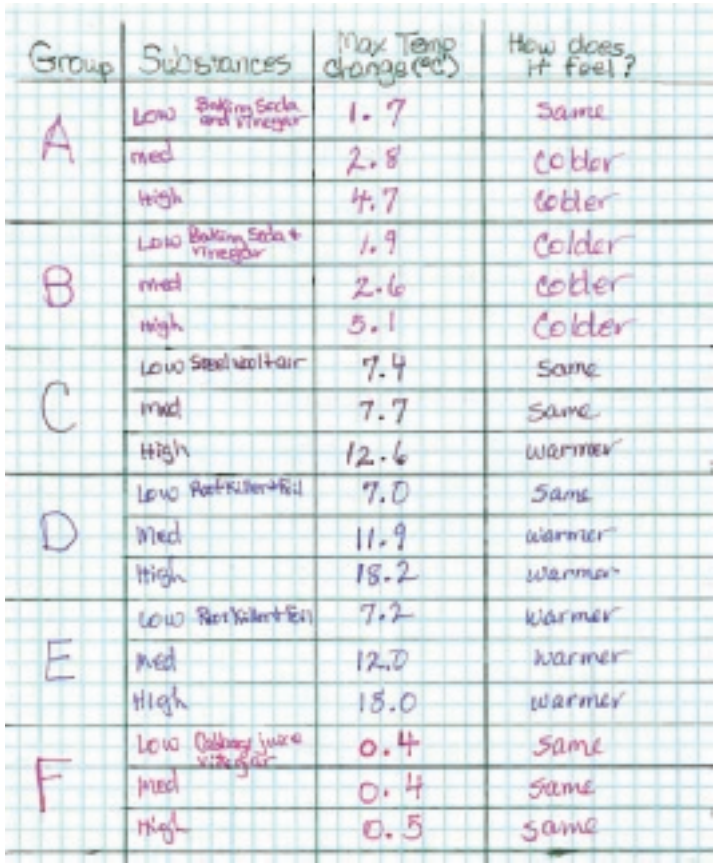
- Students identify that energy is being transferred out of the reaction system and into the thermometer when the temperature is increasing.
- Students identify that energy is being transferred from the thermometer into the reaction system when the temperature is decreasing.

What to do

- Remind students to take responsibility for their group roles and to support others as needed once their tasks are complete.
- If students are struggling to determine the maximum temperature change for the reaction that causes a temperature decrease and has a negative value (baking soda in vinegar), have them create a number line to see that temperature changes can occur in either direction.
- Ask questions about the direction of energy flow between each reaction and the thermometer to start students thinking about energy. This will help them with the questions at the end of the handout, *Class Data for Chemical Reactions Lab*.
- Do not be concerned at this time if students are not able to explain the direction of energy transfer between the thermometer and the reaction system when the temperature decreases. If they cannot correctly identify the direction of energy transfer with this investigation, be patient with them. There are multiple opportunities for students to grapple with these ideas that are often counterintuitive.

Work in small groups to transfer data to the handout. As small groups are finishing their investigations, hand out *Class Data for Chemical Reactions Lab* and ask students to complete the rows for their group's chemical reaction. Point out that *Class Data for Chemical Reactions Lab* provides instructions on how to determine the maximum temperature change. This will be a negative number (indicating a decrease in temperature) for groups investigating the baking soda and vinegar reaction. Provide additional support to those groups as needed.

Share data from small groups in a class data chart. Display **slide K** and enter class data directly into the whole-class data table as each small group shares their data. You could also create the whole-class data table on a whiteboard or chart paper. Ask students to add data to their own copy of *Class Data for Chemical Reactions Lab* as groups share.



Group	Substances	Max Temp change (°C)	How does it feel?
A	Low Baking Soda and Vinegar	1.7	Same
	med	2.8	Colder
	high	4.7	Colder
B	Low Baking Soda + Vinegar	1.9	Colder
	med	2.6	Colder
	high	5.1	Colder
C	Low Steel wool + air	7.4	Same
	med	7.7	Same
	High	12.6	warmer
D	Low Rust + Salt + Air	7.0	Same
	Med	11.9	warmer
	High	18.2	warmer
E	Low Rust + salt + Air	7.2	warmer
	Med	12.0	warmer
	High	15.0	warmer
F	Low Calcium juice + vinegar	0.4	Same
	med	0.4	Same
	High	0.5	same

4. Find patterns in the data and track energy flow from our investigation.

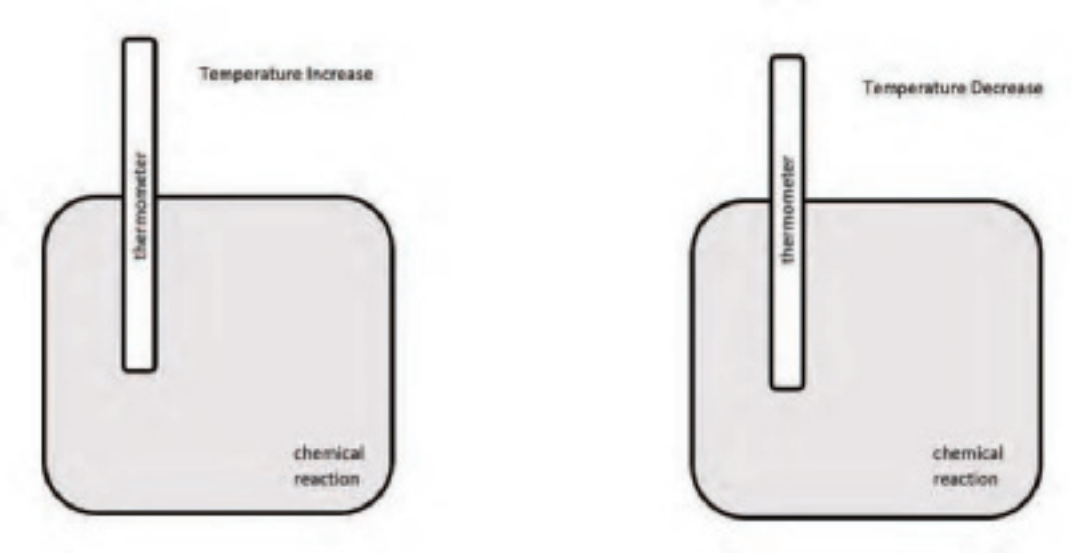
5 MIN

Materials: science notebook, *Class Data for Chemical Reactions Lab*, whole-class data table

Answer sensemaking questions at the end of *Class Data for Chemical Reactions Lab* in small groups. Ensure that students have recorded all the class data on their individual copy of *Class Data for Chemical Reactions Lab*, including the largest temperature change for each of the three tests for each chemical reaction.*

Show **slide L**. Ask students to work in small groups to answer the questions at the end of *Class Data for Chemical Reactions Lab*. If needed, read the questions aloud and instruct students to work through the questions in groups of 2 to 3. Have students attach the handout to their science notebooks.

1. Which chemical reaction(s) caused an increase in temperature?
2. Which reaction do you think is the best candidate for trying in our homemade flameless heater? Why do you think that?
3. Think back to what we learned in *Cup Design Unit*. What happens to particles when the temperature increases? You can use words and/or pictures to explain your thinking.
4. What happened to the temperature when we added *more* reactants?
5. You put a thermometer into the chemical reaction. On the following diagrams that show two types of reactions, draw an arrow between the thermometer and the chemical reaction to show the direction of energy transfer in each reaction. Do this for both reactions.



If students do not finish in class, assign the questions as a home learning activity.

Assessment Opportunity

Building towards 3.A.2: Collect data that support choosing the chemical reaction that has the ability to transfer the most energy to the food system.

What to look for and listen for

- Students propose moving forward with the root killer and aluminum foil in saltwater reaction as the best candidate for trying in their homemade flameless heater because it causes the greatest temperature increase.
- Students identify the direction of energy flow into or out of the reaction system based on the temperature changes.

*** Supporting Students in Developing and Using Energy and Matter**

Students have the opportunity to use the CCC of energy and matter: flows, cycles, and conservation as they answer questions at the end of *Class Data for Chemical Reactions Lab*. Students began thinking about energy flow to and from a thermometer in Lesson 2. In this lesson students have the opportunity to build on these ideas and apply them to several different reaction systems with thermometers. They will consider both reactions that get warm (exothermic) and reactions that get cool (endothermic) and model the direction of the energy flow in both.

What to do

- If students are having a hard time deciding which exothermic (warming) reaction with which to move forward, ask them to consider the mass of the solid substances in addition to the maximum temperature change. The root killer and aluminum reaction causes a larger temperature increase for a lower mass of solid reactants.
- Students will track the flow of energy into and out of the reaction systems. This is the focus CCC that students will be using in this activity. If students struggle with this task, especially for the endothermic reaction, there will be additional opportunities for them to master this concept.

Home Learning Opportunity

Instruct students to finish recording energy flow and answering sensemaking questions on *Class Data for Chemical Reactions Lab*. Make sure that all students have the entire set of class data and the sensemaking questions available so that they can analyze the results as a whole.

End of day 1

5. Building Understandings Discussion About Our Class Results

20 MIN

Materials: science notebook, *Class Data for Chemical Reactions Lab*, whole-class data table, cards for the Word Wall (exothermic and endothermic), What We Do as Engineers poster, chart paper (optional), markers (optional)

Lead a Building Understandings Discussion starting with our class results.* Show **slide M** and have students take out their science notebook and answers to the sensemaking questions on *Class Data for Chemical Reactions Lab*. Ask students to look at their responses for the sensemaking questions on the handout. While reviewing the handout, remind students that they can always revise their answers with new ideas.

Key Ideas

Purpose of this discussion: Share the patterns found in the whole-class data and that some reactions caused an increase in temperature, some caused a decrease, and some didn't really have a temperature change. This leads us to choose the root killer and aluminum foil in saltwater reaction because it resulted in the largest temperature increase. Once we learn about what root killer and aluminum are, we start thinking about how the increase in temperature happened and where the energy is flowing.

Listen for these ideas:

- Some combinations didn't heat up at all. The baking soda in vinegar actually got cold!
- Some chemical reactions caused an increase in temperature, some caused a temperature decrease, and some stayed the same.
- When root killer and aluminum reacted, they caused a temperature increase.

*** Supporting Students in Developing and Using Energy and Matter**

When discussing energy transferred to or transferred from a chemical reaction, ensure you emphasize that the energy is transferred when the particles of the reactants break apart from each other *and rearrange* to form the products. It is often thought that energy is released when chemical bonds are broken when in reality it requires an energy input to break the chemical bonds. When new bonds are formed in the process, energy is released. It is the overall process—breaking bonds of the reactants *and* the rearranging to form new bonds—that determines what the

- We think the root killer and aluminum foil in saltwater is the best reaction to use because it caused a greater temperature increase than the vinegar-dipped steel wool and air, and we can get root killer and aluminum foil pretty easily from a grocery or hardware store, so that will be good for a homemade flameless heater.
- In the reactions that got warm, energy transferred from the reaction to the thermometer. In the reactions that got cool, energy transferred from the thermometer to the reaction.

Add these words to the Word Wall:

- endothermic
- exothermic

Review what happened to the temperature. Start the discussion by reviewing what happened to the temperature in each of the chemical reactions.

1. Which chemical reactions caused an increase in temperature?
2. Which chemical reaction do you think is the best candidate for trying in our homemade flameless heater? Why do you think that?

Suggested prompts	Sample student responses	Follow-up questions
What happened to the temperature in each of the chemical reactions?	*The steel wool in vinegar plus air and root killer plus foil felt warmer.* *The cabbage juice plus vinegar felt a little bit warmer at the beginning but then felt the same.* *The baking soda plus vinegar one felt really cold.*	*For example, if we touched the side of the cup, did it feel warmer, colder, or stay the same?*
Scientists have some words for when a reaction causes a temperature change. Could someone remind me what the two temperature changes were again?	*One is like in the root killer and foil cup, where when we combined them they felt warmer.* *The other is like the baking soda cup, where it was mixed with vinegar and felt colder.*	*OK, great. Scientists call the one that feels warmer an exothermic reaction and the one that feels cooler an endothermic reaction. Could I have two volunteers summarize these two words?*
So, now that we have some terms to use, which reaction do we think is the best candidate for trying in our homemade flameless heater? Why do you think that?	*We think that the root killer and aluminum foil in saltwater reaction is the best candidate. We think this because it got 18.2 degrees warmer.* *The root killer one had the largest temperature change, so we think that's the one to use.*	*OK, let's try using our new scientific terms. Is this reaction endothermic or exothermic or neither?*

net energy change of the reaction will be. Chemical bonding is above grade level, but you can help dispel the idea that energy is released when bonds are broken by careful language. Make sure you include the whole process of particles breaking apart from each other and rearranging when discussing energy release and absorption from chemical reactions.

*** Attending to Equity**

Supporting Emerging Multilinguals: When new scientific words like *exothermic* and *endothermic* are introduced, it can be helpful for emerging multilingual students to see a representation of the new term in multiple ways. For example, students can (1) write the term, (2) draw a representation of the term, (3) use their own words to write an explanation for what the term means, and (4) use the new term in a sentence.

Suggested prompts	Sample student responses	Follow-up questions
Let's think about which way energy is flowing in this reaction. You put a thermometer into the reaction. In the last lesson you thought about what was happening with energy when the thermometer was showing an increase in temperature. Look at the last question on Class Data for Chemical Reactions Lab. What direction did the energy flow when the temperature increased?	*It went from the reaction to the thermometer.*	*What is the "it" you are talking about?*
Can you use that idea of energy flowing from the reaction to the thermometer to explain why, if you touched the outside of the container, it would feel warm?	*It would feel warm because energy flows from the reaction system out to your hand.* *If energy flows into your hand, it will feel warm.*	*And what is the new name we have for this type of reaction—one that feels warm and energy flows from the reaction system to the surroundings?*

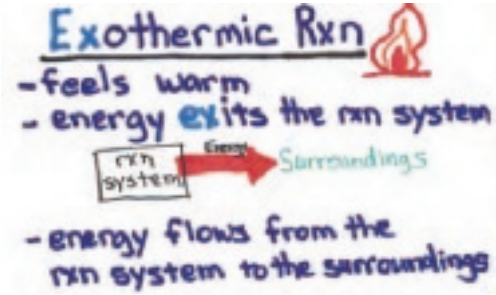
Add *exothermic* to the Word Wall. Say, *In an exothermic reaction, energy is transferred from the reaction. It exits the reaction and goes to the surroundings.**

Add the following to the Word Wall:

Exothermic: -feels warm

-energy transfers from the reaction to the surroundings

-energy exits the reaction system

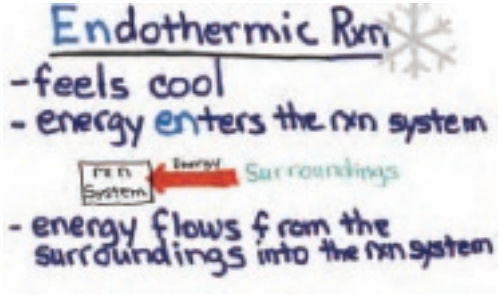


Add *endothermic* to the Word Wall. Have students consider endothermic reactions by leading a short discussion similar to the one below.

Suggested prompts	Sample student responses	Follow-up questions
We had a reaction that got colder. How do you think the energy flowed in that reaction?	*It seems like it would be opposite—flow into the reaction. But that doesn't really make sense.*	*Does someone have an idea for how to explain this?*
Let's think of how it would feel if this reaction occurred in a simple plastic cup. If you were holding it—touching the side of the reaction container—how would that feel?	*It would feel cooler.*	*If your hand felt cooler, then how was energy flowing to make you feel that way?*

Suggested prompts	Sample student responses	Follow-up questions
If energy was leaving your hand, where was it going?	*Into the surroundings.*	*Wait, your hand is part of the surroundings!*
So, if energy was leaving your hand—which is part of the surroundings—where was it going?	*Into the reaction system?*	*And what do we call this type of reaction?*
Can someone summarize what we have figured out about energy flow for an endothermic reaction?	*In an endothermic reaction, it feels cooler because energy is flowing from the surroundings to the reaction system.*	*Let's add this to our Word Wall.*

Say, *To help you remember these reactions, think about this—in an endothermic reaction, the energy enters the reaction from the surroundings. Let's add this to our definitions on the Word Wall.* Have students copy the information into their notebook. Encourage them to include pictures to help them remember both terms.



Endothermic: -feels cool

-energy enters the reaction system

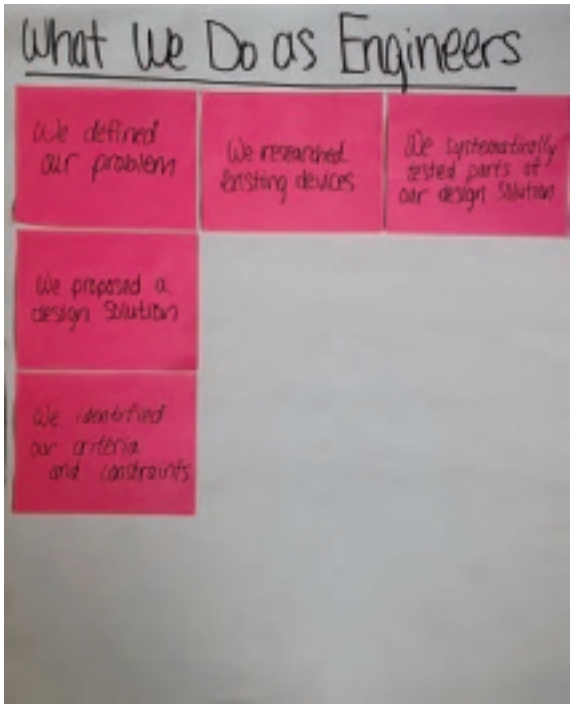
-energy transfers from the surroundings to the reaction

Extend the discussion to safety considerations. Say, *One of the things we wanted to make sure of is that whatever chemical reaction we use in our heaters is safe enough for people to work with. So let's think about the safety of the root killer and aluminum reaction. Groups D and E mixed saltwater, aluminum foil, and root killer in the cup. We use aluminum, salt, and water all the time, so those should be OK. Root killer is less common, and the label has warnings about getting it on your skin, in your eyes, or swallowing it, so those are things we need to pay attention to. But it is made for people to put down their drains and can be purchased at local hardware stores without special restrictions. So people are already using it for everyday activities.*

Update individual Progress Trackers. Display **slide N**. Say, *On the first day of this lesson, we did something else that engineers do. Take out your science notebook and turn to your Progress Tracker. What did we do as engineers? And how did what we figured out help us with our homemade flameless heater design?*

Suggested prompts	Sample student responses
What did we do as engineers?	*We tested several reactions.*
How did we test these reactions?	*We divided and conquered!* *We tested different amounts.* *And, we tested different chemical reactions.*

Say, *We had a plan to do these tests—we had a systematic way of testing these reactions. Do you think engineers do this? Why is it important for engineers to do this?* Have students record their response in their individual Progress Tracker. Add a sticky note or card to the What We Do as Engineers poster as shown in the image. See an example Progress Tracker below, including possible student responses.



What did we do as engineers?	What did we figure out that can help us with our designs?
We systematically tested parts of our design solution.	• We divided tasks among our classmates and tested several different reactions. This helped to reduce time and save resources. • We figured out that we will use root killer and aluminum foil in saltwater in our homemade flameless heaters. • This reaction worked best because it caused the greatest temperature increase compared to the other reactions we tried, and the ingredients are easy to obtain.

Summarize what we've talked about and motivate a discussion about the chemical reaction. Say, *So we've decided that the root killer and aluminum foil in saltwater reaction is what we want to try for our homemade flameless heater.*

Suggested prompt	Sample student response	Follow-up question
We talked a bit about the safety of the reactants, but are the reactants the only substances involved in this chemical reaction? Do the root killer, aluminum foil and saltwater stay as root killer, aluminum, salt, and water?	*No! It's a chemical reaction, so new substances are made after the atoms rearrange.*	*Do we know what those new substances are?*

Say, *So we should probably figure out what the products of the reaction are so we can find out if they pose any hazards. Additionally, I've heard some of you wondering what root killer is made up of and what is really going on with this reaction between it and aluminum foil.*

Discuss the chemical reaction happening with the root killer. Show **slide O** or write the chemical equation on the board or chart paper**:**

$3CuSO_4 + 2Al \rightarrow 3Cu + Al_2(SO_4)_3$

Additional Guidance

Taking the time to consider this chemical equation is a helpful connection back to the *Bath Bombs Unit* unit for students as they account for how the atoms rearrange in this reaction and confirm that matter is conserved. Students are not expected to balance chemical equations, as that is beyond the scope of the middle-school grade band. This lesson builds on the DCIs, modelling activities from *Bath Bombs Unit*, as well as the CCCs of cause and effect relationships. Students should come to this lesson knowing that different particles should be represented in different ways to distinguish them from one another in their models. Students will also build on their understanding of energy transfer from *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*. Students should be comfortable representing the direction of energy transfer with arrows and the amount of energy by the size of the arrows. Students will expand on this prior learning as they combine particle models and energy transfer models in this lesson.

Say, *When I look at the label on the root killer, it tells me that it's copper sulfate.* (Point at "3 $CuSO_4$".) *It's a substance that we can get at the hardware store to flush down toilets to kill tree roots in our sewer pipes. This is the chemical reaction that occurs when root killer and aluminum foil are mixed together in saltwater.* (Point at or write out the rest of the chemical reaction.) *Remember, the reason we have to use saltwater is to remove an outer layer on the aluminum foil so that the reaction will happen.*

Additional Guidance

Technically, the root killer container might indicate that it contains **copper sulfate pentahydrate** ($CuSO_4 \cdot 5H_2O$). Copper sulfate is a type of salt known as a hydrate, wherein the five water molecules are part of the copper sulfate crystals. As the crystals dissolve in water, the five water molecules become part of the solution and are indistinguishable from the other water molecules. The molecules that participate in the actual reaction are indicated in the chemical equation that is shared with students.

Use the following prompts to conduct a discussion about the safety of the products from the chemical reaction. Students should be familiar with the term *products* from *Bath Bombs Unit*.

Suggested prompts	Sample student responses
Let's remember what's going on when we write down a chemical reaction like this—I think some labels would help us. What labels can we use for all these molecules over here that we start with, and everything over here that we end with after the reaction?	*The particles we end with are called products, and the particles we start with are called reactants.*
And here by this arrow in the middle—what is going on with the molecules during the chemical reaction?	*The particles in the reactants break apart from each other and rearrange to form the particles of the products.*
*(Display **slide O** if it's not already showing.) Copper is one of the reaction products. What kinds of things is copper used for? Based on its uses, do you think it is hazardous?*	*Copper is used in jewelry, pots and pans, and even pennies. We don't think it is very hazardous.*

Suggested prompts	Sample student responses
The other reaction product is aluminum sulfate. It is commonly used for water purification and can be found in deodorants and baking powder. Would it be used in these things if it was very hazardous?	*Probably not. We should still make sure it doesn't get in our food.*
How do we feel? Does anyone have any other questions about this reaction?	*(If there are no questions, continue with the lesson. If students have a lot of questions or confusion, continue discussing with the alternate activity suggested in the next activity.)*

6. Co-construct particle-level models of the reaction.

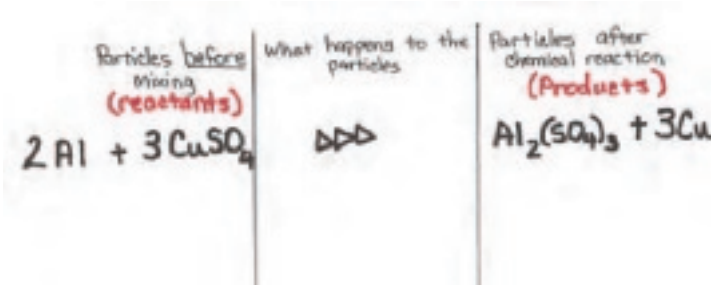
15 MIN

Materials: science notebook, chart paper, markers, classroom consensus model from end of Lesson 2, Key Model Ideas poster from *Bath Bombs Unit* (optional)

Gather in an Engineers Circle. Display **slide P**. Use the Engineers Circle to revisit results of increasing the reactants to motivate the need to revisit the particle-level interactions. Say, *In Bath Bombs Unit we zoomed in to the reaction and represented the reactants and products as particles. This may help us figure out what is going on with our tests and the energy that is flowing through the systems. Since we know now that we get more energy from a reaction with more reactants, can someone use that idea and the idea that the reactants are made from particles to explain why we get more energy out of a system with more reactants?* Allow students to offer ideas. They should reason that

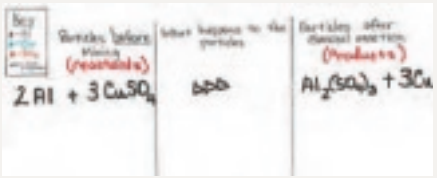
- more reactants mean more particles,
- there are more particles to break apart and rearrange, and
- the amount of energy must be related somehow to the particles.

Continue by saying, *In Lesson 2 we ended with a model that had the reaction system and several other boxes with parts of the surroundings*. Point students to the classroom consensus model from Lesson 2. Indicate the part of the model that represents the chemical reaction. This part is our focus now. *Let's start with just the particles and worry about the energy once we have the particles set up. Where would this particle model go on the classroom consensus model from Lesson 2?* Students should say that the particle model would be a part of the reaction system. The whole reaction system includes the saltwater that was added, but the salt and water are not part of the chemical reaction.



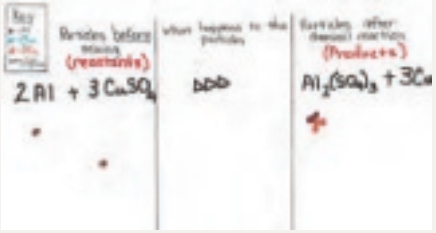
Conduct a class discussion as the class builds a particle model of the reaction. Emphasize that we are just zooming in to the particles in the chemical reaction. Use the sample dialog below to guide the discussion as you build a particle model of the reaction so we can use it to figure out how energy interacts with our systems. Ask students to draw the model in their notebook as you draw it on the board. Begin with the chemical reaction in a table similar to one we used in *Bath Bombs Unit*.

Say, *We learned in Bath Bombs Unit about two different kinds of particles—atoms and molecules. You may notice that aluminum in the reactant side is not combined with anything else—so it is an atom. It isn't important for our work here to distinguish between atoms and molecules, so we will just use the term "particles" to represent all atoms and molecules in our reaction. If the particles are different, we should represent them in a different way.*

Suggested prompts	Sample student responses	Follow-up questions
This is the reaction we decided to move forward with. Let's think of this reaction as particles. What are the different particles involved in this reaction?	*Aluminum!* *Copper!* *Sulfur.* *Oxygen.*	*Look at the sulfur and oxygen in the reactants and the products—indicated by the "S" and the "O". What do you notice?*
Since the sulfur and oxygen stay together, can we just think of them as one particle? We will call it "sulfate".	*Yes! That would make it easier!*	*Should we represent these particles all in the same way? Or are they different?* *Let's make a key.* 
Let's start with aluminum, a-l. In the reactants it is big 2-a-l and in the products it is a-l little 2 and it is written with the sulfate—s-o little 4. Can someone tell me if there is a difference in the way I should represent the aluminum?	*It means that there are two aluminums on both sides.*	*That is important for conservation of matter, right? Do I represent the two aluminums the same way or differently?*
So if there is a big number in front of the symbol, it tells us how many separate particles there are. If there is a little number—a subscript—after the symbol, it tells us how many particles are connected. How would I show big 2-a-l?	*Two aluminum particles that are not connected.*	*And how would I show a-l little 2?*

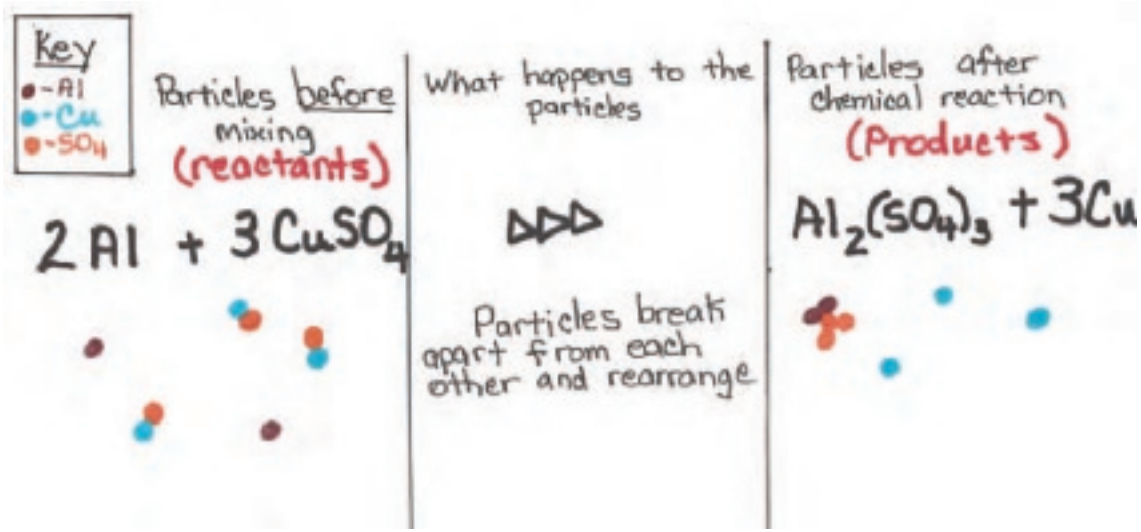
Attending to Equity

Supporting Universal Design for Learning: Use *representations* like color coding and/or letter or number coding to foreground parts of the model. Create a key to track what colors, symbols, or letter or number codes represent different parts of the system. The example model uses different colors to represent different types of particles. It is equally acceptable to use different shapes, drawn textures, or other ways to distinguish particles. What is important is that different particles are represented in different ways. While color coding is a useful way to quickly reference the parts of the model, letter or number coding helps ensure accessibility for any student who may be color blind. If color coding is used, consider a color palette that uses orange, blue, black, or dark brown.

Suggested prompt	Sample student response	Follow-up question
But it looks like the two aluminums in the products are connected to something else. How would I represent that?	*The sulfate is connected to the two aluminums—they are one big particle.*	*(Add this to the diagram:)* 

Complete the model and share with a partner. Display **slide Q**. Ask students to complete the model using the same conventions. Tell them to write a short statement of what happens to the particles when they react and put it in the middle column. Then ask them to share with their elbow partner and make revisions if they learn something from their partner.

Have students share ideas as you complete the class model on the board with students. Have students check their ideas. Complete the middle section by asking students to explain what happened to the particles from the first column to the last. Remind students that in *Bath Bombs Unit* they learned some particles break apart and rearrange in a chemical reaction.



Additional Guidance

We are not trying to show the mechanism for dissolving. As in *Bath Bombs Unit* we do not distinguish between molecular substances and ionic lattice structures and the different processes they undergo during dissolving. This

is above grade level, and students will have the opportunity to figure out the dissolving process in high school. It is sufficient here that students show single units of a compound separating from other units of the compound as they dissolve. Students are not expected to show dissociation as separate ionic particles.

If students need extra support with the chemical reaction and the numbers of particles, then offer support using the Alternate Activity described here.

Alternate Activity

If students need further support in understanding the chemical equation and how it helps show that the atoms we start with are the same as the atoms at the end (they are just rearranged), you can connect back to the Key Ideas from *Bath Bombs Unit* and continue the discussion. Start with reminding them of the Key Model Ideas poster from *Bath Bombs Unit*. Bring out the Key Model Ideas poster if you still have it in your classroom. If students are confused, then break down every atom in this chemical reaction, $3CuSO_4 + 2Al \rightarrow 3Cu + Al_2(SO_4)_3$. In *Bath Bombs Unit* students did not see a chemical equation that used parentheses, so that may be a point of confusion that arises and needs to be clarified.

Below are some suggested prompts for that extended conversation.

Suggested prompts	Sample student responses
OK, so look at the a-l for aluminum—how many aluminum atoms are there in the reactants?	*There are two aluminum atoms because they're by themselves and don't have a little number, but there's a big two to show that there are two of them.*
Cool. So let's look at the products side. How many copper atoms do we have in our products?	*There's no little number, just a big three, so that's three atoms of copper.*
Hmmmm . . . but we only had one copper atom in each molecule of copper sulfate in our reactants, so where did the three atoms of copper come from in the products?	*There is only one copper atom per molecule, but we had three molecules of copper sulfate in our reactants, so that's where the three atoms came from—one from each molecule.*
OK, so let's see if we can figure out where the atoms came from in this other product—aluminum sulfate—I can see where the two aluminum atoms are, but what do you think is going on with these parentheses?	*It could be like parentheses in math that say "do this first" for what's inside of them. So I think it's like there are three of those s-o-4s, so that would be three sulfur atoms, and three times four oxygen atoms, so twelve oxygen atoms.* *Yeah, and that matches up with the reactants because we had three of those molecules with the s-o-4 to start with, too; so that's the three sulfur atoms and three times four oxygen atoms again.*

Suggested prompt	Sample student response
So, we can account for all these atoms, then, right? We can see how they all got rearranged in this reaction? Which key model idea helped us figure this out?	*In a chemical reaction, the amount of matter at the beginning in the reactants is the same amount of matter at the end of the reaction in the products. This is because all the atoms we started with are still there. No new atoms can appear that weren't there to start with.*

7. Add energy to the particle-level reaction model.

10 MIN

Materials: science notebook, chart paper, markers

Shift focus to considering energy in the reaction. Display **slide R**. Now that students understand the particles involved in the copper sulfate and aluminum reaction, help them shift to thinking about what is happening with the energy during an exothermic reaction. Use the example dialogue as you add to the class model.

Suggested prompts	Sample student responses	Follow-up questions
Now that we understand what is happening to the matter—the particles—in our chemical reaction, what else do we know about this particular reaction?	*We know it gets hot when the copper sulfate and aluminum react!*	*We know what kind of reaction this is. Can someone rephrase using one of the words from our Word Wall?*
Our reaction that we want to use in our homemade flameless heater system is exothermic. Let's add this to our particle model. Where on the model does it make the most sense to identify where the reaction is heating up?	*In the middle section where the particles are breaking apart from one another and rearranging.*	*Why do you think that is the best place?* *(Add "exothermic" to the middle section of the model.)*
What evidence do you have that the reaction was exothermic?	*It got hot!*	*What happens to that energy?*
OK, so when these particles rearrange, something about that causes an energy transfer to the surroundings. How could we represent this on our particle model?	*We used an arrow to show energy flow on the Energy Transfer Model earlier. We could show an arrow from the chemical reaction—where they are rearranging—to the reaction system.* *And we could show an arrow from the whole reaction system to our food—that is the energy transfer we are interested in!*	*Let's add those ideas to our model!*

Supporting Students in Developing and Using Energy and Matter

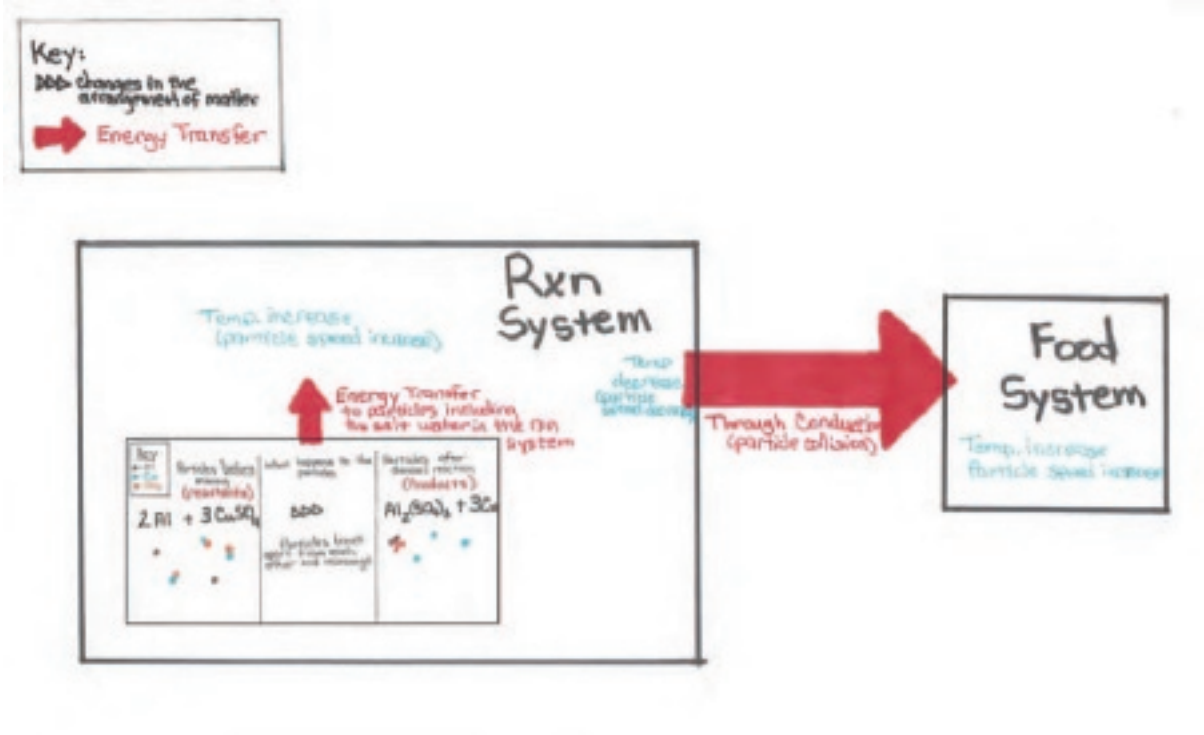
This discussion of energy transfer from the chemical reaction is tricky—especially when you are limited in middle school to the depth to which you can explain. If students wonder where the energy comes from, the answer will get into high school-level content. One way to address their curiosity if it comes up is to ask them what they *do* know about the reaction. They know

- particles break apart and rearrange in the reaction and
- energy is transferred to the surroundings in an exothermic reaction.

Students can reason that the energy must come from the reaction.

Add energy ideas to the model. Continue working with the class to add these energy ideas to the model. Have students consider each system that is represented in their investigation. The reaction system has more than just the copper sulfate and the aluminum; it also includes the saltwater. The chemical reaction is a subsystem of the reaction system. The surroundings outside the reaction system that we are most interested in is the food system since that is the energy transfer we want to maximize.

Place the particle model in the *Rxn System* box to represent the chemical reaction between aluminum and copper sulfate.



Assessment Opportunity

Building towards: 3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

What to look and listen for

- Students who can represent or describe the chemical reaction at a particle level
- Students who connect the particle-level interactions to the transfer of energy to or from the chemical reaction

What to do

- Listen as students respond to questions about energy transfer and how that is related to particle interactions.
- Monitor students as they are labeling and discussing the model with the class.
- Pose questions to students for clarification of their thinking about energy flow between systems or between subsystems and systems.

Navigate to the next class. Say, *Our focus is on the transfer of energy from the reaction system to the food system even though we know that there is energy transferred to other places like the air, the cup, et cetera.* (Point to the recent Energy Transfer Model.) *In the next class we will focus on just the energy transfer between systems.*

End of day 2

8. Navigation and Energy Transfer Models

5 MIN

Materials: science notebook, pencil, *Energy Transfer Models*, chart paper, markers, class Energy Transfer Model from previous class

Recall the initial energy model. Begin the class by highlighting the initial Energy Transfer Model we ended with in the previous class. Point to the model and say, *In the last class we figured out how energy was transferring between particles in the reaction system and the surroundings. But, we don't have to keep drawing all the particles.* (Point to the particle model subsystem.) *We figured that out!* Display **slide S.** *We can move forward by just showing the energy transfer between the reaction system and the food system.*

Continue the discussion similar to the example dialogue below.

Suggested prompts	Sample student responses
Now we understand what is happening to the matter—the particles—in our chemical reaction. Besides testing different reactions and finding the exothermic reaction that we want to use, what else do we know about the aluminum foil and root killer reaction?	*Well, we tested different amounts of the reactants and got different results.*
Let's think back to our test results again and focus on the copper sulfate and aluminum investigation. When we compare what happened with 1 gram of reactants versus 2 grams and 3 grams, what pattern did we see with the temperature when we tested more reactants?	*When we used more reactants, we saw a greater temperature change.* *When we had more aluminum foil and copper sulfate, we saw the temperature go up higher.*

*** Supporting Students in Engaging in Developing and Using Models**

This is an opportunity for students to continue developing models to show relationships between the matter in a chemical reaction and the energy transfer resulting from that reaction. Students begin by building on particle models that they developed in *Bath Bombs Unit* to represent this new chemical reaction. Next students will focus on the energy transfer and show that transfer using arrows in their models. Emphasize to students how these models help them think about and use the ideas about invisible things (particles) or processes (energy transfer). Also emphasize that doing so will help them predict and explain what might happen in other chemical reactions and processes.

Suggested prompts	Sample student responses
Interesting. So more reactants heated up the thermometer more, so we saw those higher temperatures. In Lesson 2 we recalled how a thermometer detects a temperature change. What is happening to the energy when the number on our thermometer goes up?	*When the number on the thermometer goes up, more energy is being transferred to it.*
So then, if all this is true, which system should have more energy coming out of it? The one-gram system or the two-gram system?	*So, if the two-gram system heated up the thermometer and other things more, then more energy must have come out of the two-gram system compared to the one-gram system.*
But all of our substances in the one-gram and two-gram setups started at the same temperature, right?	*Right.*
What evidence do you have that they all started at the same temperature?	*Our thermometers in the one-gram and two-gram cups started at the same temperature or very close to each other.*
So, if the one-gram and the two-gram systems started at the same temperature, then why did more energy come out of the two-gram system?	*We aren't sure.*
What is the only difference between the one-gram system and the two-gram system?	*The number of grams.* *The amount of particles in each system—there are more particles in the two-gram system than in the one-gram system. Twice as many more!*
So then why do you think more energy came out of the two-gram system than the one-gram system?	*There are more particles to start with, so more particles broke apart and more particles rearranged. That would mean more energy coming out!*

Conclude the discussion by summarizing. Say, *So it seems that thinking on the particle level—what we cannot observe—helped us understand something we do observe: a greater temperature increase when there are more particles, more reactants.*

Motivate moving to an Energy Transfer Model. Say, *We have explained a lot with our particle models! Why was that important to our design of a homemade flameless heater?* Students should share that knowing that more particles in the reactants mean more energy transferred out of the reaction system will help heat their food. They will need to use this knowledge to get the right amount of energy transfer to warm their food. Display the model from the end of the last class and continue by saying, *This was the model we ended with in the last class. You have mentioned that the reaction system will transfer energy to the food system. You modeled this in the last lesson, and so far in this lesson we have focused on the chemical reaction.*

Begin a model to track the energy transfer between these systems.* Direct students' attention to the model you ended with in the last class. Say, *When scientists and engineers are trying to figure something out, they often think about*

*** Supporting Students in Developing and Using Systems and System Models**

It's important to make students aware of the crosscutting concepts they use in the same manner and to the same degree that students learn about and use disciplinary core ideas and science and engineering practices. In this instance, articulating the important parts of the system and how the parts interact is useful for students to help them identify which parts to test and manipulate through investigations.

If students struggle with the idea of subsystems, have them think of an everyday example of a complex system that includes subsystems. An example would be the house or apartment they live in as a large, complex system. There are many subsystems within that larger system. The electrical system that provides light for the structure is one example. The plumbing system that brings water and flushes the toilets is another subsystem. Our body is another complex system that is made of subsystems. Students may be familiar with the circulatory, digestive, and nervous systems. These are examples of subsystems within a larger body system.

the systems involved. They identify the parts of the systems and how those parts work together. Our chemical reaction is a subsystem of the reaction system—it is part of the whole reaction system. Let's shift our focus from the very small, particle-level models to the larger, system-level views to think about energy.

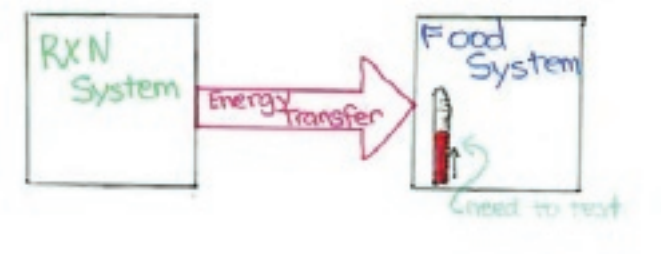
Continue the discussion by connecting to work engineers do by identifying systems and subsystems, how the MRE has systems and subsystems, and how now we will shift from thinking about the interacting particles in the copper sulfate and aluminum reaction to the energy transfer from that reaction. We will focus on the reactions we tested on the first day of this lesson. Tell students we will focus on only the 1.0-g and 2.0-g systems since we have already established the pattern that as the amount increases, so does the temperature.

Shift focus to the food system. Say, *In our tests, we saw evidence that things outside of the 1-gram reaction system were heating up, right? The thermometer, the cup itself, our hands, and the air nearby. We are interested in the energy that transfers into the food system.*

Students should recognize that to use a chemical reaction to warm food, the energy transfer to the food system is the important place to focus. Use the sample dialogue to motivate testing the idea that the temperature of the food will increase.

Suggested prompts	Sample student responses
Are we convinced that the temperature of the food would increase if we had the thermometer in the food instead of the reaction system?	*I think it will!* *I'm not sure. It probably depends on how much food there is and what kind of food is there.* *We need to test this!*
So you think we should test this—OK, we will mark that.	

Draw a simple Energy Transfer Model. Draw a simple box model on the board showing energy transfer from the reaction system to the food system. Explain to students how this is very similar to the model we had before, but it focuses on the parts of the model most closely related to our design problem. Make a note that we should test the idea that the thermometer would respond similarly in the food as it does in the reaction system.



Continue by saying, *We know there is energy transferring from the reaction system and going other places—air, cup, et cetera—you had this on your model from Lesson 2. But, we are going to reduce that as much as possible by using some sort of insulated system. We learned a lot about that in the Cup Design Unit unit. We also learned in that unit that temperature was a measure of the average energy—kinetic or motion energy—of all the particles in the system. Let's keep that idea in mind as you make predictions about the energy transfers and temperature changes.*

Additional Guidance

From Lesson 12 of the *Cup Design Unit* unit, students figured out these important ideas that will help them in this lesson and throughout this unit.

- Kinetic energy is transferred from one particle to another in a particle collision.
- Temperature is a measure of the average kinetic energy of the particles in a sample of matter.
- The total kinetic energy of a sample of matter is the sum of the kinetic energy of all the particles in that sample. If you add more particles, the total kinetic energy increases but the temperature (the average kinetic energy) might stay the same.

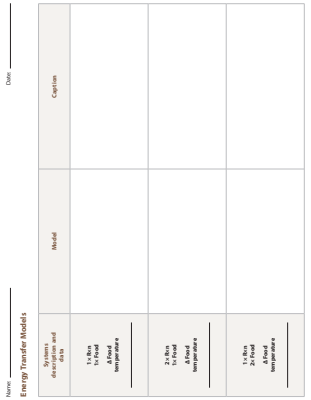
Leverage these ideas and encourage students to use these ideas to make predictions, reason with evidence, and make sense of the investigations. If your students did not have the *Cup Design Unit* unit, they should still be able to figure out the ideas in this unit, but it may take them a little longer to reason through evidence. Their reasoning and experience in this unit will set them up to figure out the relationship between kinetic energy and temperature of systems of particles.

Introduce the *Energy Transfer Models* handout. Say, *We are pretty sure that since the reaction system gets warmer, energy will transfer to the food. But we are going to test our ideas because we aren't sure how much energy will transfer and how much the temperature will change.*

Motivate the need to do additional tests. Talk with students about these ideas we have agreed on and some ideas we aren't sure about.

- We know that when we use more reactants more energy is transferred out of the reaction because our thermometer shows an increase in temperature.
- We have decided that we want to measure the food to see how the temperature changes because we haven't tested that.

Say, *We know more reactants means higher temperatures, but how would we show that in our models?*



9. Create a new Energy Transfer Model for a different amount of reactants.

8 MIN

Materials: science notebook, pencil, partially completed *Energy Transfer Models*, chart paper, markers

Prepare students to think about the 2X reaction/1X food system. Display **slide T**. Discuss with the class the idea of the 1.0- and 2.0-gram systems representing a 1X reaction system and a 2X reaction system—this is how they are labeled on *Energy Transfer Models*. Thinking of doubling or halving the reactants is something the students will do in later lessons as they scale their systems up and/or down. Students have already tested (with a thermometer in the reaction) both the 1X reaction/1X food system and the 2X reaction/1X food system. Encourage students to think of their previous investigations with 1.0 gram and 2.0 grams of each reactant and the data they collected.

Assign student pairs to create their own Energy Transfer Models. Have student pairs copy in the first row of *Energy Transfer Models* the simple box model you just made on the board for the 1X reaction/1X food system. They should

*** Supporting Students in Engaging in Developing and Using Models**

This is one example of students developing a model to describe unobservable mechanisms. Here students are using arrows to show energy transfer and will adjust the size of the arrows to indicate

work with their partner to create a new Energy Transfer Model in the second row that would model the energy transfer from 2X the reactants to the same amount of food. They should be ready to share their results with the class in 5 minutes. Encourage them to use the model the class made together for the 1X reaction/1X food system as an example.

Say, *Your model should explain what you predict will happen to the temperature compared to the temperature of the original reaction and food systems. Color your thermometer to show how it would compare to the reaction system in the first row. Use the size of the arrows to communicate the amount of energy flow.*

Additional Guidance

The height that students should shade their thermometers is arbitrary yet relative. Tell students this first row will be their base for comparison, and when they are considering the other two system combinations, they should think about if they predict the temperature will be higher than, lower than, or about the same as the temperature in this first row. Because of this, students should shade the thermometer in the first row about half way up. This will allow thermometers in the other system combinations to be shaded with higher temperatures or lower temperatures.

Work with a partner to develop Energy Transfer Models.* Display **slide U**. Students should work with a partner to draw their Energy Transfer Models in the first and second rows of *Energy Transfer Models*. Students may want to use a pencil, especially to shade the thermometer, so that if the data do not support their prediction, they can erase and revise their model.

Tell students that they should both be able to use their models to explain energy transfer between the 2X reaction system and the 1X food system.

Monitor student conversations and identify one model to display. While students are working, circulate among them to identify one or two models that will be productive examples to share with the class. They do not need to be perfect because we want to foster an environment where it is safe to share first-draft thinking, but choose models that will be good starting points for discussion in the next step. Be sure to confirm with the partners that they are willing to share their work with the class.

Assessment Opportunity

Building towards: 3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

What to look for/ listen for:

- Student models that represent the direction of energy transfer out of the reaction system
- Students' relative representation of temperature changes as energy flows out of reaction systems and into food systems
- Student responses to questions you pose as you monitor student pairs as they develop their models

more or less energy transfer. This unobservable mechanism causes the temperature changes that students use as evidence. Students have used this science and engineering practice as they developed the particle model of the chemical reaction that transferred energy to the surroundings. Now students are focusing on the energy transfer between the reaction system and the food system (surroundings).

*** Supporting Students in Developing and Using Energy and Matter**

If students are still struggling, consider additional experiences where students can map the flow of energy into and out of systems. Identifying the thermometer as a system helps students visualize the evidence for energy transfer to the thermometer as an increase in temperature or energy transfer away from the thermometer as a decrease in temperature. If students think the temperature changes of the food will be as much as the changes when the thermometer is directly in the reaction, have them focus on the initial Energy Transfer Model that includes the particle model of the chemical reaction. Have them consider all the energy that transfers out of the chemical reaction that does not transfer to the food.

What to do: This is the second time assessing this LLPE. You will also assess it at the end of this class. Listen as students respond to questions about energy transfer and how that changes based on the amount of matter (number of particles) in the reaction system. Pose questions to students for clarification of their thinking about energy flow between systems. Encourage students to think about amounts of energy relative to the first, 1X/1X model and use "greater than", "less than", or "about equal to" when describing the amount of energy transfer.

Additional Guidance

If students ask about the amount of saltwater, remind them that the saltwater is only used to remove an outside layer on the aluminum foil and that it doesn't participate in this chemical reaction other than to help the reactants come into contact with each other, so we do not need to include the saltwater in our Energy Transfer Model.

10. Present new Energy Transfer Models to the class. 7 MIN

Materials: science notebook, partially completed *Energy Transfer Models*, whole-class Energy Transfer Model, document camera (optional)

Allow 1-2 pairs of students to share their models. Display **slide V**. Tell the class to look for similarities and differences in the way the models that are shared compare to their own models on *Energy Transfer Models*. Also, they should look for ideas they want to use as their class model. They should focus on the clearest way to represent the energy transfer from the 2X reaction system to the 1X food system. It should be consistent with the evidence they have from their earlier investigation.

As students share, use a document camera if available to project the students' models. Invite the class to ask clarifying questions of the presenters. You should ask questions such as these:

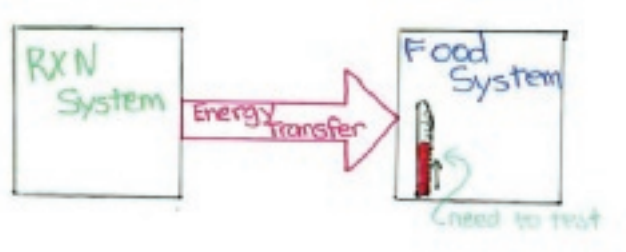
- What do you mean when you say "the energy moved"?
- What do you mean by "heated up"?
- Why did you make the arrow coming into the food system bigger than the one in the original reaction system?

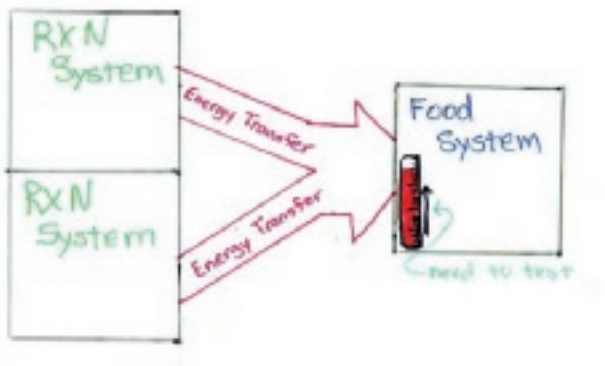
Come to an agreement as a class on a way to represent the 2X reaction system. Use the agreed-upon best ideas from the examples presented or other ideas from the class to create a class model for the 2X reaction/1X food system. The image below shows an example of the Energy Transfer Models for the 1X reaction/1X food system and the 2X reaction/1X food system.

* Attending to Equity

Supporting Universal Design for Learning: To support students in engagement and provide options for sustaining effort and persistence, this is not a moment to pick a student pair that is struggling. Try to choose a group that has a well-thought-out version of the new Energy Transfer Model. This will foster collaboration and community by allowing other students to ask questions and clarify understandings about the use of Energy Transfer Models for understanding energy transfer.

Allowing students to share their first-draft ideas will also help reinforce the classroom community in which students are trying new things and communicating with their peers. Throughout this unit, students will be sharing their designs to optimize their homemade flameless heater. Going public with first-draft ideas is important so that they learn from one another.





11. Set up doubling systems investigation.

7 MIN

Materials: science notebook, *Energy Transfer Models*, chart paper, markers

Motivate the need to consider more matter for the food system. Refer to the Energy Transfer Model the class has developed so far. Say, *Our class model helps us to explain why more matter in the reaction system transfers more energy to the food system. It also helps us predict what the temperature of the food will be. Models are used to explain and also predict!* Use the dialogue example to motivate the need to know more about how both systems interact.*

Suggested prompts	Sample student responses	Follow-up questions
What temperature did you mark on the food system with the original reaction?	*I marked my thermometer kind of in the middle on the food system.*	*How did you determine that?*
Was that the same temperature or higher or lower compared to what we got in our data for the 2-gram reaction system—the 2X system?	*I had it a little lower than the doubled reaction system.*	*Why do you think that?*

*** Supporting Students in Developing and Using Energy and Matter**

Students who think that the temperature would stay the same may think temperature and energy are the same. If the amount of reactants stays the same, their reasoning would be that the energy was the same so the temperature would be the same too.

Students who think that the temperature of the food would go up more if the food was doubled

Suggested prompts	Sample student responses	Follow-up questions
OK, but what if we doubled our food system—used a 2X food system but kept the original (1X) reaction system? What do you predict would happen in an original (1X reaction system) and a 2X food system?	*I think it would stay the same.* *I think the temperature in the food would go up more.* *I think the temperature would not go up as much.*	*What do you mean by "it"? What would stay the same?* *Say more about your thinking.* *Can you explain why you think that way?*
We have been doubling the reaction system or the food system. It sounds like we are using proportional thinking. Have you ever done that before?	*Yeah, we do that in math class!* *I know that sometimes I think about time that way—like it takes me twice as long to get to school as it does everyone else because I live outside of town.*	*Can you give me an example of what you did in math class?*

Highlight the three possibilities. Display **slide W.** Say, *It seems we have three possibilities when we double the food and we don't double the reactants: (1) the temperature stays the same, (2) the temperature increases more than when the food was not doubled, and (3) the temperature does not increase as much as when the food was not doubled.* Write these three options on the board or show the slide and ensure that students are comparing this to 1X the reactants and 1X the food. Guide the discussion so that these three possibilities come up, even if you have to offer some ideas yourself.

Fill in the data table with predictions. Refer to *Energy Transfer Models*. Say, *We already have our ideas in a model for the first two rows. We still need to test our ideas since we were wondering if the food would get warmer. Now we need to predict what will happen with the original reaction and double the food (1X reaction system and 2X food system).* Allow students time to complete the last row on the handout with their prediction. Students may want to draw with pencil since this is their prediction and they may have to revise later based on the evidence. Students will need to add labels, energy transfer arrows, and a thermometer in the food system. Tell students not to worry about the caption yet.

Call attention to the abbreviations used on the handout.

Rxn = reaction

Δ = delta or "the change in"

1X = one times the amount

2X = two times the amount

may be thinking that the increased amount of food means there are more particles. If there are more particles that are moving faster, then the temperature would be higher.

Students who think that the temperature for twice as much food and the same amount of reactants would be lower or not go up as much are considering the same amount of energy coming into the food system and having to spread out over more particles (the correct prediction). Therefore, the particles would not speed up as much and the temperature would not be as high.

Try to get all these ideas out in the class even if you offer some yourself. This will motivate the need to test these ideas and help struggling students make predictions.

12. Video of Doubling Systems Investigation

5 MIN

Materials: Doubling Systems Investigation

Set up the Doubling Systems Investigation with a video. Display **slide X**. Say, *I have a video of the tests you described. Let's watch it together and see how these results compare to your predictions. In this video you will see representative temperatures that occured from several tests—not just one. As you watch the video, record the change in temperature of each different investigation. Remember from your math classes that the delta sign or the small triangle means "change in".*

Watch the Double Reactants and Doubling Food video on YouTube (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**). Pause the video when the change in temperature is shown at the end of each test so students can record the data in the first column of their handout. Also, pause at the beginning of each test so students know which test is showing on the video and have students find the appropriate row on their *Energy Transfer Models* handout. Students should note how the results in the video compare to their predictions.

13. Revisiting Models and Completing Captions

7 MIN

Materials: *Energy Transfer Models*, chart paper, markers

Complete captions for rows 1 and 2. Have a few students share what they observed from the video and how that evidence compared to their predictions. Students should update their models, if needed, for each test compared to the 1X reaction and 1X food systems. Encourage students to use the particle model in their explanations for why the temperature increases even though they are using simple box models to show energy transfers and not particle models. Use the dialogue below as a guide and continue completing the class Energy Transfer Models on the board and encourage students to complete their models on the *Energy Transfer Models* handout. Have students jot down in the "Caption" column important ideas for each row.

If students do not know what a caption is, display **slide Y** for an example. Ask them, *Have you ever seen a diagram or picture in a magazine or newspaper? Even images on electronic sources often have a description of the image written below it as a caption. A caption explains the image in words. When you hear or share ideas that explain what your models show in words, write those ideas down in the caption.*

Use the following dialog as a guide.

Suggested prompt	Sample student response	Follow-up question
Let's start with the ones we already have sketched and make sure we understand what is going on with them. What can you say about the energy coming from the 1X reaction system compared to the 2X reaction system?	*There is more energy coming from the 2X reaction system.*	*What is your evidence for that?*

Supporting Students in Three-Dimensional Learning

This is the culmination of developing a model to describe and explain the unobservable phenomenon of energy transfer between systems. Students write captions to use with the model to explain the energy transfer between a reaction system and a food system. They explain how evidence of the temperature change supports their ideas. Their captions should demonstrate their understanding of energy transfer from the reaction system in an exothermic chemical reaction to the surroundings (the food system) and that because of this transfer the temperature of the food increases. Students should reason that because a system with twice as much mass (the 2X reaction

Suggested prompts	Sample student responses	Follow-up questions
So in the first two rows of the table, the amount of food is the same—the original (1X) amount of food. How did the temperature respond to the two reaction systems?	*The temperature of the food went up in both!* *The temperature went up more in the 2X reaction system.*	*What does it mean when the temperature goes up?*
Think about what we learned about the particles in the systems and what we learned in the Cup Design Unit unit. Can someone explain what is happening to energy in the first row with the original reaction system and food system?	*The energy from the reaction is transferred to the food.* *The energy from the reaction is transferred to the food, and the food particles move faster.*	*How does the energy transfer?* *What is your evidence that energy is transferred?*
Now can we explain the energy transfer when we doubled the reaction system and kept the food the same?	*More energy was transferred to the food when we doubled the reaction system.* *Because there was more energy transferred, the food got warmer than with the 1X system.*	*What happens to the particles in the food when more energy is transferred?* *Can someone else summarize what we have figured out about doubling the reaction system when we keep the food amount the same? You may want to write these ideas down to use in your caption on the data table. Be sure you are using the spaces in the appropriate row.*

system) has 2X the number of particles to break apart and rearrange, then there will be twice as much energy transferred from that reaction.

Explain the energy transfers with the 1X reaction and the 2X food system. Shift the focus to the last row in the data table. Continue the class discussion using the example below as a guide.

Suggested prompts	Sample student responses	Follow-up questions
OK, so when we had the 1X reaction system and the 2X food system, what did we observe? This is the last row of your data table	*The temperature of the food increased.* *The temperature increased less than when we had 1X the food and 1X the reactants.*	*Did it increase the same amount as when we had 1X the food?* *How did the evidence compare to your predictions?*
Why do you think the temperature of 2X the amount of food did not increase as much as when we had 1X the food.	*Maybe it is because we only have a certain amount of energy that can be transferred out of the 1X reaction system.*	*OK, the 1X reaction system gives us only a certain amount of energy.*

Suggested prompts	Sample student responses	Follow-up questions
But why then did that amount of energy not give us the same temperature?	*Well that amount of energy had to spread out into more stuff—more food.* *We learned in Cup Design Unit that temperature was a measure of the average kinetic energy of all the particles in the system. Since there are more particles to spread out all the energy, the average energy will be lower.*	*And how did that affect the temperature?*
Can you use the idea of the particles transferring energy to add some details to your explanation?	*When the energy is transferred out of the reaction, there is only a certain amount. This makes the particles speed up and have a higher temperature. If there are more particles because there is more food, the energy from the reaction has to spread out to all these extra particles.* *There isn't enough energy to speed up all the particles in the 2X or doubled food system as much as the energy sped up the particles in the 1X food system. That's because there are more particles in the 2X food system.*	*Can someone summarize in your own words what _____ said?* *These sound like important ideas to record in your caption for this row. Be sure to add your ideas about particles in your caption.*

Add energy transfer arrows and labels to the 1X reaction system/2X food system. Give students time to complete their models and the caption for the last row of the handout as well as other rows they need to complete. Students should add what they have figured out to the caption in each row if they haven't done so already. Collect these handouts or notebooks from students once they are complete.

Additional Guidance

Some students may want to test the 2X reaction and 2X food systems. If so, have the students make predictions on what the temperature would be of the 2X reaction and 2X food systems. Students will likely predict that the temperature of this setup will be the same as the 1X reaction and 1X food system. However, the temperature will likely be lower. If students predict a result of the same temperature, have them think about the energy transfer and how that energy transfers in this setup. Likely explanations for the result will mention the surface area of the food container that comes in contact with the reaction system, the amount of energy transferred out of the reaction system that doesn't transfer to the food, or the amount of water in the reaction system.

Assessment Opportunity

Building towards: 3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

What to look and listen for

- Student models that represent the direction of energy transfer out of the reaction system
- Student captions that explain what their model shows about energy transfer and the direction the energy flows
- Student relative representation of temperature changes as energy flows out of reaction systems and into food systems

What to do: Listen as students respond to questions about energy transfer and how that changes based on the amount of matter (number of particles). Collect and read captions for each of the reaction and food systems. Pose questions to students for clarification of their thinking about energy flow between systems. If students struggle to represent the flow of energy, encourage them to think back to previous units that represented energy with arrows. For students that are excelling, encourage them to think of additional ways to represent their ideas or additional details to add to their models that would better explain the phenomenon.

A completed table for your reference is shown in *Answer Key for Models and Captions*.

14. Updating Progress Trackers

5 MIN

Materials: science notebook, transparent tape, completed *Energy Transfer Models*, What We Do as Engineers poster

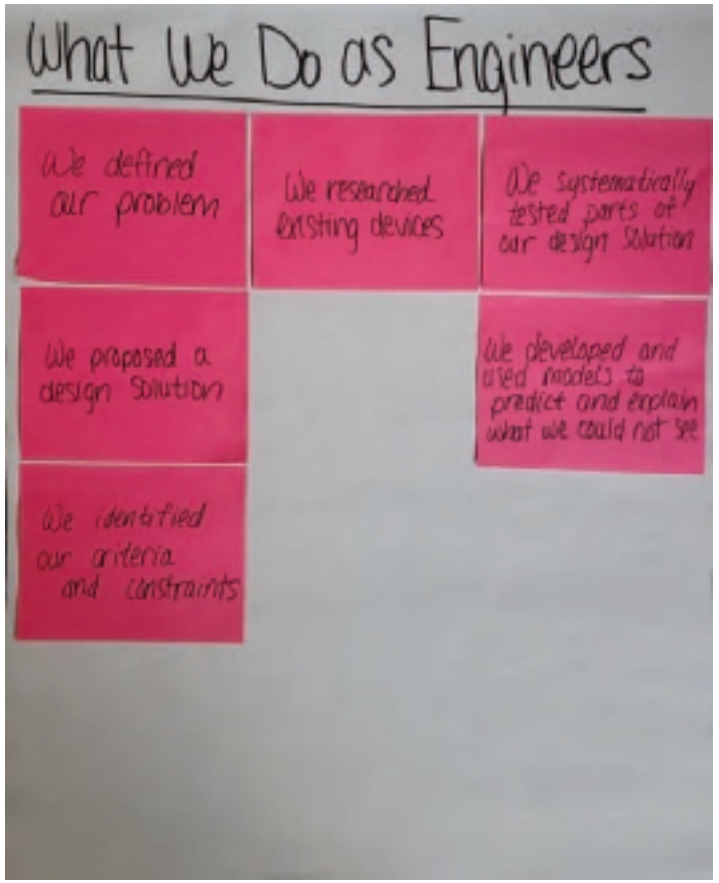
Update Progress Trackers as a class. Display **slide Z**. Have students go to the Progress Tracker section of their science notebook. Use questions like those below to help students process their work and record their thinking. Highlight important ideas and encourage students to put them in their Progress Trackers. The example shows some ideas that may surface.

Suggested prompts	Sample student responses
Think back to what we just accomplished. What did we do in the last couple of days to figure out what is going on in our chemical reactions?	*We drew models of the particles.* *We added what was happening to the energy.* *We used our Energy Transfer Models to predict temperature changes.* *We figured out and modeled what would happen when we doubled the reaction system or the food system.*
Why was drawing models of this important for our work?	*Because the models showed what was going on at the particle level—we cannot see that!* *The models helped us explain what was going on.* *They also helped us predict!*

Say, *Using models to explain what we cannot see and to make predictions is important for engineers. Let's add that idea to our Progress Trackers.* Add a sticky note or card to the What We Do as Engineers poster as shown in the image. After students have had time to enter what they did as engineers, say, *Now let's think about what we figured out while we were being engineers.*

What did we do as engineers?	What did we figure out that can help us with our designs?
We developed and used models to predict and explain what we could not see.	• In an exothermic reaction, energy is transferred from the reaction particles to other particles. • In an endothermic reaction, energy is transferred from the surroundings to the reaction particles. • The energy from an exothermic reaction is transferred to the surroundings. • We want to maximize the energy transferred to the food (surroundings).

Add the completed models handout to their Progress Trackers. When students start to share what they have figured out about doubling the reaction system or the food system, say, *We have what we figured out with these systems summarized in our captions—let's just add those to our Progress Trackers.* Have students tape their completed models handout with captions into their Progress Tracker. They should put it directly underneath their previous entry for Lesson 3. If there is no room on the page, have students tape it to the next page and write, "Continued from previous Progress Tracker".



15. Navigation

1 MIN

Materials: None

Navigate to the next lesson. Display **slide AA**. Say, *We have figured out some important science ideas that will help us design our flameless heaters*. Use the example dialogue to navigate to the next lesson.

Suggested prompts	Sample student responses	Follow-up questions
Can someone summarize one thing we figured out in the last three classes?	*We figured out that when we use more reactants it gets hotter!*	*Did all reactions get hot?* *What do we call those reactions?*
Can someone paraphrase what _____ said? Practice using our new vocabulary.	*We used an exothermic reaction to make the food get hotter.* *When we increased the amount of reactants in an exothermic reaction, the food got hotter as long as we didn't increase the amount of food.*	*Can someone add to what _____ said?*
We also increased the amount of food we were heating. Can someone summarize what we figured out about when we increased the food?	*When we doubled the amount of food but didn't double the reactants, the food did not get as hot.* *When we increased the amount of food at the same time as we increased the amount of the reactants, the food was about the same temperature as the regular amount.*	*Does someone have something to add to _____'s idea?*
Can someone explain _____'s observation?	*When we doubled the food but not the reactants, the energy from the reactants had more particles to speed up, so the energy couldn't speed these particles up as much as when the food was half as much.*	*These ideas will be important to keep in mind as you design your homemade flameless heater system.*

ADDITIONAL LESSON 3 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.6.NS.C.5 Understand that positive and negative numbers are used together to describe quantities having opposite directions or values (e.g., temperature above/below zero, elevation above/below sea level, credits/debits, positive/negative electric charge); use positive and negative numbers to represent quantities in real-world contexts, explaining the meaning of 0 in each situation.

During this lesson, students calculate the maximum temperature change for three different amounts of reactants. They report this change in temperature using positive and negative numbers to show the increase or decrease from the starting temperature.

CCSS.MATH.CONTENT.7.RP.A.1: Analyze proportional relationships and use them to solve real-world and mathematical problems.

Students will have the opportunity to use proportional relationships in this lesson as they consider energy transfer in systems that are twice the amount and half the amount. Students will predict the temperature of a food system when energy is transferred from a chemical reaction of a set mass. Then students will reason and predict temperatures of the food system when 2X the mass of reactants are used in the chemical reaction. This early practice analyzing and predicting proportional relationships will help them in future lessons as they consider halving their system and predicting the results.

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Students will help plan and carry out an investigation in day 1 where instructions are detailed, measurements are required on a timed interval, and each student has a different role and assigned tasks to ensure the investigation is successful.

LESSON 4

How much of each reactant should we include in our homemade flameless heater?

Previous Lesson

We tested different chemical reactions to determine which might be a good candidate for our homemade flameless heater. We figured out that root killer and aluminum foil caused the greatest temperature increase when mixed together in saltwater, so we moved forward with investigating the energy transfer from that system using an Energy Transfer Model.

This Lesson

Investigation

2 DAYS

We plan and conduct an investigation to determine which proportion of reactants will work best to heat up our food. Then, we reflect on what makes good instructions and identify our stakeholders. Finally, we administer a survey to our potential stakeholders to figure out what aspects they find most important.

Next Lesson

We will review the Stakeholder Survey results and decide we need to figure out what temperature we want our food to reach. We will revise our criteria and constraints for food temperature and decide on heater cost and mass. We will reorganize and refine our What We Do as Engineers board to reveal a cyclical process.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

4.A Evaluate and use accurate methods of data collection to define an optimal proportion of reactants that result in the greatest temperature change and least amount of reactants left over.

4.B Analyze data to identify patterns in numerical relationships and images to define an optimal proportion of reactants that result in the greatest temperature change and least amount of reactants left over.

What Students Will Figure Out

- The combination of reactants that results in the greatest temperature change is 8% aluminum and 92% $CuSO_4$.
- We identify our stakeholders and decide to survey them to understand their needs.

Lesson 4 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION**	A-B	Design Questions Board
2	15 min	**PLAN FOR PROPORTION OF REACTANTS INVESTIGATION** Discuss the amounts of reactants to test and what data to collect. Evaluate and discuss the investigation procedure.	C-G	*Investigation Procedure for Proportion of Reactants*, *Analyzing Our Data Collection Methods*
3	20 min	**CONDUCT PROPORTION OF REACTANTS INVESTIGATION** Different groups test different proportions of reactants and record data in their science notebooks.	H-L	Proportion of Reactants Investigation
4	5 min	**REFLECT ON TYPES OF INSTRUCTIONS** Conduct an exit ticket about what makes good instructions.	M	
				End of day 1
5	20 min	**BUILDING UNDERSTANDINGS DISCUSSION ABOUT OUR RESULTS** Make sense of our data to identify the optimal proportion of reactants that results in the largest temperature change.	N	*Small-Group Data Table*, whole-class data from Proportion of Reactants Investigation, Word Wall, Energy Transfer Model
6	5 min	**UPDATE OUR PROGRESS TRACKERS** Update Progress Trackers individually to capture what we have figured out as we systematically tested parts of our possible solution.	O	What We Do as Engineers board, sticky notes, markers
7	12 min	**REVISIT REFLECTIONS ON INSTRUCTIONS AND IDENTIFY STAKEHOLDERS** Discuss the importance and components of clear and easy to use instructions. Think about who will be using the homemade heaters, identify stakeholders, and add to our Progress Trackers.	P-Q	What We Do as Engineers board, Word Wall, sticky notes, markers
8	8 min	**DISCUSS STAKEHOLDER PREFERENCES AND ASSIGN HOME LEARNING** Discuss conducting a survey in order to figure out stakeholder preferences and assign a Stakeholder Survey to give to students' community members for home learning.	R-S	Safe Minimum Cooking Temperatures Chart (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
				End of day 2
		SCIENCE LITERACY ROUTINE		Student Reader Collection 2: *The Heat Is On*

Lesson 4 • Materials List

	per student	per group	per class
Proportion of Reactants Investigation materials **Student Procedure Guide** **Student Work Pages** 	• indirectly vented chemical splash goggles • nonlatex apron • nitrile gloves • Science Notebook • *Small-Group Data Table* • *Investigation Procedure for Proportion of Reactants* • *Analyzing Our Data Collection Methods*	• 1 tray • 2 8-oz. Styrofoam cups (new or used) • 1 8-oz. Styrofoam cup (new) • 1 cup lid • 1 digital thermometer • 1 digital scale • 2 pieces of 10 by 10 cm square parchment paper • 1 plastic spoon • 1 coffee filter • 1 plastic funnel • 1 rubber band • paper towels • 6.5 grams copper sulfate • 7.0 grams shredded aluminum foil • 70 mL saltwater	• chart paper and markers (optional)
Lesson materials	• *Investigation Procedure for Proportion of Reactants* • *Analyzing Our Data Collection Methods* • Science Notebook • *Small-Group Data Table*		• Design Questions Board • whole-class data from Proportion of Reactants Investigation • Word Wall • Energy Transfer Model • What We Do as Engineers board • sticky notes • markers • Safe Minimum Cooking Temperatures Chart (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Materials preparation (45 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Make one copy each of *Analyzing Our Data Collection Methods*, *Small-Group Data Table*, and *Investigation Procedure for Proportion of Reactants* for each student. Trim *Small-Group Data Table* to fit science notebooks.

Be sure you have materials ready to add the following words to the Word Wall: *optimal*, *stakeholders*. Do not post these words on the wall until after your class has developed a shared understanding of them.

Be sure you have materials ready to add to the What We Do as Engineers board. This includes both 4″ by 6″ and 3″ by 3″ sticky notes.

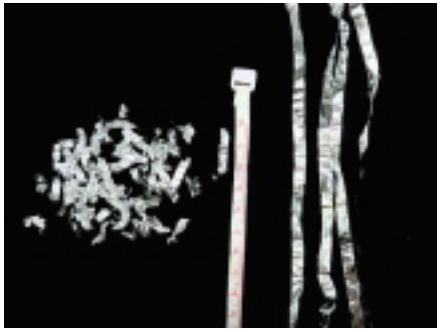
Decide how you will arrange your classroom to allow for students to have a discussion in the Engineers Circle so all students can see each other and the centrally located space where the What We Do as Engineers board, the Word Wall, the Energy Transfer Model, and the whole-class data from Proportion of Reactants Investigation are posted.

Review this page and create a copy of this chart to use with your classes (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Make sure the lab has engineering controls—eyewash station and shower—available.

Day 1: Proportion of Reactants Investigation

- **Group size:** 6 groups of 3-5 students
- **Setup**
  - Prepare saltwater for a single class by adding 2.5 g of table salt and 420 mL of water to a container. Stir to make sure all the table salt dissolves. Divide the saltwater evenly among 6 containers for groups to use. ***Be sure to leave the saltwater out at least a day in advance to come to room temperature.***
  - Prepare 42 g of shredded aluminum foil per class by running ~8″ x 11″ pieces of aluminum foil through a paper shredder. A crosscut paper shredder is preferred since it cuts the aluminum into small pieces (~2 cm x 0.5 cm), whereas strip-cut paper shredders produce long strips that will then need to be cut into smaller pieces. You may need to run a few pieces of aluminium foil through the shredder to remove any paper bits before you collect foil to use in class. You will need another approximately 72 g per class for both Lessons 6 and 9, if it would be easier to prepare it all now. Divide the aluminum pieces evenly among 6 containers for groups to use.
  - Obtain 18 8-oz. Styrofoam cups and 6 lids and put together 6 sets of 3 cups and a single lid. Label each cup with the groups' letter IDs (A through F, each group getting 3 cups and a lid). Reuse 12 of the cups from previous lessons. Use 6 new cups (1 per group) so that students can collect the liquid after the testing in a clean cup for easier color comparison.
  - Prepare trays of supplies for groups to use in their investigation. There will be a tray for each group (A-F). Place the following on each tray:
    - 1 set of 3 cups and 1 lid (One cup for each group should be new. The other 2 cups can be reused from previous lessons.)



- 1 digital scale, 1 digital thermometer, 1 rubber band, 2 pieces of parchment paper, 1 plastic spoon, and some paper towels
- 1 coffee filter and 1 plastic funnel
- 1 container of at least 70.0 g (70.0 mL) of prepared saltwater
- 1 container of at least 6.5 g of copper sulfate crystals ($CuSO_4$)
- 1 container of at least 7.0 g of aluminum foil pieces
- Make sure that students have access to a timer or clock and a pencil.

Safety

Ensure that the lab has engineering controls (eyewash station and shower) available.

1. Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
2. Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
3. Follow your teacher's instructions for disposing of waste materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.
8. Use caution when working with heated liquids—this can burn skin!
9. Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

Be sure to remind students to firmly place lids and gently swirl the Styrofoam cups so as to avoid the escape of liquid from the cups.

Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.

- **Notes for during the lab:** When students remove the lid from the reaction mixture and filter the liquid from the solids, they may notice a metallic smell. They may also observe tiny bubbles on the surface of the liquid due to the generation of small amounts of hydrogen gas. This is not hazardous in the quantities with which students work. Groups using an excess of copper sulfate (A-D) may also notice some undissolved blue copper sulfate crystals during filtration. They should proceed with the filtration as directed in *Investigation Procedure for Proportion of Reactants* and record this observation in their *Small-Group Data Table*.
- **Disposal:** Solid wastes (including pieces of aluminum and copper) can be disposed of in the garbage. Dispose of liquid waste as directed in the teacher reference *Safety Information for Copper Sulfate Pentahydrate*.

- **Storage:** Unused saltwater, aluminum foil, and copper sulfate can be retained for future lessons. Rinse all Styrofoam cups and plastic spoons and save for another lesson or next year; although the Styrofoam cups from the processes involving metals will be stained, this should not interfere with the experiment.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

In previous lessons students figured out which chemical process to use and that increasing the amount of reactants increases the amount of energy transferred out of the system. However, we don't know how much of each of the reactants to use to get the most energy transferred out of the reaction system. We figure out that there is an optimal proportion of reactants to use for the largest energy transfer to the food system, which can be identified by the largest temperature increase and observations of the products. Students begin to refine how they will create their instructions while considering homemade heater users and other potential stakeholders.

Where We Are NOT Going

The amounts of aluminum and copper sulfate reactants were chosen based on the stoichiometry of the chemical reaction. Stoichiometry can be used to find the right proportion of reactants needed to *completely* react one reactant with the other reactant, resulting in no leftover reactants when the reaction takes place. In this case, when the *molar* ratio of $CuSO_4 \cdot 5H_2O$ to Al is 1.5 (3:2), the reactants are present in more or less stoichiometric amounts, i.e., neither is present in excess (this is approximate, as we are not accounting for any Al_2O_3 on the surface of the aluminum foil). Therefore, the combination of 0.5 grams of Al to 5.5 grams of $CuSO_4$ yields the greatest temperature change. This explanation is beyond grade band; however, students should qualitatively see that, for the other proportions of the reactants tested in this lesson that do not perform as well, there is an excess of one of the reactants (e.g., excess foil left over or the solution remains blue with less copper forming).

Students may want to test additional proportions of reactants. If you choose to test other combinations of reactants, be sure to conduct multiple trials of those combinations, in addition to those listed in *Investigation Procedure for Proportion of Reactants*.

LEARNING PLAN FOR LESSON 4

1. Navigation

5 MIN

Materials: Design Questions Board

Navigate to today's work. Display **slide A** and make sure that the DQB is visible. Say, *Last time, we figured out that mixing copper sulfate and aluminum foil together transferred a lot of energy out of the reaction system. It seems like we've got a good start for creating a flameless heater, including a good reaction to use. But I'm wondering, how exactly can we help people use that reaction in order to build their own flameless heater? Turn and talk with an elbow partner and discuss what we should do as our next steps if we want to help people make homemade heaters to warm up their food. What else do we need to figure out about the reaction system?*

After a minute, bring the class back together to share their ideas.

Suggested prompts	Sample student responses
Will someone share something that we learned about our reaction? What did we figure out last time about mixing the substances?	*We learned that the amount of substance is related to how much energy gets transferred. Mixing up more substances transfers more energy than when we mixed smaller amounts.*
What else do we need to figure out about the reaction system in order to create a homemade flameless heater?	*(Answers may vary.)*
Last time, we saw what happened when we changed the total amount of reactants and total amount of food. Are there other amounts in our reaction that we could change?	*Yes, we could use more aluminum than copper sulfate (or vice versa) to see if those different amounts of reactants transfer more or less energy.* *We could change the amounts of saltwater.*

Motivate testing different amounts of each reactant. Say, *So we figured out that adding more food means we have to add a lot more reactants in order to transfer more energy to the food system.* Display **slide B**. Remind students that, in Lesson 3, we tried equal amounts of aluminum and copper sulfate (3 grams of Al and 3 grams of CuSO). But if we want to heat up the most food to the ideal temperature, are equal proportions of reactants the best combination to use? Ask students to turn and talk with a partner. After 1 minute, ask a few students to share their ideas. Students will likely say that they are not sure or don't think it will get hot enough.

2. Plan for proportion of reactants investigation. 15 MIN

Materials: *Investigation Procedure for Proportion of Reactants*, *Analyzing Our Data Collection Methods*

Turn and talk about systematic testing. Display **slide C**. Ask students to turn and talk with a partner: How can we systematically test what amount of each reactant will work best? After 1 minute, ask a few students to share their ideas. Students will likely suggest combining different amounts of each reactant and measuring the change in temperature.

Discuss the different amounts of each reactant to try. Say, *OK, so we should combine different amounts of each reactant. Let's think about how to systematically test this.* Display **slide D**.

Suggested prompts	Sample student responses	Follow-up questions
For our small-group investigations in Lesson 3, we used three grams of each reactant. If we want to compare different proportions of reactants to this, what does this mean for the total grams of reactants we need to use?	*We should use six grams total so that we can compare.*	*Why is it important to keep the total amount of reactants we use constant?*
What amount of each reactant should we try in order to compare to what we tried in Lesson 3?	*We could try some combinations where we use more of one and less of the other.*	*Can you give me an example?* *So are you saying we should test some with more aluminum than copper sulfate and some with less?*
What data should we collect to determine which combination works best?	*We should record the temperature.* *We need to see how much the temperature changes.*	*Just once? How many times should we record it?* *Why is it important to record the change in temperature?*
So, we can measure the temperature of the system. What other observations could we make about the products?	*We could see what it looks like afterward compared to what we started with.* *Maybe we could look for a color change?*	*For groups that tested the copper sulfate and aluminum in Lesson 3, what observations did you record?*

Introduce a procedure that will be used for data collection. Say, *I have a procedure we can use to collect these data, but I want your help to be sure that our methods will get us credible data with the fewest errors so that we can use it for making decisions later.*

Hand out *Investigation Procedure for Proportion of Reactants* and *Analyzing Our Data Collection Methods*. Display **slide E**. Say, *If we want to figure out which combination of reactants, which proportion of each, is going to work the best for our reaction, then we need to trust our data. One way we can make sure our data are reliable is to check our procedures. We want*

to make sure our methods get us the data we need and that we are measuring our variables accurately and doing everything we can to reduce possible errors.

Evaluate the first part of the procedure as a class. Read "Part 1: Measuring Reactants" of the procedure together as a class. Then focus students' attention on *Analyzing Our Data Collection Methods* and solicit ideas for the row for the first part of the procedure. Work together as a class to complete this first row of the table.

Suggested prompts	Sample student responses
Why is this part of the procedure important for answering our question?	*If we want to figure out what proportion of reactants to use, we have to know how much of each we are using.*
Do you think the methods that are suggested for measuring the reactants will help us get accurate data to answer our question? In what ways?	*Yes. We use a scale to weigh the materials.* *Yes. It says how to use the materials to weigh it, including folding the paper so that the stuff doesn't fall out.*
Are there additional things we can do to make sure we are being accurate when we measure the reactants?	*Measure really carefully—be sure no material is left hanging off somewhere or dripping.* *We should measure to the nearest 0.1 gram.* *We can record exactly how much we used.*

Work with a partner to evaluate the rest of the procedure. Display **slide F**. Give students 5–7 minutes to review the remaining parts of the procedure and add to *Analyzing Our Data Collection Methods*. As students work, circulate and probe student thinking with prompts, such as the following:

- Why is that part of the procedure important for answering our question?
- Are there methods that we have used in other investigations that have helped us get accurate data?
- If different groups are testing different combinations of reactants, how can we compare our results of what is remaining afterward?

Discuss ideas as a whole class. Display **slide G**. Ask students to share some ideas for how the methods suggested will help answer our question "Which proportion of reactants will work best?" and how to make sure they are most accurate. Focus the bulk of the discussion on observing what is remaining afterward and how to compare across groups, since this is not a method they have used in previous lessons.

Suggested prompt	Sample student response
Let's start with measuring temperature. Why is this part of the procedure important for answering our question?	*We are trying to get a reaction that increases in temperature to heat up our food, so we have to measure the temperature to see what works best.*

Suggested prompts	Sample student responses
Do you think the methods described will help us get accurate data? What do we need to do to make sure we are accurate?	*Keep the thermometer in the solution the whole time.* *Record the starting and ending temperature (not just the max temperature).* *Keep the thermometer right in the middle of the "food" being measured.*
Why do you think it's important to examine what is remaining after the reaction is over?	*We could see how much copper is produced.* *We could see what is used in the reaction.*
How could we know if there is copper produced? What color would it be?	*Maybe it would be blue like the copper sulfate.* *Maybe it would be like a penny, like copper metal.*
What would it mean if a lot of aluminum was left over? *What if the solution stayed really blue?*	*If there was a lot of aluminum left over, then it didn't get used up in the reaction.* *If the solution stayed really blue, I think that would mean there was a lot of the copper sulfate still there.*
How can we compare our results across groups in a way that gets us reliable or accurate data? Can we just describe that it is blue? Or say there is a lot of the aluminum left?	*We need to compare the color of the solution to a standard (maybe how it would be before the reaction) or compare to other groups to see if it is actually different or not. Describing different shades of blue and different amounts of reactants left over is hard to describe in a way that we can accurately compare.*

Summarize the discussion. Say, *So it sounds like, while we have experience with methods of collecting the temperature carefully, we have some new ways of comparing what is left over to help us more-accurately report the results.*

Assessment Opportunity

Building towards: 4.A. Evaluate and use accurate methods of data collection to define an optimal proportion of reactants that result in the greatest temperature change and least amount of reactants left over.

What to look for: See *Key for Analyzing Our Data Collection Methods* for sample student ideas.

What to do: If students are struggling with articulating why examining the solids and liquids after the reaction is useful in answering our question, cue them to look at the chemical equation and identify what we end up with at the end (copper and no aluminum by itself). Pose questions, such as, "If there is a lot of aluminum left, what does that mean in terms of the reaction?" If students don't suggest comparing their remaining solids and liquids to those of other groups, refer to different blue objects in the classroom, and ask for different students to describe the colors. This should help reveal the need to compare to more-accurately describe the solution.

3. Conduct proportion of reactants investigation. 20 MIN

Materials: Proportion of Reactants Investigation

Prepare science notebooks to collect small-group data and assign proportions of reactants to groups. Display **slide H**. Hand out *Small-Group Data Table* and have students tape it into their science notebook. In order to get multiple data points given the limited materials available, explain that you have selected two quantities where there is more aluminum than copper sulfate and one where there is more copper sulfate than aluminum, as shown below and on **slide H**.

Groups	Grams of aluminum	Grams of copper sulfate
A & B	0.1	5.9
C & D	0.5	5.5
E & F	4.5	1.5

Additional Guidance

The amounts of aluminum and copper sulfate reactants were chosen based on the stoichiometry of the chemical reaction. Stoichiometry can be used to find the right proportion of reactants needed to *completely* react one reactant with the other reactant, resulting in no leftover reactants when the reaction takes place. In this case, when the *molar* ratio of $CuSO_4 \cdot 5H_2O$ to Al is 1.5 (3:2), the reactants are present in more or less stoichiometric amounts, i.e., neither is present in excess (this is approximate, as we are not accounting for any Al_2O_3 on the surface of the aluminum foil). Therefore, the combination of 0.5 grams of aluminum to 5.5 grams of copper sulfate yields the greatest temperature change. This explanation is beyond grade band; however, students should qualitatively see that, for the other proportions of the reactants tested in this lesson that did not perform as well, there is an excess of one of the reactants (e.g., excess foil or the solution remains blue with less copper forming).

Conduct investigation in small groups. Display **slide I** and review the safety guidelines. Display **slide J.** Remind students to use *Investigation Procedure for Proportion of Reactants* as they collect data for their assigned amounts. Allow about 15 minutes for students to conduct their investigation and add their maximum temperature change data to the class data table. Make sure that each group has and knows to use the 1 new cup for collecting the liquid after the reaction so that the colors can be compared more easily. The remaining cups can be reused from previous lessons. Project a class data table shown on **slide K** or create a table on chart paper.

Additional Guidance

Students may notice tiny bubbles on the surface of the copper sulfate and aluminum reaction when they take the lid off of the cup after monitoring the temperature for 5 minutes. Although we may think of aluminum foil as being pure aluminum metal, it is actually covered with a very thin layer of aluminum oxide since aluminium reacts very rapidly with oxygen in the air. Sodium chloride in the saltwater is able to disrupt the aluminum oxide layer to expose pure

aluminum, which not only reacts with the copper sulfate but can also react with water to produce hydrogen gas. Since students will be using this reaction in their design, you can share this explanation with them if it comes up.

Revisit suggestions for improving accuracy of data collection. As students are finishing the investigation, show **slide L**. Tell them to revisit *Analyzing Our Data Collection Methods* and the suggestions they made in the last column. Ask them to revise or add new suggestions based on their experience with the investigation and data collection, marking any additions with a star. When students are finished, collect *Analyzing Our Data Collection Methods*.

4. Reflect on types of instructions.

5 MIN

Materials: science notebook

Reflect on types of instructions. Show **slide M** and tell students to turn to the next blank page in their science notebook. Ask them to take the next 5 minutes to respond to the prompts on the slide:

- What parts of the instructions were the most helpful?
- Why is it important to have instructions that are clear and easy to follow?
- What makes instructions clear and easy to follow?

Say, *Now that you've conducted the investigation using the instructions in Investigation Procedure for Proportion of Reactants, reflect on your group's experience following the instructions. Were there any parts of the instructions that were particularly helpful or confusing to you? Why do you think that is? Take a few minutes to consider what makes good instructions. On a new page in your notebook, title the page "Instructions Reflection" and respond to the prompts on the slide.*

Photograph reaction products. While students complete their exit ticket reflections, you will need to photograph the contents of each group's filter paper as well as the filtered liquid in their cups. It will be useful to have these images on hand during the upcoming Building Understandings Discussion. Example images are shown in *Sample Data for Proportion of Reactants Investigation* for reference. Strive to make images as comparable as possible by photographing the filter papers and cups at the same location under the same lighting. If it is helpful, upload these images to the slides for easy reference during the next class period.

Alternate Activity

The contents of each group's filter paper and their cup of filtered liquid can be saved for the next period's Building Understandings Discussion. If you elect to do this, cover each cup to minimize evaporation. Note that prolonged exposure to air will result in the oxidation of any elemental copper on the filter paper causing it to change from a burnt-red color to a greenish-blue color.

Safety Precautions

To minimize pollution of the aquatic environment, collect all liquids from the copper sulfate and aluminium reaction mixtures and react them with excess aluminum so that all copper sulfate will be converted to aluminum sulfate (in solution) and copper metal (a solid). Use the blue color of the solution as a visual estimate of how much copper sulfate

remains in the solution; the less blue the solution, the less copper sulfate remaining. After a reaction with excess aluminum, the solution containing sodium chloride and aluminium sulfate can be poured down the drain with running water (since aluminum sulfate is not an environmental hazard), and the aluminum and copper solids can be disposed of in the trash. See *Safety Information for Copper Sulfate Pentahydrate* for more information.

End of day 1

5. Building Understandings Discussion About Our Results

20 MIN

Materials: science notebook, Small-Group Data Table, whole-class data from Proportion of Reactants Investigation, Word Wall, Energy Transfer Model

Gather in an Engineers Circle to analyze our results. Display **slide N**. Project or post the class data and have images of the filtered products available for students to see. Navigate to today's discussion by asking students where we left off at the end of the investigation last time. Then lead a Building Understandings Discussion to draw conclusions about the optimal proportion of reactants that results in the largest temperature change and what this means for our design solutions. Sample data are provided in *Sample Data for Proportion of Reactants Investigation* for your reference.

Key Ideas

Purpose of this discussion: Draw conclusions about the optimal proportion of reactants that results in the largest temperature change and greatest conversion of reactants into products and about what this means for our design solutions.

Listen for these ideas:

- The combination of reactants that worked the best was 0.5 g of aluminum and 5.5 g of copper sulfate.
- This combination had the greatest temperature change and seemed to react more completely than the other proportions tested. For other proportions we tested, there was either excess aluminum or excess copper sulfate and the temperature change was less.
- The best proportion of reactants is 8% Al and 92% $CuSO_4$.
- We should use a similar proportion of Al to $CuSO_4$ in our design solutions.

Suggested prompt	Sample student response	Follow-up questions
What claim can we make about which proportion of reactants worked the best?	*When we used 0.5 grams of aluminum and 5.5 grams of copper sulfate.* *Groups C and D.*	*Do you agree or disagree?* *Who can restate what X just said?*

*** Attending to Equity**
Universal Design for Learning: Use this opportunity to identify examples of vocabulary from students' own contexts. Have students think about how words we use every day can have similar and different meanings in an engineering context. This move can increase student *engagement* by broadening the class mission to explain not only the use in our classroom engineering context but also familiar everyday contexts.

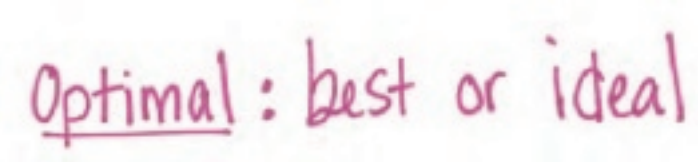
*** Attending to Equity**
Universal Design for Learning: Students can use a calculator to help determine the percentages. Allowing alternatives for use of tools, such as a calculator, can remove barriers for students in *expressing* their understanding by keeping the focus on the learning

Suggested prompts	Sample student responses	Follow-up questions
What is your evidence?	*The temperature for 0.5 grams of aluminum and 5.5 grams of copper sulfate changed the most.* *The 0.5 grams of aluminum and 5.5 grams of copper sulfate combination got the hottest.*	*Can you say more about that?*
What did you notice about what was left over for groups C and D compared to the other groups?	*You can't really see any aluminum left.* *There is a lot of copper sulfate at the end.* *The solution is not as blue compared to when we used 0.1 grams of aluminum.*	*Can you show us what you mean with our products here?* *Did you notice anything else as you tried your assigned amounts?*
Let's look at what was left over after combining 4.5 grams of aluminum and 1.5 grams of copper sulfate. *What do you think it means in terms of the reaction for there to be a lot of leftover aluminum?*	*If there is leftover aluminum, then maybe it didn't all get used in the reaction.* *Maybe there isn't enough copper sulfate to react with all of the aluminum.*	*So are you saying that there is too much aluminum compared to the copper sulfate?*
What did you notice about what was left over for a reaction where there was less aluminum compared to the amount that worked best? What do you think this means?	*There is leftover copper sulfate—we can see some blue crystals on the filter paper.* *The aluminum is all gone, but the solution is still really blue.* *There isn't enough aluminum to react with the copper sulfate.*	*Can someone restate what they think is happening in this case?*
What do you think this means for why the 0.5 grams of aluminum and 5.5 grams of copper sulfate worked the best?	*If you have too much of one reactant over another, the reaction does not work as well.* *For the combination that worked the best, all of the aluminum and copper sulfate are used in the reaction.*	

goal (in this case determining the relative proportions of each reactant so that we can use that in our designs). Use of such tools can help provide a match between a student's abilities and the demands of the task.

*** Supporting Students in Engaging in Using Mathematics and Computational Thinking**
Students apply mathematical concepts from the CCSS for 6th grade math to determine the optimal proportion of reactants by calculating the percentage of each substance. They should know to find a percentage they need to take a part (like 0.5) over the whole (5.5 + 0.5) and then find the equivalent proportion over 100 to get the percentage. While students should be able to calculate this, it may be a useful time to have some kind of anchor chart reminding them that a percentage is calculated as a part over a whole or showing a sample calculation of a percentage from a ratio. Additionally, showing strategies from their math class on finding equivalent ratios, like ratio tables or double number-line diagrams, may be helpful.

Add *optimal* to the Word Wall. Say, *So, we have figured out that 0.5 grams of aluminum with 5.5 grams of copper sulfate is the best or optimal proportion of reactants. We can use the word "optimal" to describe the proportion we think will work the best in our designs. This word is used in everyday language. Do we mean the same thing when we're using it in our context? What is the everyday definition, and what is our engineering definition? This word seems important for our work. Let's add "optimal" to our Word Wall.* *



Shift to discussing how we can use this information in our design solutions. Say, *Let's look at our Energy Transfer Model to see how that can help inform our design solutions.*

Suggested prompts	Sample student responses
Let's think about the particle zoom-in piece of our model we discussed in Lesson 3. How are the particles different here than the way we did our experiment in Lesson 3? What changes when we change the proportion of reactants?	*There are different amounts of each reactant's particles in the reaction system.*
In Lesson 3, we figured out that increasing the total amounts of reactants while keeping the proportions the same in our system resulted in more energy transfer to the food system.	*More or less energy is transferred depending on the proportion.* *When there is excess aluminum or excess copper sulfate, the energy transfer out of the reaction system will be less than when the reactants are at the optimal proportion.*
*How does changing the **proportion** of reactants affect this arrow? (Point at arrow coming out of reaction system to food system.)*	*When it's at the optimal proportion, the arrow will be bigger.*

Say, *How can we use these results to inform what amounts of reactants we use in our homemade flameless heaters? When we investigated the proportion of reactants, we used a total of six grams of reactants. What if we want to use more than six grams of reactants? How can we scale this up but keep the same proportion so that none of the reactants are left over?*

Calculate the optimal amount of each reactant used in terms of percent of the total reactants.*

Suggested prompts	Sample student responses
One way we can use this information is to figure out what percentage of the total amount of reactants we use is aluminum and what percentage is copper sulfate.	*It was fifty-fifty.*
Let's think about some of the amounts we tried. In Lesson 3 we used three grams of each reactant. What percentage of the total reactants was aluminum and what percentage was copper sulfate?	*Fifty percent of the total reactants was aluminum, and fifty percent of the total reactants was copper sulfate.*

Suggested prompts	Sample student responses
OK, so to calculate a percentage, we need to compare the amount of the reactant used to the total amount of reactants.	*0.5 grams of aluminum.*
What was the optimal amount of aluminum we used?	
And what was the total amount of reactants used?	*Six grams.*
So, to figure out the percentage of aluminum, what do we need to do?	*Divide the amount of aluminum we used (0.5 grams) by the total amount of reactants (6 grams) and then multiply by 100.*

Help students calculate the percentages of each reactant. They should see that the optimal amount of each reactant was 8% aluminum and 92% copper sulfate.*

Apply what we have figured out to our designs. Discuss students' ideas for how to use this information in their design solutions.

Suggested prompts	Sample student responses
OK, so our systematic testing helped us figure out that the optimal amount of reactants is 8% aluminum and 92% copper sulfate.	*We could just use the same amounts of each that we tested here.*
How could you use this information to inform your design solutions?	
What if you wanted to use more than six grams of the reactants? How could we scale this up but keep the same proportion so that none of the reactants are left over?	*We could just double or triple each amount of reactant.* *We could take our total amount of reactants we want to use and then figure out what 8% of that total is for the aluminum and what 92% of the total is for the copper sulfate.*

Assessment Opportunity

Building towards: 4.B Analyze data to identify patterns in numerical relationships and images to define an optimal proportion of reactants that result in the greatest temperature change and greatest conversion to products.

What to look for: Refer to the Key Ideas box above.

What to do: If students are struggling to connect what they see with the remaining solids and liquids after the reaction to their temperature change results, draw attention to the reaction equation and pose questions, such as these:

- What did the reactants look like before?
- How does that compare to what is left afterward?
- How does the pattern in appearance of the products (what is left afterward) correlate with the temperature change pattern?

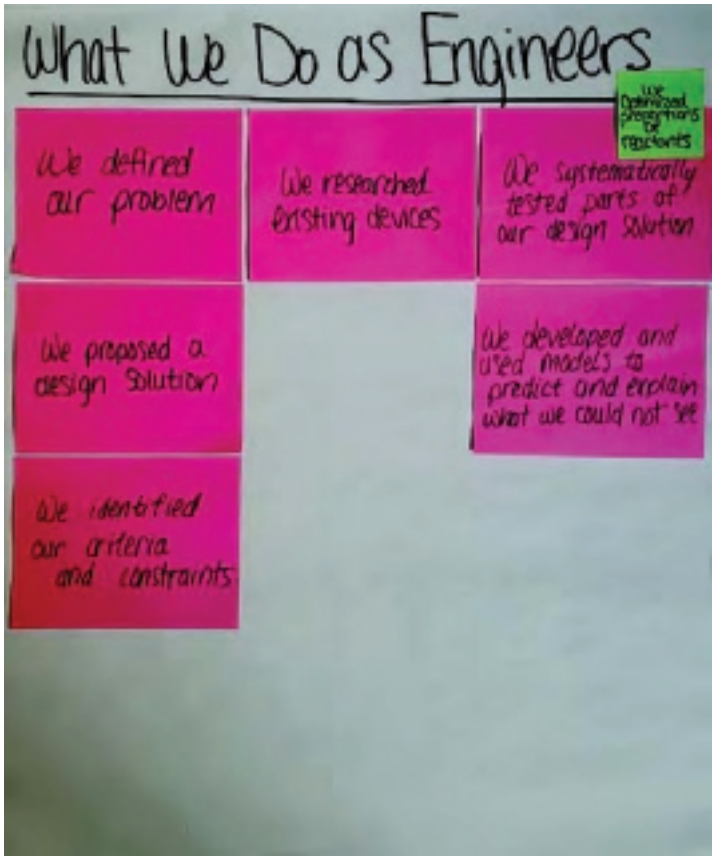
6. Update our Progress Trackers.

5 MIN

Materials: science notebook, What We Do as Engineers board, sticky notes, markers

Update Progress Trackers. Display **slide O** and have the What We Do as Engineers board visible. Direct students to the Progress Tracker section of their science notebook. Ask students what part of our What We Do as Engineers board we have been working on. Listen for students to say "systematically testing parts of our design solution." Ask students to add what they have figured out through that systematic testing on the right side of their Progress Tracker. Add a 3" by 3" sticky note to the What We Do as Engineers board that indicates that we systematically tested "proportions of reactants." See the example Progress Tracker here, including possible student responses.

What did we do as engineers?	What did we figure out that can help us with our designs?
We systematically tested parts of our design solution (proportions of reactants).	• The best combination of reactants is 8% Al and 92% $CuSO_4$.



7. Revisit reflections on instructions and identify stakeholders.

12 MIN

Materials: science notebook, What We Do as Engineers board, Word Wall, sticky notes, markers

Turn and talk about reflections on instructions. Display **slide P** and ask students to turn to the Instructions Reflection they completed last time in their science notebook.

Say, *We've figured out that the amount of energy transferred out of this reaction depends not just on the total mass of reactants but also on the proportion of reactants. To figure that out, we followed a set of instructions to conduct an investigation. Turn and talk with a partner about your reflections.*

Conduct a brief share out. After partners have had a couple minutes to discuss, conduct a brief share out of ideas.

Suggested prompts	Sample student responses
Why is it so important to have instructions that are clear and easy to follow?	*If the instructions are confusing, the thing you are trying to do might not work.* *If you are working with chemicals and the instructions are not clear, you could get hurt.*
What kinds of things make instructions clear and easy to follow?	*Pictures and diagrams.* *An overview of what needs to be done.* *Numbered steps.* *Using simple and descriptive language.* *Specific amounts.*
Clear and easy-to-use instructions was something we added to our Criteria and Constraints list back in Lesson 1. Who will be trying to follow our homemade heater instructions?	*The people at home who want to heat up their food.* *People needing warm food during a natural disaster.* *We will try to follow our own instructions, and other groups may also try them.*

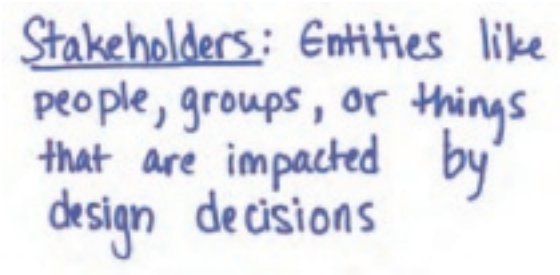
Revisit a definition of *stakeholders* from *Unit 6.5: Where do natural hazards happen and how do we prepare for them? (Tsunami Unit).* Say, *OK, we mentioned all these things that we want our instructions to do and we identified some potential users of our instructions and designs. Remember when we talked about these types of users as well as other people who might be affected by our designs in Tsunami Unit, we called them "stakeholders." Let's think a little bit more about all the stakeholders that might exist for our homemade flameless heater designs.*

Suggested prompts	Sample student responses
Who will benefit from using these homemade heaters?	*People who will get to eat warm food will benefit.* *People caught in snow storms or other natural events.* *People who may not have access to a stove.*
Great! What else might be important to the people building and using these homemade heaters?	*It should not be difficult to make them.* *It should be easy to get materials.* *Cost.* *They should be safe to use.*

Suggested prompt	Sample student responses
Let's think about nonuser stakeholders. Are there any other people or even things that will be impacted by our homemade heater design?	*the environment* *emergency organizations, like FEMA* *recycling centers* *landfills* *places that sell the root killer, like gardening places* *companies that make root killer*

Add *stakeholders* to the Word Wall. Say, *So it sounds as though there are potentially both positive and negative effects possible for stakeholders. They don't always benefit from a design, so can we use the word "impacted"?*

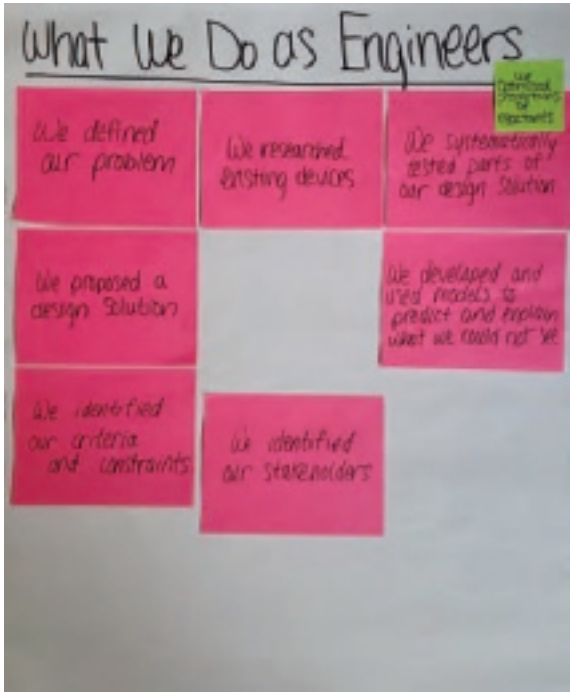
It's a little more general and could be positive or negative. And based on what we know from Tsunami Unit and what you all said about our homemade heaters, it seems like a stakeholder is not always an individual person either. We also named groups of people, like businesses or companies, and even things like the environment that could be stakeholders.



Update our Progress Tracker to include what we've learned about identifying our stakeholders. Have the What We Do as Engineers board visible. Say, *Engineers refer to the people or things that are impacted by design decisions as stakeholders. Let's see if we can specifically identify our stakeholders for this design and add this to our Progress Tracker.* Show **slide Q**. Direct students to the Progress Tracker section of their science notebook and update the What We Do as Engineers board in the moment with a 4" by 6" sticky note that says "we identified our stakeholders."

Suggested prompts	Sample student responses
What should we record in our tracker? Who exactly did we identify were the stakeholders for this particular design?	*People who want to eat warm food.* *People who will be buying the supplies. People who are making the heaters.* *(Possible others mentioned previously.)*
Great, go ahead and keep track of that in your Progress Tracker. This is such an important idea, so I'm also going to add this to our Word Wall. Can someone help me come up with a definition for stakeholder that we could use for any project, not just this one?	*People who would use whatever you are designing.* *People who would get help from what you are designing.* *People who would get jobs making or selling what you design.* *Companies that could make or sell the product.* *(Possibly: The environment that would be impacted by resource use or energy use from producing (maybe disposing, recycling) the materials.)*

What did we do as engineers?	What did we figure out that can help us with our designs?
Identified stakeholders	Our stakeholders are • a person buying supplies and making the heaters, • a person eating the food heated up by the heater, • the environment (if students bring it up—not critical), and • nonusers who might be affected by use or disposal (if students bring it up—not critical).



8. Discuss stakeholder preferences and assign home learning.

8 MIN

Materials: Safe Minimum Cooking Temperatures Chart (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Discuss how we can figure out stakeholder preferences. Show **slide R** and have students turn and talk with a partner about what questions they would find useful to ask a stakeholder. Say, *It seems like we've identified who our stakeholders will be for our designs. We had some thoughts about what might be important to them, but how can we be sure? Is there a way we can really find out what's most important to them? What questions would you ask?*

Gather and refine questions to ask stakeholders. Conduct a brief discussion to compile questions to create a Stakeholder Survey specific to your classes. Say, *You all have some great ideas! Let's get these ideas out on the table and then we can create a survey that we can use with our stakeholders.*

Suggested prompt	Sample student responses
What did you and your partner talk about? What questions will be important to ask stakeholders about?	*What's most important to you about building and using a flameless heater?* *Do you know what a flameless heater is?*

Suggested prompts	Sample student responses
So it seems like our stakeholder questions are a little generic or vague. How can we gather more-specific feedback? Which parts or aspects of our homemade heater designs should we ask our stakeholders about?	*How fast the food heats up.* *How easy it is to make.* *How easy it is to get the supplies.* *How easy it is to use.* *How safe it is.*
Looking at our criteria and constraints, is there anything else that we should ask about?	*How much would you pay to build a flameless heater?* *How hot would you want your food to be?*

Create Stakeholder Survey. Refer to *Student Electronic Surveys: Why + How-To* from Lesson 1 to create a Stakeholder Survey for your classes. Using Google Forms (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), add the first class's questions to the "Questions" page on the form. With subsequent classes, make sure to conduct the discussion before opening the survey and then refine existing items or add new items as they come up. Say, *I have this survey template that I thought we could use to compile all the classes' survey ideas together. Let's take the items that we just talked about and add them to it. Each class will add to this throughout the day, and we can all collect stakeholder feedback with this single survey. This will provide us with a wide range of stakeholder input that can help inform our designs.*

Home Learning Opportunity

Here are some things to keep in mind as you create your survey:

- It is recommended to have no more than 4 to 5 questions.
- Try to focus questions on parts of the flameless heater and aspects of its use.
- See this example—survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)—for ideas, but use specific ideas from your class conversations.

Let students know that they have some time to conduct this survey. The survey results will be referred to at the beginning of Lesson 5, but students can continue administering the survey until Lesson 6. During Lesson 6, we will dig deeper in our survey data in order to inform our design prototypes and instructions. Students can share the survey with stakeholders in a variety of ways, including sharing the link, recording responses on their own device, or recording responses on a paper copy of the survey.

Assign Stakeholder Survey as home learning. Show **slide S**. Share the survey link with your students and ask them to use it to survey potential stakeholders in their lives (friends, family, household members, neighbors, and so forth). See *Student Electronic Surveys: Why + How-To* for more information about how to share the survey link with students.

ADDITIONAL LESSON 4 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.6.RP.A.3.C Find a percent of a quantity as a rate per 100 (e.g., 30% of a quantity means 30/100 times the quantity); solve problems involving finding the whole, given a part and the percent.

In this lesson, students determine the relative proportion of each reactant that showed the optimal temperature change by calculating the percentage of each reactant.

SCIENCE LITERACY: READING COLLECTION 2

The Heat Is On

1 **Exothermic and Endothermic Reactions**
2 **Chemistry Club**
3 **Thawing Out Ice Melt Myths**
4 **Never Mix These Chemicals**
5 **The Exo Expo**

Literacy Objectives

- ✓ Read to find out how chemical reactions produce or absorb heat.
- ✓ Read to learn practical uses of chemical reactions.
- ✓ Compare exothermic and endothermic reactions.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 3–4.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Write a narrative about an exothermic reaction caused by mixing household chemicals in response to the reading.

Instructional Resources

Student Reader

Collection 2

Science Literacy Student Reader, Collection 2
"The Heat Is On"

Exercise Page

EP 2

Science Literacy Exercise Page
EP 2

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 3: What other chemical reactions could we use to heat up food?
- Lesson 4: How much of each reactant should we include in our homemade flameless heater?

Standards and Dimensions

NGSS

MS-PS2-3: (Building toward) Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Disciplinary Core Ideas

PS1.B: Chemical Reactions

Science and Engineering Practice(s): SEP; Analyzing and Interpreting Data

Crosscutting Concept(s):

CCSS Cause and Effect

English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

CCSS.ELA-LITERACY.W.7.3

Write narratives to develop real or imagined experiences or events using effective technique, relevant descriptive details, and well-structured event sequences.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

endothermic reaction **exothermic reaction**

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

product **reactant**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page

EP 2

2. Preview the assignment and set expectations. (Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Chemical Reactions and Energy unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *In "Exothermic and Endothermic Reactions," you will learn the difference between chemical reactions that release energy and those that absorb energy.*
  - *In the second selection, you'll read about lots of different ways we experience chemical reactions every day.*
  - *"Thawing Out Ice Melt Myths" shows how chemical reactions can make driveways and roads safe.*
  - *In "Never Mix These Chemicals," you'll find out about how mixing certain household products can be hazardous.*

- *The final selection presents works of art that have been created to show exothermic chemical reactions.*

- Distribute Exercise Page 2. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a narrative about creating a chemical reaction by mixing common household products.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What are some benefits of chemical reactions to humans?	*Chemical reactions can be used to clean surfaces, melt ice, and cook food.*
What are some dangers of chemical reactions to humans?	*Mixing certain chemicals can cause explosions, burns, or choking fumes. They can be hazardous to your health and safety.*
What benefits of chemical reactions have you experienced?	*Soap removes dirt from hands and clothes.* *Baking soda makes cakes rise.* *Fireworks are pretty.*
Have you ever had a negative experience with a chemical reaction? If so, what was it?	*When I mixed vinegar and too much baking soda in a candy recipe, it boiled over and I got burned.* *I left my shiny, new bike outside for a long time, and it got covered in rust.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
Why is it important to follow a trusted recipe when baking waffles?	*If there is too much baking soda or salt, the batter could expand out of the waffle iron when cooking it.* *If there is not enough baking soda or salt, the waffle will not rise.*
What reactants have you used when creating chemical reactions?	*salt and baking powder for making pancakes* *soap and water to wash away grime* *adding heat to eggs* *breathing in oxygen and breathing out carbon dioxide*

SUPPORT—Have students watch a video that uses time-lapse video to watch a chemical reaction.

- Refer students to the Exercise Page 2. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to write a story about mixing household products that create a safe chemical reaction.*
  - *In the selections, you read about common household chemicals that can have a bad reaction when mixed.*
  - *Come up with a story about a chemical reaction from mixing common household chemicals. Your story can be funny or scary. It can be true or fiction.*
  - *Make sure the climax of your story involves a chemical reaction that explains the reactants and the products of the reaction so that others can learn from your story.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 2

4. Facilitate discussion.

(Friday)

Facilitate class discussion about the reading collection and writing exercise.

The five reading selections help to explain how chemical reactions, including endothermic and exothermic reactions, are used in everyday life.

Pages 14–15 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "Exothermic and Endothermic Reactions"?	*It explains the difference between two different types of chemical reactions.*
What is the difference between an endothermic and an exothermic chemical reaction?	*Endothermic reactions absorb heat.* *Exothermic reactions release heat.*

Student Reader

Collection 2

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 14–15 Suggested prompt	Sample student responses
What are some examples of endothermic and exothermic reactions?	*Endothermic reactions:* *cooking an egg* *baking cookies* *Exothermic reactions:* *setting off fireworks* *lighting a match* *rusting metal*

SUPPORT—Break the words *endothermic* and *exothermic* into their word parts. Explain that *endo* is from a Greek root that means "internal" or "inside." Contrast that with *exo,* a Greek root that means "outside." The Greek root *therm* means "heat" or "warm." Challenge students to think of other words with these roots.

Pages 16–17 Suggested prompts	Sample student responses
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first selection was about defining endothermic and exothermic reactions. The second selection gives examples of the two types of chemical reactions.*
How does making a pizza involve endothermic reactions?	*In the hot oven, the dough absorbs heat, which causes the dough to rise.*
How is making ice a physical change that is exothermic, while melting ice is an endothermic physical change?	*When making ice, water releases its heat and changes from a liquid to solid (or water to ice).* *When melting ice, water absorbs heat and changes from a solid to liquid (or ice to water).*

CHALLENGE—Have interested students research where salt comes from, how so much of it is available to be used on icy roads, and how much it lowers the freezing point of water. Have them find out the difference between rock salt and table salt. Ask them to report their findings to the class.

Pages 18–19 Suggested prompts	Sample student responses
What is the general purpose of the third article, "Thawing Out Ice Melt Myths"?	*It explains how using salt to melt ice helps keep icy roads safe in winter.*
How does salt help keep roads safe?	*Ice forms when the temperature of water reaches 32 degrees Fahrenheit or 0 degrees Celsius. Road salt lowers the freezing point of water and makes it more difficult for water to freeze.*
Why do you think salt is used in making homemade ice cream?	*Salt lowers the freezing point of ice, causing it to melt and making the ice colder. Being colder enables the cream and sugar to create ice cream.*

EXTEND—Have students watch a video that shows how ice cream is made, demonstrating how salt affects the freezing and boiling points of water.

Pages 20–21 Suggested prompts	Sample student responses
What is the general purpose of the fourth article, "Never Mix These Chemicals"?	*It describes how mixing some common household chemicals can be dangerous.*
What household products do you have in your house that could be hazardous if mixed with other chemicals?	*bleach, vinegar, ammonia, hydrogen peroxide, rubbing alcohol, baking soda*
What should you do if someone accidently mixes the wrong chemicals together?	*Get fresh air if there are fumes.* *Change your clothes if the mixture is spilled on them.* *Wash your skin with lots of water.* *Get medical attention if your skin is burned or if you get the chemicals in your eyes.*

Pages 22–23 Suggested prompts	Sample student responses
How does the last selection relate to the other selections in this collection?	*It helps you think about how chemical reactions can be works of art.*
Why would artists create artwork that shows chemical reactions?	*Chemical reactions can be beautiful, stunning, and surprising.* *Some chemical reactions produce beautiful colors or interesting effects.*
Do the artworks in this selection represent endothermic or exothermic reactions?	*All are exothermic reactions, giving off energy.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 2, students will write a story about a chemical reaction that is caused by mixing the wrong household chemicals. It should be engaging and provide a lesson to others.

Use the rubric provided on the Exercise Page to supply feedback to each student.

LESSON 5

How can we refine our criteria and constraints?

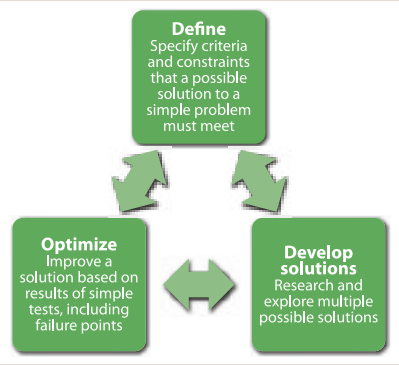
Previous Lesson

We planned and conducted an investigation to determine which proportion of reactants will work best to heat up our food. Then, we reflected on what makes good instructions and identified our stakeholders. Finally, we administered a survey to our potential stakeholders to figure out what aspects they find most important.

This Lesson

Putting Pieces Together, Investigation

1 DAY



In this lesson, we review the Stakeholder Survey results and decide we need to figure out what temperature we want our food to reach. We analyze readings about food temperatures to revise our criteria and constraints. We also determine the optimal solution for our homemade flameless heater, including total cost and mass for our homemade flameless heater design. We reorganize and refine our What We Do as Engineers board to reveal the cyclical process of engineering design.

Next Lesson

We will work in teams to revise our designs for our homemade flameless heaters. We will build prototypes and test them using a Design Testing Matrix based on our criteria and constraints. We will reflect on our work with self-assessments of our engineering work and our teamwork.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

5.A Analyze data by identifying patterns to define an optimal operational range for our homemade flameless heater designs that best meets criteria for success because 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.

What Students Will Figure Out

- Our optimal solution needs to
  - cost no more than $12 ($3 for the heater),
  - have a total mass of less than 700 grams, and
  - heat food to 40–47°C.
- Engineers use a cyclical process (Define, Develop, Optimize) to design solutions.

Lesson 5 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Reflect on the Stakeholder Survey conducted in Lesson 4 and consider what else we need to know to inform our designs.	A	
2	10 min	**OBTAIN INFORMATION ABOUT FOOD TEMPERATURE FROM VARIOUS SOURCES** Obtain and discuss food temperature information from readings to narrow down a target temperature range for their designs.	B-C	*Reading: How hot does food need to get so that people do not get sick?*, *Reading: What temperatures cause scald burn injuries?*, *Reading: What temperature range makes food enjoyable to eat?*
3	5 min	**DEFINE A TARGET FOOD TEMPERATURE RANGE** Use existing data to discuss and define a target food temperature range for our designs.	D	*Reading: How hot does food need to get so that people do not get sick?*, *Reading: What temperatures cause scald burn injuries?*, *Reading: What temperature range makes food enjoyable to eat?*
4	12 min	**REVISE INITIAL CRITERIA AND CONSTRAINTS CHART** Remain in Engineers Circle to use the information collected about food temperature to revise and reorganize the Criteria and Constraints chart to keep track of our optimal design features.	E-H	Criteria and Constraints chart from Lesson 1, chart paper, markers, scale, all parts of the prepackaged MRE from Lesson 1
5	8 min	**ORGANIZE THE CLASS-LEVEL WHAT WE DO AS ENGINEERS BOARD** Update our Progress Tracker, reflect on what we have done so far, and organize the class-level What We Do as Engineers board.	I	What We Do as Engineers board, 3 x 3" sticky notes, markers
6	5 min	**NAVIGATION** Think about what steps to take next in order to efficiently plan and revise our homemade heater designs.		Criteria and Constraints table, What We Do as Engineers board, markers

End of day 1

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages** 	• science notebook	• *Reading: How hot does food need to get so that people do not get sick?* • *Reading: What temperatures cause scald burn injuries?* • *Reading: What temperature range makes food enjoyable to eat?*	• Criteria and Constraints chart from Lesson 1 • chart paper • markers • scale • all parts of the prepackaged MRE from Lesson 1 • What We Do as Engineers board • 3 x 3″ sticky notes • Criteria and Constraints table

Materials preparation (30 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

If you want to do fewer readings, you can print only the first page of *Reading: What temperature range makes food enjoyable to eat?* and use the data table for analysis.

Be sure that you have materials ready to add the following words to the Word Wall: *trade-off*, *optimize*. Do not post these words on the wall until after your class has developed a shared understanding of the meaning of the words.

Decide how you will arrange your classroom to allow for the Engineers Circle so all students can see one another and the centrally located space where the charts are posted.

Be sure you have materials ready to add to the What We Do as Engineers board. This includes 3″ x 3″ sticky notes and a marker.

Make sure a scale and the prepackaged MRE you saved from Lesson 1 are easily accessible so that you can weigh the total MRE at the end of this lesson. After weighing, check the food packages from the MRE. If they are damaged, punctured, or opened, discreetly dispose of them (after students have left the room). If the food packages are sealed, keep them for next year (to the date indicated on the package) or follow your school's policy or procedure to send the food home with a student who wants it.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

In the previous lesson, students identified an optimal proportion of reactants and identified and began surveying stakeholders about the most important design aspects. In this lesson, a preliminary review of survey results gets students wondering to what temperature food should be heated. This leads students to refine the criteria and constraints they listed in Lesson 1 and define an optimal solution that includes food temperature, cost, and mass. They reflect on the work they have been doing as engineers and revise the What We Do as Engineers board into a cyclical process that can be used going forward.

Where We Are NOT Going

Students will not do a thorough analysis of the Stakeholder Survey results until Lesson 6. It is not important to focus on concerns about foodborne illness because students conclude that stakeholder-users will heat ready-to-eat food.

LEARNING PLAN FOR LESSON 5

1. Navigation

5 MIN

Materials: None

Recap what we are trying to accomplish with the Stakeholder Survey. Open up and project the data from the Stakeholder Survey that students designed. Say, *Wow, you all are gathering some interesting data. Let's look at what we have so far, but let's keep collecting more responses so we have more data to help us design our prototypes and write our instructions. If you haven't had time to survey many stakeholders, try to gather more data before our next class.*

Turn and talk with a partner. Display **slide A** and have students discuss the question "According to our survey, what do stakeholders say is most important to them?" Return to displaying the class Stakeholder Survey data so that students can use it to discuss.

After a few minutes, have students share patterns that they see in the data.

Suggested prompts	Sample student responses
According to our survey, what parts or aspects of the flameless heater are most important to them?	*Most people thought that things about heating the food—like how hot it gets and how long it takes to get hot—were most important.*
So it seems like the stakeholders care about the temperature that our devices will be able to heat food up to. They want hot food. I'm wondering, what do you think they mean by "hot food"? How hot is hot?	*Hot enough to taste good but not burn you.* *Probably not boiling.*

2. Obtain information about food temperature from various sources.

10 MIN

Materials: science notebook, *Reading: How hot does food need to get so that people do not get sick?*, *Reading: What temperatures cause scald burn injuries?*, *Reading: What temperature range makes food enjoyable to eat?*

Transition to thinking about ways to obtain more information about food temperatures. Say, *So it looks like our stakeholders have given us information like they want their food to be warm, be safe to eat, not burn them, et cetera, but what exactly is warm enough?*

Suggested prompt	Sample student response
How can we figure out the food temperature we should be aiming for when we design our flameless heaters? What other information do we really need?	*We probably need to find some information about the best temperature for the taste of food and for safety.*

*** Attending to Equity**

Universal Design for Learning. Asking students to annotate the readings with symbols or tags can help students manage information so that they can express their understanding. Students may need additional support in obtaining information from the provided readings. Consider including any of the following options to support

Suggested prompts	Sample student responses
When you say "safety" it seems like you are talking about burn protection. Are there any other safety concerns we need to learn more about?	*I think you might need to cook food to a certain temperature to make sure you don't get sick if there is bacteria or something in your food.*
How might we get this information?	*We could taste the food at several different temperatures and rate what temperature makes it taste best.* *We could do an investigation and ask people at what temperature their food tastes best.* *It probably isn't safe to try eating food at different temperatures to find out if bacteria would make you sick, but I bet we could do some research about food safety and how to make sure food doesn't make you sick.* *We could also look up temperatures that are dangerous and could cause burns … that is also probably not safe to test.*
Where are some reliable places we could check to look up some of that information?	*Maybe government health websites like the CDC.* *Isn't there a government body that oversees food safety … the FDA?*

Read and annotate sources to find information that will define our target temperature range.* Say, *You all had some great ideas about ways to investigate the temperature range at which food tastes best. Unfortunately, since this is a science lab, we need to maintain our safety protocols and can't eat food in the lab. However, I collected some information similar to what we might have investigated in class and other information from sites like you just suggested.*

Organize students into groups of 3 and distribute the readings *Reading: How hot does food need to get so that people do not get sick?*, *Reading: What temperatures cause scald burn injuries?*, and *Reading: What temperature range makes food enjoyable to eat?*. Assign each member one of the readings and instruct them that they are responsible for reading and reporting on that resource to their group. Remind students that the purpose of this reading is to figure out the temperature range at which we want the food heated by our homemade heaters to be.

Show **slide B**. Say, *Based on our last discussion, it seems like these are the three main questions we think we need to answer in order to define our target temperature range.*

1. *What temperature is too hot?*
2. *Does food need to get to a certain temperature to avoid illness?*
3. *How warm does food need to get for people to enjoy the taste?*

students who read below grade-level:

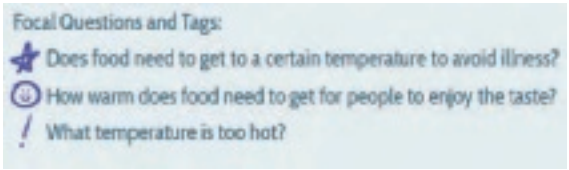
- Have students work with a partner as they read and annotate their assigned reading.
- Strategically assign particular readings based on student reading level and interest. Alternatively, assign only the first page of handout or student reference *Reading: What temperature range makes food enjoyable to eat?*, which includes only the taste test results in table form, to students who may benefit from focusing on just the visual display of data.
- Provide a checklist with the 3 focal questions and their tags for students to use as they read. See **slide B**.
- Allow for a competent aide, partner, or "intervener" to read the text aloud.

*** Supporting Students in Engaging in Obtaining, Evaluating, and Communicating Information**

When students are working on their own, check in with individual students and notice whether they are identifying and noting the central ideas to answer one or more of the focal questions. If students are not adding notations or if they are using a lot of time to annotate parts of the reading

Underline or use arrows to highlight important information in your reading and then tag it using these symbols to note which question the information is helping us answer. Add any other notes or questions you have as well. *

Share information in small groups to answer focal questions about food temperature. Display **slide C** after students finish their individual work and ask small groups to systematically discuss each focal question and record in their notebook what they have figured out. They should take turns sharing the information that each group member learned that helps answer the focal questions.



not directly related to the focal questions, direct them to the slide and encourage them to focus on using the tags to be specific about the information they want to report to their small group.

Assessment Opportunity

Building towards: 5.A.1 Analyze data by identifying patterns to define an optimal operational range for our homemade flameless heater designs that best meets criteria for success because 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.

What to look and listen for:

- Individual student notations, including tags, that align to the three focal questions
- Students using what they learned to build on the information presented by teammates that was obtained across the three resources
- Students using patterns they have identified to define upper and lower limits of the temperature range to which the food should be warmed

What to do: Circulate during individual work time and remind students to use the tags and question prompts to focus their reading and notes. Consider providing a checklist with the focal questions and symbols (as shown on **slide B)** for students to check off as they read. As students are sharing information in small groups, encourage them to use the specific notes they recorded to contribute to the small-group discussion. As you circulate, use the question prompts to keep student conversation moving forward.

3. Define a target food temperature range.

5 MIN

Materials: science notebook, *Reading: How hot does food need to get so that people do not get sick?*, *Reading: What temperatures cause scald burn injuries?*, *Reading: What temperature range makes food enjoyable to eat?*

Define a target temperature for the food that our homemade heaters will warm up. Bring students to the Engineers Circle with their science notebook and something to write with. Display **slide D** and facilitate a Consensus Discussion to bring Key Ideas to the surface that help answer each focal question:

1. What temperature is too hot?
2. Does food need to get to a certain temperature to avoid illness?
3. How warm does food need to get for people to enjoy the taste?

Key Ideas

Purpose of this discussion: Students will use the information they learned from examining survey data and informational resources to come to consensus on the optimal temperature range to which food should be heated by the homemade heaters we design.

Listen for these ideas:

- Because we'll use ready-to-eat food, we don't need to worry about heating it so hot as to kill any bacteria (as long as the package of food hasn't been opened).
- Temperatures of 48°C and above could seriously injure someone.
- All people surveyed agreed that 40°C was a temperature warm enough for food to taste good.

Suggested prompts	Sample student responses
What did you learn about our first focal question: What temperature is too hot?	*We had data showing that food that was 48° C can burn someone badly, so we probably don't really want the food to get that hot.*
I know some of us were worried about making sure we could kill anything that might make us sick. What about our next focal question: Does food need to get to a certain temperature to avoid illness?	*Well, we would need to get food really hot to kill bacteria if we were cooking raw food.* *Since the food we are heating up is ready to eat, we could actually eat it at any temperature as long as we don't leave it out for too long after opening it.*
OK, so it looks like our maximum temperature should be under 48°C, so let's say 47°C. What about the lower end of our temperature range? How warm does food need to get for people to enjoy the taste?	*We read a source that said food actually tastes better when it is warm because of the way that different kinds of taste buds work at different temperatures.* *Data from a tasting survey showed that the minimum temperature at which all of the people said the food tasted good was 40° C.*

Assessment Opportunity

Building towards: 5.A.2 Analyze data by identifying patterns to define an optimal operational range for our homemade flameless heater designs that best meets criteria for success because 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.

What to look for: See Key Ideas above.

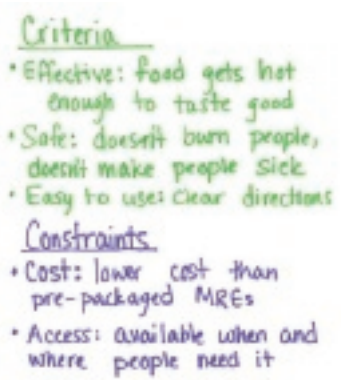
What to do: If students struggle to identify the Key Ideas, cue them to look back at the annotations on their readings and identify places where they used specific symbols. Refer to **slide B** as needed to remind students of the symbols and associated focal questions.

4. Revise initial Criteria and Constraints chart.

12 MIN

Materials: Criteria and Constraints chart from Lesson 1, chart paper, markers, scale, all parts of the prepackaged MRE from Lesson 1

Organize the criteria we need to consider for our design solutions. Draw students' attention to the initial Criteria and Constraints chart that was created in Lesson 1. Say, *Now that we have a more-specific idea about the range of temperature to which food should be heated, we should update our list of criteria and constraints. But now, after looking at this chart, it seems like we have a lot of different ideas we are going to need to consider. It seems like it would be easy to get too focused on one of these criteria or constraints while accidentally ignoring others. Let's reorganize this list so that we can keep track of all our criteria and constraints.*

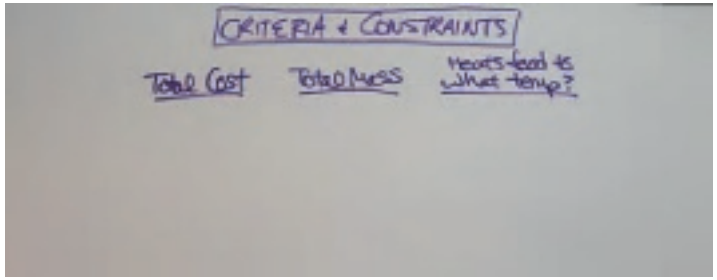


As the discussion unfolds, use a new sheet of chart paper (posted in landscape orientation) to create a table using the headings that students suggest.

Suggested prompts	Sample student responses	Follow-up questions
Let's consider our stakeholders, and remember, our stakeholders are entities who are impacted by our design decisions. If people are not able to get these materials, will it even matter how well our homemade heater design works? What do we need to consider to make sure everyone who needs these will be able to get them?	*We need to make sure people can afford them.* *We need to make sure the materials are easy to get and not too expensive.*	*So one category we need to consider is cost, right?*
OK, so people need to be able to afford these materials, but we need to also keep in mind that they might not have cars, and they might have to be carrying a crate full of supplies to make them or keeping a crate of supplies in the trunk of their car so they can be prepared.	*Yes, so maybe we should have some limits on weight, too, then.*	*All the supplies could get pretty heavy. How could we make sure people could still carry them?*

Suggested prompt	Sample student response	Follow-up question
We just did some work figuring out the temperature criteria, so it's probably important to keep track of that as well. We originally said that our homemade heater had to actually heat food. Can we add anything more specific to that now?	*Yes, we want it to be able to warm food to somewhere between 40°C and 47°C.*	*OK, you've given me a range of temperatures. What would the heading of that category be?*

Add a row that describes the characteristics of our optimal solution. Say, *OK, we know these are some things we should think about in our designs. Our goal is to come up with an optimal solution so people can successfully use our designs. If we design an optimal solution* (label the row "optimal solution"), *what would be the specific targets for these criteria and constraints? Let's start with food temperature since we just talked about that. What is the temperature range we identified?* Write "40–47°C" under the "Heats food to what temp?" category.



Decide as a class the constraints we want to define for cost. Use ideas about what we think our stakeholders will want and need to decide as a class what a reasonable cost would be.

Say, *How should we decide what the specific constraints should be for cost? We looked at some data in Lesson 1 about how much it would cost to buy a premade MRE. Let's check out a range of prices for MREs.* Display **slide E**.

Suggested prompts	Sample student responses
What do you notice about these prices?	*There is a wide range of prices—anywhere from about $12 to $25. Most are around $20.*
Cost is probably an important factor for our stakeholders. How can we make sure that our homemade MREs are a better choice cost-wise compared to prepackaged MREs?	*To be the lowest cost option we should try to make the cost less than the lowest price of the prepackaged MREs.*
According to these prices, how much does the food alone cost?	*The one with the heater not included says $9.75.*
OK, let's reserve about $9 for the food. What is the cheapest cost listed for a full MRE—heater plus the food?	*The 12 pack is the cheapest, $11.83 per MRE with a heater.*
Rounding to the nearest dollar that's about $12 per MRE, so let's make our total cost of heater plus food less than $12. If we reserve $9 for food and our total cost limit is $12, how much money do we have left for our heater cost? How did you figure that out?	*Total cost is $12 minus $9 for food equals $3 left over for the heater.*

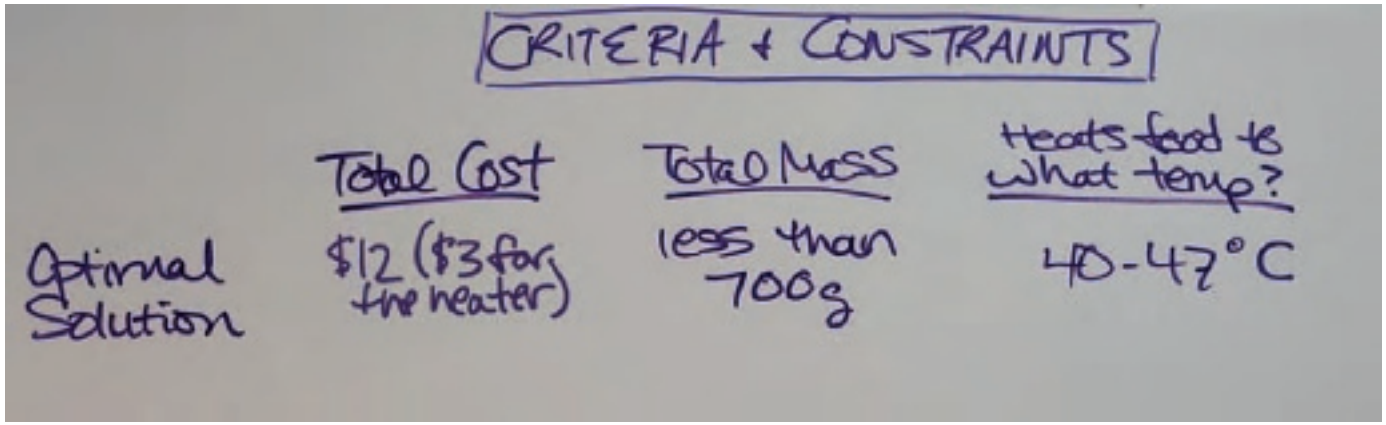
Record these values in the "cost" column of the "optimal solution" row.

Decide as a class how we should limit weight. Display **slide F**. Continue using our stakeholders to think about the criteria and to decide as a class what constraints we need to place on our design solutions with regard to weight. Say, *We are now left to think about our total mass.*

Turn and talk about the questions on the slide. Monitor student conversations and listen for suggestions to weigh the MRE.

Suggested prompts	Sample student responses
How is the weight of our MRE going to affect our stakeholders?	*People are going to have to carry a box of supplies to make these for their families, or they are going to have to fit it in a box to store in the trunk of their car.*
How could we figure out how much a store-bought MRE weighs?	*We can just put the MRE that we have on a scale.*
What might be a good way to constrain the mass of our homemade MRE?	*Well, for cost we wanted to make sure they cost less than the premade MREs you could buy, so maybe we could say we don't want these to weigh more than the premade MREs do.*

Weigh the premade MRE. Place the entire MRE on the scale and read the mass. Say, *It looks like this MRE has a mass of about 700 grams. That's about one and a half pounds. Since we said we want our homemade versions to weigh the same or less, let's make sure to stay under the total mass of the premade MRE.* Add this value to the new Criteria and Constraints table.



Say, *If we need to stay within this constraint for weight, what does that mean for our homemade heater materials? How much of that do we need to use for the substances we mix together, and how much food could be included? Do we need to think about packaging? How much of the premade MRE's weight was actually just packaging? Remember in Tsunami Unit when we talked about trade-offs? We need some way to consider trade-offs about our total mass without just guessing what's going to work best.*

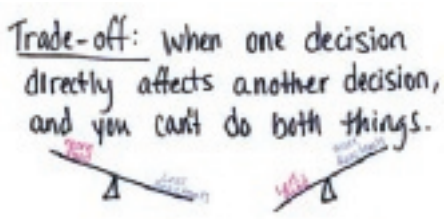
Discuss the trade-off between the amount of food and the amount of reactants. Display **slide G**.

Say, *If our constraint is 700 grams total for the mass of the flameless heater, packaging, and food, we need to figure out how much of that mass we could use for each part. To make our calculations easier for a moment, let's assume that packaging will take up 300 grams of this mass. So that leaves us to consider food and reactants in that 400-gram limit for now.*

Use **slide G** and **slide H** to lead a discussion with the class to help see the trade-off between the amount of food and the amount of reactants.

Suggested prompts	Sample student responses
If we use 400 grams of reactants, how much food could be included in our test?	*None!*
What about if we include 400 grams of food in our test, how much reactants could we use?	*None!*
*(Display **slide H**.) So if we have 300 grams of reactants, how much food can we include?*	*300 grams of reactants leaves 100 grams for food.*
What about if we use 100 grams of reactants?	*100 grams of reactants leaves 300 grams for food.*

Add the word *trade-off* to the Word Wall. Say, *This balancing act is an example of a trade-off. If we add 100 grams of reactants then we have to take away 100 grams of food in order to stay within the 400 grams weight constraint. A trade-off is when one decision directly affects another decision, and you can't do both things. There is a trade-off between how much food we can include and how much reactants we can use and still stay under our weight limit and get our food hot. We're using this a little differently than we did in Tsunami Unit. Let's add it to our Word Wall so that we can be mindful of how we can use trade-offs to inform our designs.*



5. Organize the class-level What We Do as Engineers board. 8 MIN

Materials: science notebook, What We Do as Engineers board, 3 x 3" sticky notes, markers

Update our Progress Tracker to include what we've figured out about criteria and constraints in our designs. Remain in the Engineers Circle and direct students to the Progress Tracker section of their science notebook. Display **slide I**. Say, *Great! This is a big step—we just refined the criteria and constraints for our design. Let's add this to our Progress Tracker and our What We Do as Engineers board.* Add a sticky note to the What We Do as Engineers board that indicates that we "refined" our criteria and constraints.

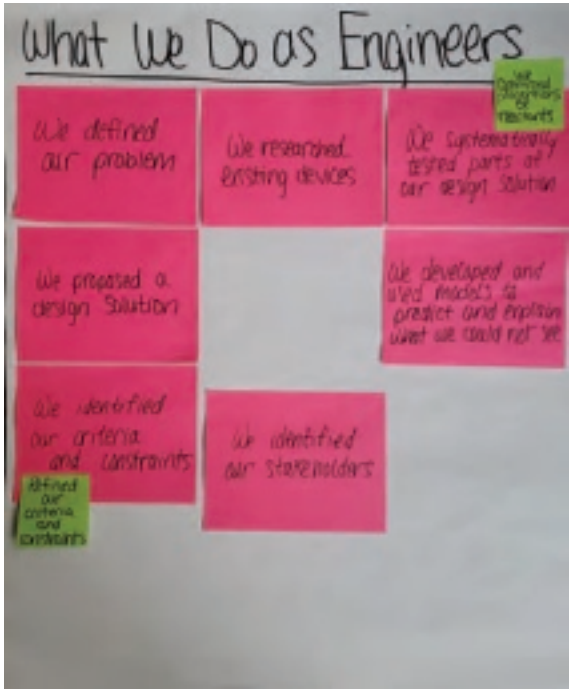
Suggested prompt	Sample student responses
How could we summarize what we have just figured out in our last discussion? What do we need to include in our optimal solution?	*We want the total cost of our design to be no more than $12 and no more than $3 for the heater.* *We want the total mass of our design to be less than 700 grams.* *We want the food to get to a temperature between 40–47°C.*

What did we do as engineers?	What did we figure out that can help us with our designs?
We refined what our solution needs to do.	Our optimal solution needs to • cost no more than $12 ($3 for the heater), • have a total mass of less than 700 grams, and • heat food to 40–47°C.

Organize the class-level What We Do as Engineers board. Say, *Let's take a moment to check in with our What We Do as Engineers board. We've added a few things to our Progress Tracker so far, but before we add them to our board, which seems to be getting kind of full, should we think about seeing if it makes sense to organize these things in some way?*

Turn and talk with a neighbor to see if there is a way to organize these elements. Say, *We've been recording these descriptions of things that engineers do to help us think about this design process. I wonder if it would make sense to organize these in some way that will help us think about this process. Turn to an elbow partner to discuss how you might want to see these organized. If you are having trouble reading the chart on the wall, take a look at the headings in the left column on the Progress Tracker in your science notebook.*

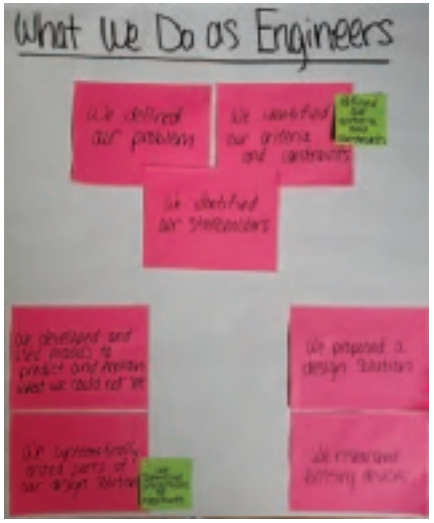
Give students a minute to look at the stickies and discuss, then bring the class back together. Move the sticky notes off the What We Do as Engineers board or off to the side so that there is room on the chart paper to reorganize them.



Suggested prompts	Sample student responses
Does anyone see similarities or patterns in these things that engineers do that jumped out at them?	*There was a group of things that really focused on identifying or defining.*
OK, do you want to come up and pull out the stickies that you think belong in that group? As you are organizing them, read them so that the class can follow along.	*We defined our problem and identified our stakeholders.* *We also identified and refined our criteria and constraints.*
Does everyone agree with that grouping? We have several stickies left over. Do these all go in the same group or are there differences between them?	*When we proposed a design solution based on existing heaters, we did some research to figure out how those worked. It's kind of like we were doing research to develop our ideas.*
OK, do others agree? Let's group those together. What do we have left?	*The two that are left seem to be about testing and figuring out how to make our design better. Through that testing, we figured out what proportion of reactants worked the best.*

Add to the class-level What We Do as Engineers board. Say, *These groups seem reasonable; should we give them headings?*

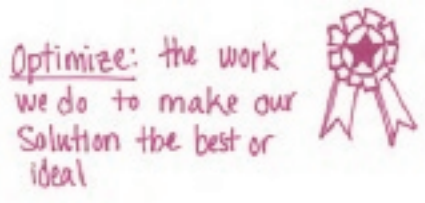
As the discussion progresses and the class decides what to name each heading, record the name above the group of sticky notes.



Suggested prompts	Sample student responses
How would you categorize this top group of stickies?	*It seems like all of those have to do with defining either the problem or what we need to consider about the problem or the solution.*
Great, I heard you mention the word "define," so let's use that as the header for that first category. What about the other groups? If we look at the next category as we move clockwise, what do you think they have in common?	*Someone earlier said they were about figuring out more about the options that already exist. Maybe this category could be "research and development" or "concept development" or something.*
OK, I think that makes sense, so something about how we develop solutions? What about this last category? What does that seem to show?	*It seems like those are things engineers do to find the best version of their ideas. Testing things in a systematic way and developing models seems pretty precise, so it's like they are getting to the final, polished product maybe?*

Suggested prompt	Sample student response
So that group seems to be about improving the solution by developing a plan and systematically testing to get closer to our optimal solution? "Optimize" is the word engineers use to talk about the work they do to make their solution the best it can be. Let's add this word to our Word Wall. What picture or image would make sense to mean to make something the best it can be?	*Maybe a ribbon or trophy?*

Add "optimize" to the Word Wall. Work with the class to build the representation of the word *optimize* for the Word Wall.

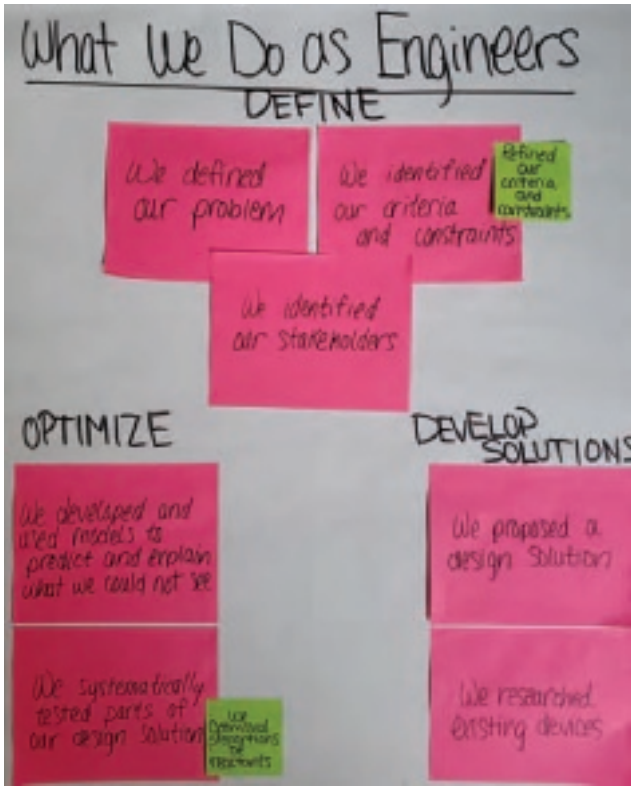


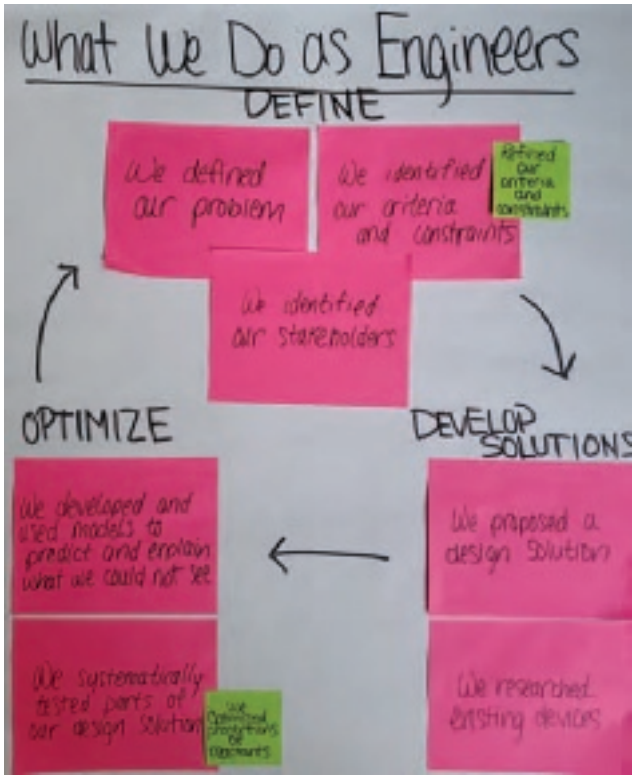
Suggested prompts	Sample student responses
Great! Just now we kind of organized these groups in three corners on our chart—because there wasn't that much room to do much else with them. Maybe we should instead arrange these more in a line? So we have a start-to-finish linear path?	*Well, no, because just today we added more to the "define" group, so maybe this is a cycle that keeps happening until we have a finished product.*
Well, if that is true, maybe we can predict what we need to do next then? Let's test this idea using what we have done so far and see if it follows any pattern or order. Let's start with what we did in Lesson 1—where did we place those elements? Go ahead and refer to your Progress Tracker if you need to remember when we did each element.	*We "defined our problem" and "identified our criteria and constraints," and then we "proposed a design solution" based on what the heaters we saw looked like.*
OK, so in Lesson 1 it looks like we spent some time in "define" and then moved to spend some time also in "develop," but what about Lesson 2?	*We researched two store-bought heaters—we put that in the "develop" category, too, since we needed to learn more about how to develop our own.*
What about Lesson 3?	*We "systematically tested parts of our design solution" and also "developed a model to help us plan how to improve our design." Those are both in that "optimize" group.*
In Lesson 4, it seems like we were still "systematically testing" in the "optimize" category, what else did we do? Where did that go?	*We also "identified our stakeholders," which is in the "define" category.*
OK, we just added what we did so far today to the "define" group also, so it does seem like this is following a specific order, and it does seem like it is a cycle. How could we indicate that on our board?	*We could use arrows to show the path from "define" to "develop" and then from "develop" to "optimize."*

Additional Guidance

The headings for the three categories on the example artifact we show were pulled directly from *NGSS Appendix I*. Students may come up with other words to describe these groups. As long as student ideas for category names are reasonable and conceptually the same, it is better to use the classroom consensus headings than to "force" the language posted on the example artifact. Clarifying questions and talk moves that lift up the key words that students mention as part of their response will be helpful to come to consensus on reasonable descriptors for each group.

Add arrows to the What We Do as Engineers board. Say, *Can I have a volunteer come up to add arrows to this chart?*





Additional Guidance

The chart in *NGSS Appendix I* shows arrows pointing in both directions between these three categories. If students argue for arrows going bi-directionally between any of these categories, and can justify it using what they have experienced, and the class is in consensus, it is OK to show arrows going in both directions between the categories. However, at this point students have only really seen the flow of this process in one direction between each category. There will be an opportunity in future lessons to revise the arrows to indicate that the process is not happening in only one direction.

6. Navigation

5 MIN

Materials: science notebook, Criteria and Constraints table, What We Do as Engineers board, markers

Navigate to Lesson 6 by thinking about next steps. Say, *Now we have a better vision for what our design goals should be, and we have a process for what engineers do, so what's next?*

Suggested prompts	Sample student responses
OK, so far, we've worked in "Define," "Develop" and "Optimize," and today we ended back in "Define" as we worked on refining our criteria and constraints and narrowed down what our optimal design should do. Using this engineering process that we've developed, where should we go next?	*It seems like the next step would be the "Develop Solutions" piece.* *We need to develop designs that meet these criteria and constraints.* *We should do the "design solutions" one again; we should "refine" that one.*
How do we get started on this? Should we just throw some random amounts of chemicals together to heat up random amounts of food? Would that be a responsible use of our resources?	*No, we only have so much stuff to work with, and if everyone is trying a lot of random things, we could run out of materials.* *Even if we had enough materials, we don't want to waste them.*

Say, *Great, that's where we'll go next time!*

Update the table of contents. As a reminder, have students periodically update the table of contents in their science notebook.

ADDITIONAL LESSON 5 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

CCSS.ELA-LITERACY.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).

CCSS.ELA-LITERACY.RST.6-8.10 By the end of grade 8, read and comprehend science/technical texts in the grades 6-8 text complexity band independently and proficiently.

In this lesson, students read grade-level appropriate informational text in order to refine the criteria of their homemade flameless heaters. Students must integrate the information found in the texts and their accompanying charts and graphics and cite specific textual evidence to support their decisions about the criteria for the homemade flameless heaters.

LESSON 6

How can we redesign our homemade flameless heater?

Previous Lesson

We reviewed Stakeholder Survey results and decided to figure out what temperature we want our food to reach. We analyzed readings about food temperatures and revised our criteria and constraints. We also determined the optimal solution for our flameless heater, including cost and mass. We reorganized and refined our What We Do as Engineers board to reveal a cyclical process.

This Lesson

Investigation

3 DAYS

After a discussion about available packaging materials and what our how-to instructions should be like, we get into teams and revise our designs for our homemade flameless heaters. After our teacher checks our plans for safety, we build prototypes and test them using a Design Testing Matrix based on our criteria and constraints. We reflect on our work with a self-assessment of how well our team works together as engineers and how well we individually met expectations as teammates.

Next Lesson

We will compare our flameless heater designs with other teams and identify the most promising design characteristics. We will realize that we don't know how to evaluate how easy our designs are to follow because we never had anyone else besides our own design team put them together.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

6.A Undertake a design project to construct and test a solution that meets specific design criteria and constraints, including the transfer of energy.

6.B Apply scientific ideas, results from testing designs, and the interactions identified on system models to modify our designs in order to improve the flow of energy to food.

What Students Will Figure Out

- Designs need to be tested to inform modifications that will lead to a better solution.
- Different kinds of models are helpful for testing design solutions.
- The instructions we write to help people build a heater are critical to the success of the solution.

Lesson 6 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**REVISIT OUR WHAT WE DO AS ENGINEERS BOARD AND PROGRESS TRACKERS** Review Progress Tracker entries from last time to navigate into today's work.	A	What We Do as Engineers board
2	12 min	**PARTICIPATE IN A WHOLE-GROUP DISCUSSION ABOUT INFORMATION WE STILL NEED** Revisit our Ideas for Investigations chart to guide a discussion about the packaging materials we can use.	B-H	*Materials Cost List*, 1 3" x 3" sticky note, DQB, Ideas for Investigations chart, 3" x 3" sticky notes, Criteria and Constraints chart, markers, 7.2 Lesson 6 Massing MRE Entree (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**), 1 container of water-bead soup
3	8 min	**PREPARE FOR TEAMWORK AND REDESIGN OF HEATERS** Review expectations for teamwork and plan for the different types of models that teams will use in their redesigns.	I-J	*Teamwork Self-Assessment*, transparent tape, Criteria and Constraints chart
4	20 min	**WORK IN TEAMS TO MODEL OUR REDESIGN ON PAPER** Consider available packaging materials and work together in teams to model their designs, including cost, mass, amount of reactants to use, assembly instructions, and how energy will be transferred throughout the device.	K-L	1 sheet of chart paper or butcher paper, paper clip, team names on slide K or chart paper, Criteria and Constraints chart, initial consensus model from Lesson 1 (optional), Planning and Modeling Homemade Heaters
				End of day 1
5	5 min	**PARTICIPATE IN A WHOLE-GROUP DISCUSSION ABOUT WRITING INSTRUCTIONS** Revisit our ideas about instructions to guide a discussion about what our how-to instructions might be like.	M	Planning and Modeling Homemade Heaters
6	20 min	**FINISH MODELING DESIGNS ON PAPER AND WRITING INSTRUCTIONS** Complete team designs and have them approved by the teacher.	O	Planning and Designing Homemade Heaters
7	8 min	**PREPARE TO BUILD PROTOTYPES** Work in teams to start assembling their prototypes but without the addition of saltwater (that will be added when the class is ready for testing).	P-R	Constructing Prototype Homemade Heaters

8	12 min	**PREPARE TO TEST DESIGNS** Meet in an Engineers Circle to prepare for systematic design testing, discussing how to record data, and reviewing procedures to follow.	S-X	*Design Testing Matrix*, transparent tape
				End of day 2
9	20 min	**TEST PROTOTYPES** Test teams' designs, recording data in their science notebook and on their Design Testing Matrix.	Y-AA	*Design Testing Matrix*, *Engineering Design Rubric*, Testing Prototype Homemade Heaters
10	7 min	**SELF-ASSESS ENGINEERING PRACTICES IN TEAMS** Work in teams to assess their work as engineers.	BB	*Engineering Design Rubric*, highlighters
11	3 min	**SELF-ASSESS TEAMWORK INDIVIDUALLY** Independently rate using the Teamwork Self-Assessment.	CC	*Teamwork Self-Assessment*
12	10 min	**UPDATE PROGRESS TRACKER** Consider how our work today was similar to but different from what we've done before as engineers and add two entries to our Progress Trackers.	DD	What We Do as Engineers board, 3" x 3" sticky notes, markers
13	5 min	**COMPLETE AN EXIT TICKET** Reflect on their group's design solution by thinking about system interactions using an Energy Transfer Model.	EE	*Exit Ticket*
				End of day 3

Lesson 6 • Materials List

	per student	per group	per class
Planning and Modeling Homemade Heaters materials		• 1 digital scale • various containers • plain water • *Design Must-Haves* • access to *Materials Cost List* • *How-to Instructions Must-Haves*	
Planning and Designing Homemade Heaters materials		• 1 digital scale • various containers • plain water • *Design Must-Haves* • *How-to Instructions Must-Haves* • access to *Materials Cost List*	
Constructing Prototype Homemade Heaters materials	• indirectly vented chemical splash goggles • 1 nonlatex apron • nitrile gloves	• 1 digital scale • various containers • plain water • 21 grams hydrated water beads • cup with no more than 6 grams of shredded aluminum • cup with no more than 65 grams of copper sulfate • 2 4″ x 4″ parchment paper squares • *Design Must-Haves* • *Scaling Down Design*	

	per student	per group	per class
Testing Prototype Homemade Heaters materials	• indirectly vented chemical splash goggles • 1 nonlatex apron • nitrile gloves	• 1 tray • 1 digital thermometer • 1 digital scale • various containers • plain water • 21 grams of hydrated water beads • cup with no more than 6 grams of shredded aluminum • cup with no more than 65 grams of copper sulfate • 2 4″ x 4″ parchment paper squares	• saltwater
Lesson materials **Student Procedure Guide** **Student Work Pages**	• Science Notebook • *Materials Cost List* • 1 3″ x 3″ sticky note • *Teamwork Self-Assessment* • transparent tape • *Design Testing Matrix* • *Engineering Design Rubric* • *Exit Ticket*	• 1 sheet of chart paper or butcher paper • paper clip • highlighters	• What We Do as Engineers board • DQB • Ideas for Investigations chart • 3″ x 3″ sticky notes • Criteria and Constraints chart • markers • 7.2 Lesson 6 Massing MRE Entree (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) • 1 container of water-bead soup • team names on slide K or chart paper • initial consensus model from Lesson 1 (optional)

Materials preparation (45 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prepare the handouts:

- Print one copy for each student of each of these handouts: *Design Testing Matrix*, *Exit Ticket*, *Materials Cost List*, *Teamwork Self-Assessment*, *Engineering Design Rubric*.
- Print one copy for each group of each of these handouts: *Design Must-Haves*, *How-to Instructions Must-Haves*, *Scaling Down Design*.
- Trim handouts *Design Testing Matrix* and *Teamwork Self-Assessment* to fit science notebooks.

Be sure that you have materials ready to add the following word to the Word Wall: *prototype*. Do not post this word on the wall until after your class has developed a shared understanding of its meaning.

You may choose to make a handout of the procedures found on **slide V** and provide them to each group as they test their prototypes.

You may choose to invite students to bring in additional materials they'd like to use to build their homemade heaters, and/or you might collect other locally supplied materials, such as cardboard, packing peanuts, differently shaped bottles or containers, and so forth. If you do add other materials to those available for design construction, update the digital version of *Materials Cost List* accordingly and/or have students estimate what the costs of these materials would be for someone else who would be assembling these heaters at home. Students will use *Materials Cost List* again in Lesson 9, so if you do print copies of it, you may want to consider using sheet protectors and/or collecting them to redistribute in Lesson 9.

Take the time to intentionally plan the design teams that students will work with for the remainder of this unit. Use the observations you've made about how students have been working together in small groups and partnerships during the unit so far to inform how you arrange groups of students as design teams. List team member names on **slide K** or on a piece of chart paper, leaving space for teams to add their team name (which they will decide on before modeling their designs).

Decide how you will arrange your classroom to allow for 8 teams to work together. If you already have tables or desk groups, this will likely be an easy task. However, if your classroom has individual desks, you may need to teach students how to move the furniture into group workspaces or plan 8 various locations around the classroom for teams to use.

Reminder: *Prepare all substances and solutions, perform a temperature safety test with the copper sulfate crystals, and hydrate the water beads at least a day before students conduct their investigations. It is important that substances and solutions have time to come to room temperature.* Since students will be measuring the temperature changes caused by the chemical reaction, it is critical that all substances and the saltwater solution have fully come to room temperature. Avoid storing substances and solutions near windows or HVAC equipment that may be hotter or colder than the rest of the room.

Make sure the lab has engineering controls—eyewash station and shower—available.

Day 1: Prepare the water beads needed for day 2 and test the copper sulfate and aluminum foil reaction students will use on day 3.

- Prepare the water beads by hydrating them the day before students will be using them. Exact water bead absorbency will vary by brand, but for approximately 166 grams of hydrated water beads, add a half teaspoonful (about 4 grams) of dry water beads to 400 mL of water. Cover the container to reduce evaporation and allow the water beads to stand for 8–12 hours to fully hydrate. See photos below of the water beads added to the water to start and then after 10 hours of soaking.
- Copper sulfate comes in various crystal sizes from powdered to very large crystals. The size of crystals that you use in this lab will greatly affect the time it takes for the reaction to get hot and how hot the reaction gets. It is important that you test the reaction using the same size copper sulfate crystals that your students will be using before students do the reaction in class. Doing so will allow you to know the maximum amount of copper sulfate to allow students to use to keep the reaction from getting too hot.
- Avoid using powdered or very small crystals of copper sulfate. The image shows the crystal size of common Root Kill on the top. The bottom of the image shows the crystal size of copper sulfate that is too small. If you choose to use copper sulfate from your school's existing laboratory supplies, ensure the crystal size is similar to Root Kill.
- The temperature of the food (water bead mixture) should not go above 48°C. If the temperature of the food mixture in your test goes above this temperature, adjust the amounts of copper sulfate and aluminum that students are allowed to use.
- Use *Testing Reaction for Maximum Temperature* for instructions for your test. Be sure to do this before your students begin testing their prototypes on Day 3.

Days 1 and 2: Planning and Modeling Homemade Heaters

- **Group size: 8 teams of 3–4 students per team**
- **Setup**
  - Have a variety of containers and lids available for teams to use in their designs, such as plastic food storage containers and various sizes of ziplock bags. You may also choose to provide insulating packaging, such as cardboard or bubble wrap, or invite students to bring in boxes, bottles, or other materials they would like to use in their designs.
  - Have water available for students to use as a proxy for the saltwater they will use during testing—they should be able to plan how much saltwater they will want in their design without actually running the reaction. Since it will not be used in testing, this water need not be at the same temperature as the other materials.
  - Be sure each team has access to a scale.
- **Notes for during the lab:** Teams may explore with various packaging materials, amounts of water (as a proxy for the saltwater they'll use in their design), and masses as they plan and draw models for their designs. They will not be constructing their actual prototypes during this planning time.

Safety

Ensure that the lab has engineering controls (eyewash station and shower) available.

1. Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.

2. Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
3. Follow your teacher's instructions for disposing of waste materials.
4. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
5. Wash your hands with soap and water immediately after completing this activity.
6. Never eat any food items used in a lab activity.
7. Never taste any substance or chemical in the lab.
8. Use caution when working with heated liquids—this can burn skin!
9. Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions using copper sulfate or root killer. Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.
    - **Disposal:** At the end of the day, the plain water can be poured down the drain. Do not dispose of any other materials as teams will continue to use them on days 2 and 3 of this lesson.
    - **Storage:** Make a plan for how teams will keep their models safe and out of the way while other classes use the room. Consider making space on a back table, counter, or bookshelves to collect the teams' models.

Day 2: Constructing Prototype Homemade Heaters

- **Group size: 8 teams of 3–4 students per team**
- **Setup**
    - Each team may want to use up to about 62.5 grams of "food," which is a mixture of hydrated water beads added with water that has been prepared by hydrating them the day before.
    - Plan how you'd like to distribute hydrated water beads to students. You may choose to keep them all in one place with a cup as a scoop for students to measure into their containers, or you may choose to supply each team with a smaller container of their own to measure from.
    - Keep the water beads covered when not in use so that they don't begin to dry out.
    - Teams will need access to plain water to add to their hydrated water beads to create the "water bead soup" that they will use as a proxy for food during testing. They will use approximately 1 part water beads and 3 parts plain water for the total mass of their "food."
    - Prepare 48 grams of shredded aluminum foil per class by running ~8" x 11" pieces of aluminum foil through a paper shredder. A crosscut paper shredder is preferred since it cuts the aluminum into small pieces (~2 cm x 0.5 cm), whereas strip-cut paper shredders produce long strips that will then need to be cut into smaller pieces. You may need to run a few pieces of aluminum foil through the shredder to remove any paper bits before you collect foil to use in class.

Optional advance prep: You will need another approximately 64 grams of shredded foil per class for Lesson 9. You could also cut that amount now and store it until it is needed.

- Fill 8 Styrofoam cups per class with about 6 grams of shredded aluminum foil each. Teams can bring these cups to their work areas to measure out the amount they need for their design and return whatever they don't use still in the cup.
- Fill another 8 Styrofoam cups per class with about 65 grams of copper sulfate per cup. Teams can bring these cups to their work areas to measure out the amount they need for their design and return whatever they don't use still in the cup.
- Each team will need a scale and two 4" x 4" pieces of parchment paper on which to mass their materials (unless they are measuring directly into a container).
- **Notes for during the lab**
  - After the teacher completes the safety check of their models on paper, teams may start the construction of their prototypes: massing and packaging water beads for food and massing copper sulfate and aluminum prior to testing their model. No saltwater should be used yet (that is reserved for testing on day 3).
- **Safety:** Safety recommendations for students and teacher(s)

Ensure that the lab has engineering controls (eyewash station and shower) available.

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.
- Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.
- During the design step, confirm that teams will use
  - *no more* than 55 total grams of reactants (copper sulfate + aluminum) and
  - *no less* than 250 mL of saltwater in order to keep the reaction from getting dangerously hot.
- **Disposal:** Do not dispose of any materials after day 2, but keep them for testing on day 3.
- **Storage:** Make a plan for how teams will keep their models safe and out of the way while other classes use the room. Consider setting designs on blank paper labeled with the team's name on a back table, counter, or bookshelves.

Day 3: Testing Prototype Homemade Heaters

- **Group size: 8 teams of 3-4 students per team**
- **Setup**
  - On day 2 prepare 2,500 mL of saltwater per class. For each 500 mL of water, add 3 grams of table salt. So, if you're mixing all 2,500 mL at one time, add 15 grams of table salt. If you're making several batches (for multiple classes) at one time, use the ratio of 6 grams of table salt for every 1 liter of water (so a 4-liter pitcher would require 24 grams of table salt). Stir to make sure that all the table salt dissolves. Be sure to leave the saltwater out at least a day in advance to come to room temperature. Keep the saltwater in pitchers or beakers that are easy to pour from so that teams can measure out what they need into their own containers.
  - Teams may still need access to the following materials to prepare for testing on day 3 if they did not fully assemble their designs on day 2:
    - containers and other packaging materials
    - hydrated water beads
    - plain water
    - Styrofoam cups containing about 65 grams of copper sulfate (to carry to their workspace and measure out what they need for their design)
    - Styrofoam cups containing about 6 grams of shredded aluminum (to carry to their workspace and measure out what they need for their design)
    - 4" x 4" parchment paper sheets for massing materials (unless they are measuring directly into a container)
  - Each team will need a tray and a digital thermometer.
- **Notes for during the lab:** Be sure to confirm that students are venting the containers in which their reactions are happening to avoid buildup of hydrogen gas or having them pop open and cause a splash.
- **Safety:** Safety recommendations for students and teacher(s)
  - Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
  - Immediately wipe up any spilled water and/or granules on the floor—this is a slip and fall hazard.
  - Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
  - Wash your hands with soap and water immediately after completing this activity.
  - Never eat any food items used in a lab activity.
  - Never taste any substance or chemical in the lab.
  - Use caution when working with heated liquids—this can burn skin!
  - Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.
  - Be sure to remind students that when they're stirring or swirling their reactants, they should use a lid and be careful to avoid spills.

- **Disposal**
  - Save any *unused* saltwater solution, aluminum foil, and copper sulfate for upcoming labs.
  - Solid wastes (pieces of aluminum and copper) can be disposed of in the garbage.
  - Dispose of liquid waste as directed in the teacher reference *Safety Information for Copper Sulfate Pentahydrate*.
  - Rinse containers and leave out to dry and reuse in future lessons.
  - **Storage:** Unused saltwater, aluminum foil, and copper sulfate can be retained for future lessons. All containers and cups can be retained for future lessons.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students will be determining the amount of reactants they need to use in order to transfer energy to the "food" in their heater designs. To avoid dangerously high temperatures, it is critical that you check students' design plans before they begin building their prototypes. Specifically, you need to confirm that teams are planning to use

- *no more* than 55 total grams of reactants (copper sulfate + aluminum) and
- *no less* than 250 mL of saltwater.

If their plans do not meet these requirements, tell them to adjust their plans accordingly to be sure their device is safe.

Students are instructed to use at least 250 mL of saltwater to support their success in designing. However, do not announce the limitation for the dry reactants before students begin designing because it would be too easy for teams to just plan to use close to that maximum amount without reasoning through their calculations.

Also, check to be sure each team has planned to vent the container or package holding their reactants. This expectation is clarified for students before they begin modeling. Like the prepackaged MRE heaters, we do not want our homemade heaters to trap the small amount of hydrogen gas they produce or become a hazard if heated air inside were to cause them to pop open. Hydrogen gas is not toxic to breathe, and it dissipates quickly in the air, but it is flammable, so we do not want to create a situation where it is contained.

Water beads are mixed with plain water in a 1:3 ratio as a proxy for food during testing. Adding water beads to the water helps differentiate the "food" from the saltwater that is also required during testing. However, using a higher proportion of water beads than this takes longer to heat. Additionally, it is difficult to find an accurate temperature of the water beads themselves when they are not mixed with water. So, we recommend that students use a "soup" of approximately 1 part water beads to 3 parts water for their "food."

Note that our design groups are referred to as "teams" to emphasize the importance of collaboration in engineering design. Expectations for good teamwork are a specific focus of this lesson, with discussion before designing begins and use of a self-assessment at the end for reflection. Students will stay in the design teams assigned in this lesson for the remainder of the unit.

Where We Are NOT Going

The challenge of building a successful homemade flameless heater should not be viewed as a competition. Rather, the whole class is working to accomplish this task with the end goal of helping others. By sharing ideas within teams and among teams, many or all teams will be able to design an optimal solution by the end of the unit. If you hear talk in this lesson or future lessons about teams "winning" (maybe because they hit more of the criteria on the Design Testing Matrix), step in to adjust that thinking: we are working together to figure out how to make the best versions of heaters that we can in our groups.

In Lesson 7, teams will have the chance to compare their design with other teams in order to find and share the most promising ideas that can be used to optimize their design. However, the hope is that the motivation for this sharing time comes from the students. Therefore, it is not announced by the teacher in Lesson 6 that teams will compare designs next time.

LEARNING PLAN FOR LESSON 6

1. Revisit our What We Do as Engineers board and Progress Trackers. 5 MIN

Materials: science notebook, What We Do as Engineers board

Gather in an Engineers Circle to review last time's work. Display **slide A**. Give students a moment to review the What We Do as Engineers board and reread their Progress Tracker entries from the last two lessons.

Say, *Last time we were together, you said our next step might be to develop a solution. Let's discuss why we think we are ready to do this and the information that we have gathered to help us design a successful solution.*

Suggested prompts	Sample student responses
What did we do that makes us feel that we are ready to design a solution?	*We know which chemical reaction we want to use for our flameless heaters.* *We know the proportional amounts we need of each reactant to make it work.* *We refined our criteria and constraints.*
At the beginning of this unit we created a design solution. How is redesigning a solution now different from when we designed a solution at the start of this unit?	*We now know a lot more about reactions and have figured out which one will be best for transferring the right amount of energy to heat up our food. When we first tried to design a solution we did not really know anything.*
What information will be important to include or keep in mind as we work on our design solution?	*We will need to make sure that we are trying to meet all our criteria and constraints that we discussed in the last lesson.*

Say, *We have figured out a lot of what we wanted to know to help us redesign a successful flameless heater. Let's look back at our Ideas for Investigations chart to see what we've accomplished and what we might still need to figure out before we are ready for a redesign.*

2. Participate in a whole-group discussion about information we still need. 12 MIN

Materials: science notebook, *Materials Cost List*, 1 3" x 3" sticky note, DQB, Ideas for Investigations chart, 3" x 3" sticky notes, Criteria and Constraints chart, markers, 1 container of water-bead soup, 7.2 Lesson 6 Massing MRE Entree (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

Revisit our DQB and Ideas for Investigations chart to mark off what we have accomplished. Display **slide B** and give every student one sticky note. Direct students to write a check mark on the sticky note and then come up

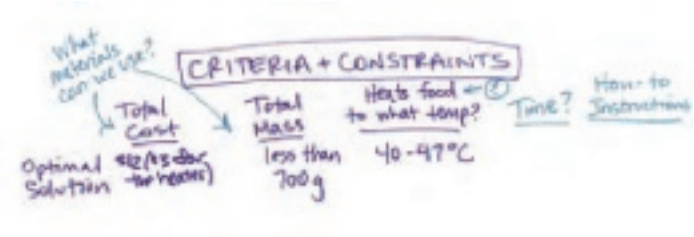
to the Design Questions Board and/or Ideas for Investigations chart and attach their sticky note near a question or investigation idea that the class has already completed. This is meant to be a quick trip to the charts and sit back down—no deliberation needed. If someone else has already put a sticky note where they had planned to, the student can add their sticky note on top of that one or find another question or investigation that has been completed. The following questions and ideas can be checked off the lists:

- What substance(s) are in the heater "compartments"? What substances can we mix to get hot? Are they safe enough for people to use?
- How hot should our food get? What temperature is comfortable to eat?
- Are these materials or substances harmful or toxic?
- How much should these heaters cost to make?

Turn and talk about what we still need to know.* Display **slide C**.

Say, *We've found a lot of answers, and I'm wondering if we have enough information now to make improvements on the designs you first created in Lesson 1. Let's compare our list of ideas for investigations and our DQB with our Criteria and Constraints chart to make sure we aren't missing any other details or ideas we would need for our redesign. Turn and talk with a neighbor about what information you still need before you're ready to try a redesign.*

After about 2 minutes of partner talk, invite students to share their thoughts. As they do, use sticky notes or markers to note on the Criteria and Constraints chart the parts for which we still need more information. (See example image shown here, with new notes added in a lighter blue.) Students will likely point out the need for detail around the following:



- mass (e.g., What materials can we use to build our homemade heater? How will they fit our criterion for total mass?)
- cost (e.g., How much will our heater materials cost?)
- instructions (e.g., How can we make our flameless heaters easier to use?)
- time (e.g., How long will our heaters take to work?)
- food substitute (e.g., If we can't have food in the classroom, what will we use instead?)

Say, *OK, so we need to spend a little more time thinking about these ideas and details to help us meet our criteria and constraints before we're ready to begin our redesigns.*

Discuss available materials. Display **slide D** and distribute *Materials Cost List*. Use prompts, such as the following, to help the class consider the materials available to use in their designs. Refer to *Materials Cost List* as well.

*** Attending to Equity**

Universal Design for Learning: There are a handful of Turn and Talk opportunities in this part of the lesson. Your students may be more *engaged* if given the opportunity for a movement break at any of these moments. Instead of staying seated to talk with a neighbor, you might ask students to "stand and talk" to a neighbor nearby or "walk and talk" with someone a little farther across the room. After a minute of chat time, regroup the class back in their seats in the Engineers Circle to continue the whole-group discussion.

Suggested prompts	Sample student responses
Remember, we already decided that we want our total homemade flameless heater cost to be $12 or less, but we're going to set aside $9 for the cost of food. Our optimal design for the heater itself should cost $3 or less. When you begin your redesign today, we have these materials available for you to use. These are all things people can buy at a hardware store or grocery store if they don't have them at home already. How do you think they fit our criterion for ease of use?	*We know the copper sulfate and aluminum foil are easy enough to get, and these containers are also things you can easily find at stores.* *If we give people clear directions about how to put the reactants into these containers, they should be pretty easy to use.*
How do you think they fit our constraint for cost?	*Even if we use several containers, along with our reactants our total cost will be within the $3 constraint.*
What else do you need to know about these materials?	*We don't know the masses of these containers. We will need to mass them when we're considering using them to be sure they fit our constraint of less than 700 grams total for the heater and food.*
Does anyone have other materials in mind they think might be helpful?	*(Accept any responses and respond accordingly.)*

Additional Guidance

You may choose to invite students to bring in additional materials they'd like to use to build their homemade heater and/or you might collect other locally supplied materials, such as cardboard, bubble wrap, differently shaped bottles or containers, and so forth. If you do add other materials to those available for design construction, update the digital version of *Materials Cost List* accordingly and/or have students estimate what the costs of these materials would be for someone else who would be assembling these heaters at home. Students will use *Materials Cost List* again in Lesson 9, so if you do print copies of it, you may want to consider using sheet protectors and/or collecting them to redistribute in Lesson 9.

Discuss the mass of available materials. Display **slide E**. Say, *While there are a lot of different mass measurements we don't know yet about our design of the homemade flameless heater, we have figured out some important ideas about the mass in previous lessons. These ideas will help make sure we design a flameless heater that actually heats up the food and can help us stay under our 700-gram limit.*

Have students refer to their Progress Tracker entries from Lesson 4 and use the following prompts to help the class consider what they already know about mass and what details they still need to figure out in order to meet the 700-g limit.

Suggested prompts	Sample student responses
In Lesson 4 we tested different amounts of reactants to see what amounts worked best. What were those amounts that worked best?	*When we had a total of 6 grams of reactants, if 0.5 grams of that was aluminum and 5.5 grams was copper sulfate, that worked the best—we got the largest temperature change with the least reactants.* *That's 8 percent aluminum and 92 percent copper sulfate.*
In Lesson 3 we saw data from a systematic test of how the same amount of reactants increased the temperature of different amounts of food. What did we figure out from those data that will help us in our designs?	*Heating up more food requires more energy—not just a little bit more energy, but a lot more.* *Heating up less food requires less energy.*
What components do we need to mass before we can design our flameless heaters?	*We will need to figure out the mass of* • *the containers* • *the reactants* • *the saltwater* • *the food*
How much food does a typical flameless heater heat up?	*We don't know.*

Let students know that each group can decide independently how much food their flameless heater is going to heat up. Suggest that it might be useful to know how much food a typical MRE flameless heater heats up to help give an estimate of how much food to include in a design. Show students the video of measuring the mass of the entree portion from a prepackaged MRE. Students can record in their science notebook that the mass of a typical MRE entree is around 215 g (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Discuss safety while considering available materials. Display **slide F**. Safety is an important criterion in designing a solution, both during the design process and for the people using the designed solution. Explain that since we cannot have food in the classroom, we will make a "soup" of water beads and plain water to use as "food" to test. Show students the water beads and describe what they feel like. The recipe for our water-bead soup will be 1 part water beads and 3 parts water. Invite a couple of students to comment about why these will be a good proxy for food. Listen for ideas such as these: "It will feel more like food because we will have solid pieces in liquid rather than just water" and "Having water beads in there will help us avoid confusing our 'food' with the saltwater used for the reaction."

Additional Guidance

The 1:3 ratio of water beads to plain water is recommended because a higher proportion of water beads than this takes longer to heat. Additionally, it is difficult to find an accurate temperature of the water beads themselves when they are not mixed with water. Most prepackaged MRE entrees also have a high liquid content with sauces or stews so they heat more consistently.

Display **slide G**. Say, *Remember how the prepackaged MRE heater was just rolled closed so that the steam and hot air and hydrogen gas could still escape? Our reaction will also be heating the air inside of the container and producing some hydrogen gas, so whatever material or packaging you use to hold the copper sulfate and aluminum cannot be completely sealed—it must have a small hole or opening to vent out those gases. Hydrogen gas is not toxic to breathe, but it is flammable, so we don't want to trap it or have open flames around while testing. It would not be safe to have a situation where the container of hot liquid and gases burst open and splashed someone. So, you'll need to plan your device to have a vent hole but avoid spilling the liquid inside.*

Safety Precautions

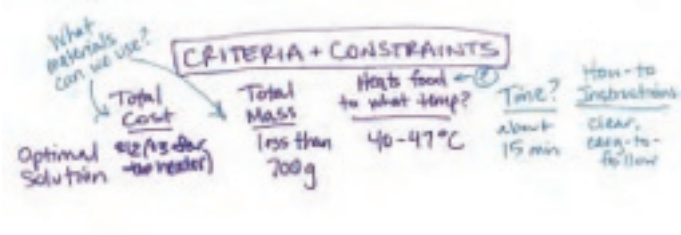
Only Ziploc-brand freezer-weight bags were tested during the designing of this unit. They did not melt when used to hold the aluminum + copper sulfate reaction. If you choose to use other brands or types of bags, you should test them ahead of time to ensure that they do not melt. No bag should be sealed completely. Plans should include leaving the bag partly unsealed or cutting a vent hole in it.

Discuss the time it might take for the heaters to work. Display **slide H**.

Say, *OK, we have one more idea still to consider: How long should our heaters take to use? We didn't set a specific criterion or constraint around this. What do you think about that?*

Listen for students to suggest time constraints such as these: "As long as the MRE heater took to work" or "About 15 minutes." Update the Criteria and Constraints chart to indicate the goal time upon which your class decides (15 minutes is recommended). See example image shown here.

Say, *Now it looks like we are ready to start our redesigns because we know what we need our designs to do to be successful!*



3. Prepare for teamwork and redesign of heaters.

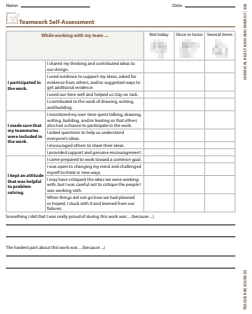
8 MIN

Materials: *Teamwork Self-Assessment*, transparent tape, Criteria and Constraints chart

Plan for what it means to be a good teammate. Have students return to their seats and display **slide I**.

Say, *Remember back in Lesson 1, each of you designed a flameless heater? You worked individually to do that. Now, for your redesign, you will be working in teams of three or four students. What will be good about working with a team rather than on your own? What might be challenging about working with a team? Turn and talk with a neighbor for a moment about those questions.*

Invite two or three students to share potential benefits of and drawbacks to working with a team. Then say, *Engineers rarely work alone. The best problem solving often happens when several people are contributing ideas and working together, but sometimes it can be hard to share the work with others. So, we have some specific expectations for each other to make our teamwork successful. Take a look.*


Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...

		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I cited evidence to support my ideas, asked for evidence from others, and/or suggested ways to test our design ideas.			
	I acted as a team member and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I monitored my own time spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged my ideas when needed.			
	I may have critiqued the ideas we were working with, but I was careful not to critique the people I was working with.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

The hardest part about this work was ... (because ...)

STEAM ACTION AND EMPATHY LAB

TEACHER PAK WOOD ED

Distribute *Teamwork Self-Assessment and instruct students to tape it into their notebook.** They will not fill it out until after they've constructed and tested their designs, but direct them to quietly read the expectations as they put the document into their notebook.

Say, *Many of these expectations will sound familiar because we have these norms in our classroom already. But some might be especially important to this work of engineering design. Can you find one or two expectations here that you will really need to focus on to help your team be successful with your flameless heater design? Turn to a different neighbor to share your idea.*

Alternate Activity

Like developing classroom norms, you could choose to have students develop their own list of teamwork expectations. Knowing that they will be working together to create a successful design, what do they need from each other to make that happen? And/or how will it look and sound to uphold the classroom norms we already have when we're working in teams? As students suggest expectations, you can fill them in on a shared document (such as the digital version of *Teamwork Self-Assessment*) and then print that out to add to their notebooks and to use as a self-assessment at the end of this lesson (and again in Lesson 9).

Plan for the two types of models that teams will create. Display **slide J**. Discuss, using prompts such as those below, why and how teams will create a model two different ways.*

* Attending to Equity

Universal Design for Learning: While *Teamwork Self-Assessment* is not assessing students on DCI, the practices, or the crosscutting concepts, this self assessment is important to support *engagement* in collaboration. Introducing *Teamwork Self-Assessment* near the beginning of this lesson, then having them reflect on and assess their participation in teamwork helps students value and foster an equitable learning community that promotes trusting and caring relationships. The use of *Teamwork Self-Assessment* should reinforce to students the value of (1) the diversity of thought among all classroom community members in pushing our learning forward and (2) providing a safe learning environment that ensures fair participation. In addition, *Teamwork Self-Assessment* should interrupt cultural norms or stereotypes that could make science experiences feel uncomfortable for some students (e.g., as being someone who is not intelligent enough to think like a scientist, who cannot do the relevant math, who cannot share their thinking).

Suggested prompts	Sample student responses
Just like our first designs, our redesigns will happen on paper first. We will not construct anything right away. In your experience, why is it a good idea to put our designs or model ideas on paper before building something?	*It's easier to change your mind on paper, like switching out materials or amounts.* *We can calculate how much we think it will cost on paper.* *You can plan without using or wasting materials.* *You can show someone else what you're thinking before you take the time to make it.*
How are designs and models similar?	*They both have components, interactions, and mechanisms in order to explain ideas.*
How are designs different from models?	*Models are usually used to help explain science ideas; designs use science ideas to help create a solution to a problem.*

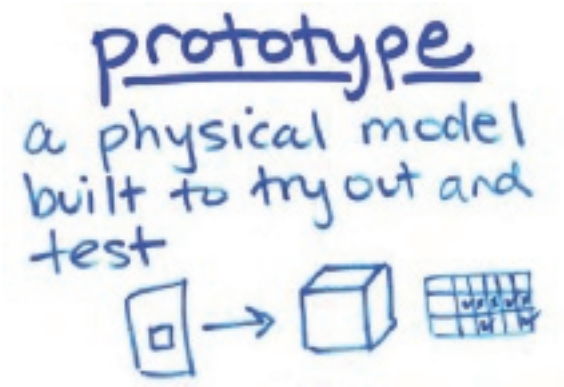
*** Supporting Students in Engaging in Developing and Using Models**

Student designs or models will help them generate data to test ideas about their designed systems—their homemade flameless heaters. Students will be able to collect data when they test their designs.

Say, *So designs have a lot of similarities to models. In fact, a design is a type of model that has a specific purpose to help create a solution to a problem. In this unit we have been working with models like our Energy Transfer Model and also working on creating a solution to a problem by modeling design solutions. When we are modeling to create a solution to a problem, let's be specific and call it a "design".*

Suggested prompts	Sample student responses
What kinds of things can a design drawn on paper allow you to show or communicate that people might not notice or learn just by looking at the constructed device?	*You can show what's going on inside the device or why it works.* *You can show what's making it work that people can't see from the outside.*
OK, so we know that modeling on paper is going to be helpful to our designs. Your team will definitely need to do that first. But then, I know you're excited to actually build these heaters, too. What will constructing a physical model allow you to do that the model on paper can't?	*We will get to test it!* *We need to actually combine the substances inside the packaging and measure the temperature of the food to see if it works!* *We can see if we meet our criteria and constraints!*
Take a look back at our Criteria and Constraints chart. Are there other criteria or constraints that a physical model could help us with?	*It will be easier to write our how-to instructions if we try putting everything together in real life.*

Summarize for the class. Say, *OK, I hear you saying that modeling designs on paper can help us plan without using up materials and can help us show others what's going on inside a device that makes it work. But when we want to actually test our device to see how it measures up to our criteria and constraints, we want a physical design—something we can build and try out. Engineers have a name for that kind of physical design that's built to try out and test. It's called a "prototype." We'll be using that word a lot as we redesign our homemade heaters, so let's add it to the Word Wall.*



See the example Word Wall definition and icon for *prototype* shown here. Work with your class to make a similar one to post on your Word Wall.

Say, *We know that designs on paper are helpful for communicating ideas to others. Engineers often have to submit a proposal or drawings of their plans before they get the go-ahead to build a prototype. Similarly, your team will need to show me your design on paper before I give you the go-ahead to build your prototype. I want to be sure you've thought through everything and that the design you're planning will be safe to build.*

4. Work in teams to model our redesign on paper.

20 MIN

Materials: Planning and Modeling Homemade Heaters, 1 sheet of chart paper or butcher paper, paper clip, team names on slide K or chart paper, Criteria and Constraints chart, initial consensus model from Lesson 1 (optional)

Collaboration

Take the time to group students intentionally for these design teams. Students will remain in these teams for the remainder of the unit (which begin working together in this lesson and will continue together till Lesson 9). Consider grouping students of different genders, math abilities, and personalities.

Supporting Emergent Multilinguals: It is helpful to intentionally group emerging multilingual students with certain peers. Sometimes this could be peers who know the same languages as them, while other times it could be peers whose English language development is slightly more advanced. It is important that this grouping be thoughtful and that it varies between different units so that students benefit from working with different peers.

Give directions for getting into teams. Say, *When I give you your teams, your first task will be to decide on a team name. This will make it easier for us to talk about the designs you create together, and choosing a name will be your first chance to show how you can follow your teamwork expectations. When you've decided on a name, send a teammate up here to record it on our slide* (or chart paper). *I will also hand each team a copy of Design Must-Haves and a piece of chart paper* (or butcher paper) *for you to use for modeling your design. Then you can get started on your work.*

Display **slide K** or the chart paper you've prepared with team members and spaces to collect their team names. Direct teams to gather at their workspaces and get started. Distribute *Design Must-Haves* and a piece of chart paper or butcher paper to each team. Be sure that the class Criteria and Constraints chart is in view so teams can use it for planning.

Allow teams the rest of today's class period to work on their designs. *Display **slide L**. Provide access to scales, containers, building materials (except reactants or water beads for food—those are reserved for constructing prototypes), and *Materials Cost List* so that students can explore how these materials could be used in their designs and find out their masses in order to meet that constraint.

*** Supporting Students in Engaging in Using Mathematics and Computational Thinking**
Teams may choose to calculate the amounts of reactants they use in one of two ways. In either case, they will want to use the most efficient proportion as found in Lesson 4. If they have a total mass in mind for the reactants that they want to use in their design, they may find the percentages of that mass for aluminum (8%) and copper sulfate (92%). Or, since they figured out in Lesson 4 that 0.5 grams of aluminum and 5.5 grams of copper sulfate were the most efficient amounts, they may choose to scale up that amount by doubling, tripling, and so forth.

As they work, circulate and check in, especially paying attention to the amounts of reactants that teams are planning to use. If you do not get to check each team's plan for reactants today, you will want to be sure to do that before they begin building.

Safety Precautions

It is critical that students' designs use *no more* than 55 grams of total reactants (aluminum + copper sulfate) and *no less* than 250 mL of saltwater, or these reactants will get dangerously hot. Also, students should plan to vent the container holding the reactants to avoid a potential "pop" that would release hot liquid or gas. If students' designs do not meet these requirements, direct them to revise their designs before building their prototypes. Students will be able to successfully heat at least 250 grams of "food" with less than 55 grams total reactants in 250 mL of saltwater or more if they use the most efficient ratio and their packaging is well designed.

Collect designs in a safe place. Remind students that they will have more time next class to finish their designs and draft their how-to instructions before they begin building their prototypes.

Before students leave the room, direct them to paper clip their *Design Must-Haves* to their chart paper design and leave them in the location you specify. Be sure these are stored in a place where they will be out of the way when other classes come in and where it's easy for you to access them if you'd like to assess them now (or wait until teams are continuing their work next time).

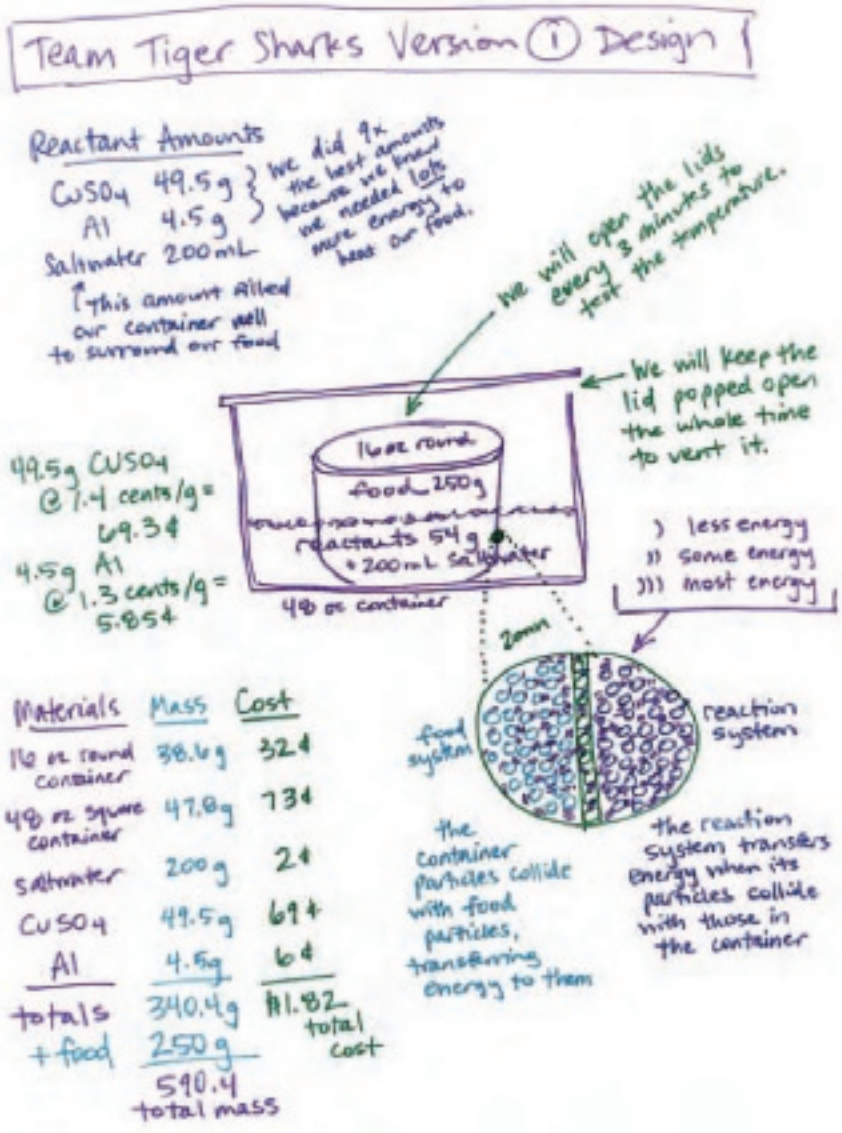
Assessment Opportunity

Building towards: 6.A.1 Undertake a design project to construct and test a solution that meets specific design criteria and constraints, including the transfer of energy.

What to look for and listen for: Teams' designs should include all the characteristics listed on *Design Must-Haves* regarding criteria and constraints and also a sketch showing the particles of the substances in the flameless heater reaction colliding with particles of the container(s) and the food to show how that transfer of energy happens.

What to do: If a team's design does not include characteristics related to the criteria and constraints (such as cost or type of materials used), remind the team to go back and add those. If a team is struggling to calculate the amount of reactants they want to use, suggest that they base their plans on prior test results, such as those from Lesson 4 (that 6 grams of total reactants in the most efficient proportion was able to heat up significantly) and consider if they might double or triple that amount (knowing that they will need more energy to heat more food). If a team's design does not include the energy transfer at the particle level, it may be helpful to refer to the initial consensus model you made as a class in Lesson 1 that shows how the MRE heater's particles were moving and ask the team to consider how that might be similar to their design. If these students experienced the previous unit, *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, referring to *Modeling What Is Happening at the Cup Wall* can help remind students about the models they drew of their cups showing the energy transfer at a particle level.

An example design is shown here, but please note that there will be many potential successful designs; there is not one correct solution to this task.



End of day 1

5. Participate in a whole-group discussion about writing instructions. 5 MIN

Materials: Planning and Modeling Homemade Heaters

Discuss ease of use and communication. Display **slide M**.

Say, *We have been working hard creating designs to help us build a working flameless heater. If we can't communicate to others how to build our flameless heater, then our design would be ineffective. In Lesson 4 we started thinking and discussing what is needed for good instructions. Think about some different experiences where you had to follow instructions, maybe to put together a toy or cook something from a recipe or like the instructions we used in one of our earlier labs. Was anything difficult about following those instructions? Was there anything about them that made it easier to follow them or that you wished for that would have helped you? Turn and talk with a neighbor about your experiences following instructions.*

Connect features of helpful instructions. Display **slide N**. Distribute *How-to Instructions Must-Haves* to each group. Have students read over the must-have checklist and see how these features connect to their experiences with good instructions. Invite students to share the connections between the checklist and how instructions can be helpful.

Suggested prompts	Sample student responses
What are some important features that need to be included to make good instructions?	*Have the steps in sequence.* *Use simple language and short sentences.* *Include illustrations or icons.** *Use diagrams with labels.* *Include a parts list.* *Put the text in multiple languages.** *Be sure to talk about safety!*
How do these features make instructions better?	*These ideas will break up the process of building the flameless heater into simple steps that help make the instructions easy to follow.*

After they complete their designs, have groups craft a set of instructions that people could use to build the flameless heater. Make sure that students use *How-to Instructions Must-Haves* to help guide them in making good instructions. Have students write the instructions on the bottom of *How-to Instructions Must-Haves*.

Alternate Activity

Extension: Your students may mention their experiences watching how-to videos as an example of helpful instructions. If time and resources are available, you may choose to give students the option of creating a video for their homemade heater assembly-and-use instructions. If you have resources but not time for videos here in Lesson 6, you may choose to offer video as an option for the redesign during Lesson 9 (as a way to improve or optimize the design for this criterion).

*** Attending to Equity**
Universal Design for Learning: Encouraging students to use icons or drawings in their how-to instructions will not only be helpful for their *expression* of these ideas, but it will support the *representation* of these ideas for the end user of this device.

*** Attending to Equity**
Supporting Emergent Multilinguals: Allow and encourage students to use both content-specific and everyday language when expressing their ideas and developing their how-to instructions. If our intent is for anyone to be able to follow these directions, we don't need to include specific science vocabulary. Also, like instructions found with many devices, if it would be helpful for a team to write their instructions in more than one language, encourage this idea.

6. Finish modeling designs on paper and writing instructions. 20 MIN

Materials: Planning and Designing Homemade Heaters

Direct students to continue their design work in teams. Display **slide O**. Allow students to retrieve their *Design Must-Haves*, *Materials Cost List*, and the design they started on chart paper last time. Again, they have access to scales and containers and building materials (other than our reactants or water beads for food) so that they can explore how these materials can be used in their design as well as find out their masses. Let them know they will have about 20 minutes today to finish their design on paper, including the draft of their how-to instructions on *How-to Instructions Must-Haves*.

Additional Guidance

Depending on how much experience your class has with problem-solving, working in teams, and designing investigations, they may need more time to develop a thorough design. Adjust the time they have for this work as needed and as your schedule allows.

Check every team's design for safety. As teams work, be sure you are circulating among them and checking in on their designs. Specifically you need to confirm that teams are

- using *no more* than 55 total grams of reactants (copper sulfate + aluminum),
- using *no less* than 250 mL of saltwater, and
- planning to vent the package that holds the reactants.

If their plans do not meet any of these requirements, tell them to adjust their plans accordingly to be sure that their device is safe.

7. Prepare to build prototypes. 8 MIN

Materials: Constructing Prototype Homemade Heaters

Direct the class for scaling down designs for building prototypes. When teams finish their designs and get their designs approved, they will be ready to begin assembling their prototypes. Say, *While the prices of these materials are relatively cheap, the cost of shipping large quantities becomes quite expensive. Therefore, to make sure we have enough materials for everyone to build their prototypes we are going to scale down our prototypes to one quarter the actual design.*

Discuss with students what this might mean in terms of the planning of their design solution.

Suggested prompts	Sample student responses
If we are going to build a design at one quarter the scale, what are all the parts that need to be scaled down?	*The reactants.* *The food.* *The containers.*
What evidence do we have from Lesson 3 to support the idea that we should not expect to see the temperature scaled down as well?	*We saw when both the food and reactants were both doubled, the temperature was about the same.*
If we are building a scaled-down prototype, how can we make sure that the actual design still meets the criteria and constraints?	*We should design the flameless heater at scale to make sure it fits our criteria and constraints. Then scale it down at the end by dividing the reactants, the food, and the containers each by four.*

Display **slide P**. Distribute a copy of *Scaling Down Design* to each group. Have students use the chart to calculate each scaled-down measurement they will need to test their design. They should use only these new measurements for testing their designs. Remind students that they will not be able to perfectly scale down the size of containers. Have students use a size of container that is as close to their calculation as possible.

Additional Guidance

When students test their scaled-down prototypes, have them refer to only the last column in *Scaling Down Design* when measuring out their reactants. Have students place their instructions and designs off to the side, this way students don't get confused on what amounts of materials they need as they are building their prototypes.

Give directions for safety. Display **slide Q** to provide safety reminders.

Give directions for building the prototype. Display **slide R** to give directions about how students may begin

- massing their copper sulfate and aluminum,
- measuring and packaging 1 part hydrated water beads to 3 parts water to make their "soup" for food,
- putting together their packaging and massing those components, and
- cutting lids or implementing other types of venting for the reactant container.

Note: No saltwater is available yet because testing will not happen until the next class—we have not yet discussed our testing procedures.

Also, take time now to show the class how they will store their unfinished heaters in the classroom before testing next time so that, when building time is over for today, they will know how to label their work and keep it out of the way until the next class.

Additional Guidance

Students may choose to make their "water bead soup" in one of two ways. They could take the total food they want to heat and divide it by 4 (for example, 200 grams of "food" divided by 4 means 50 grams of hydrated water beads and 150 grams of plain water). Or, they could mass an amount of hydrated water beads that fit easily into the container they want to use for food, multiply that mass by 3 and add that much plain water to their container. The 1:3 ratio does not need to be met exactly; it is a recommended guideline to be sure their "food" heats well.

8. Prepare to test designs.

12 MIN

Materials: science notebook, *Design Testing Matrix*, transparent tape

Gather in an Engineers Circle to plan for design testing. Display **slide S**. Say, *You all have worked hard in your teams! You have modeled on paper to plan and communicate about your designs, and we're almost ready to build prototypes. But we know that a prototype is meant to be tested. And we know that engineers rely on systematic testing to help improve their designs. So, what do we need to do when we test our prototypes to be sure that our results can help inform our future designs? Turn and talk with a neighbor about that.*

Invite students to share their thinking about this question: "How will we test our prototypes in a systematic way?" Listen for responses, such as

- we all need to record our data accurately and
- we need to gather data for all the parts of our criteria and constraints chart, such as
  - mass of the entire prototype (when and how to mass the parts or the whole thing),
  - the temperature of the "food" (when and how to measure the temperature), and
  - how long it takes to heat up (when and how to start timing).

Display **slide T**. Say, *So, I hear you saying we all need to be sure to record the same kinds of data because we're going to want to know whether we have met our criteria and constraints.* And it sounds like a matrix of criteria and constraints will really help us test our designs. I have a handout for you that's called just that—a Design Testing Matrix—and it lists our criteria and constraints across the top and has a row for you to collect data from your test in this lesson. The other rows will be for collecting other data later.*

Display **slide U** and then **slide V**. Say, *And as you mentioned, we have some procedures for everyone to follow that will help us stay safe and collect accurate data.* We need to complete all of the following:*

- *Find the mass of the entire flameless heater with food, packaging, and reactants. (You could measure those separately and add the amounts or find the total mass after you've assembled everything but before the reaction begins, depending on your design.)*
- *Test your heater on a tray (do not include that mass as part of your total—it's there just in case of spills).*
- *Be sure your reactant container is vented.*
- *Begin watching the clock as soon as reactants are combined and watch for at least 10 minutes (until the food temperature starts to decrease).*

*** Attending to Equity**

This discussion might be a good time to remind students that this task is not a competition, and we will not be declaring a winner. We are all trying to develop a device that will help people. It is possible, even likely, that several proposed solutions will work pretty well. You may have some students who need support building a growth mindset—"This is hard work, but we're sticking with it because that's how we can get better at hard things. We're working to get better, not to win. If we see someone else who is successful where we're not, we can think, 'What are they doing that I can try, too?'"

- *Follow the directions on your how-to instructions about whether to swirl or stir the reactants.*
- *Measure the food temperature at least every 5 minutes by putting the probe into the "water bead soup" (without touching the container).*
    - *Record times and temperatures in your science notebook so that you can see at what time the food reached its maximum temperature.*
- *Follow our classroom instructions for cleaning up: what materials to rinse and reuse, how to collect "spent" reactants and liquid, what to put in the trash or not, and so forth.*

Create a simple data table in science notebooks. Display **slide W** and direct students to make in their notebook a simple table (such as the one shown on the slide) to collect the time and temperature data for their design. Also have them consider the system interactions involved that cause the temperature change.

Distribute *Design Testing Matrix and display slide X.** Instruct students to add this matrix to their science notebook (over two pages, as shown on the slide).

Update the table of contents. As a reminder, have students periodically update the table of contents in their science notebook. If they don't have time now, you may choose to have students come back to this task during testing next time while they're waiting to record temperatures and so forth.

Tell students that now that we have all our testing procedures in place, we are ready for testing when we come to class next time!

End of day 2

9. Test prototypes.

20 MIN

Materials: Testing Prototype Homemade Heaters, science notebook, *Design Testing Matrix*, *Engineering Design Rubric*

Navigate into today's work. Display **slide Y** and be sure everyone is ready to be safe and record today's test data in their notebook. Display **slide Z** and briefly review the protocol for testing designs and cleanup (show **slide AA**, then flip back to **slide Z** for testing).

Alternate Activity

Extension: If resources are available, you may direct students to take photos or videos of their designs at several points during testing. These images might be helpful in informing future redesigns and/or communicating with others about their designs.

Collaboration

You may choose to have team members take on certain roles during testing. For example, one person might be in charge of reading temperatures on the thermometer, another person records data, and a third takes photos (see

*** Attending to Equity**

Universal Design for Learning: If you think it would be helpful for supporting the executive function of your students, you might create a handout checklist of these procedures (including steps specific to your classroom) so that students can self-monitor their *actions and expressions* during design testing.

*** Supporting Students in Engaging in Analyzing and Interpreting Data**

A grade 3–5 element of this practice is for students to enter data in tables and other displays to reveal patterns. Although this is an earlier grade-level element for this practice, students are being introduced to this scaffold here to help them in Lessons 7–9 to develop the practice of analyzing data to define an optimal operational range for their proposed design solution. Students will be working together within their groups and the class to help them refine their design solutions. By Lesson 10 students will be able to use a similar scaffold to independently design and optimize a solution for a different problem.

above). Another option is to have team members take turns in these tasks throughout testing in order to allow everyone a chance to participate in each of these parts of testing.

Distribute *Engineering Design Rubric* for students to begin reading during testing downtime. Say, *This is the rubric you will use to assess your work as engineers after testing. In order to use our time wisely, read through this rubric while you're waiting between temperature checks and other observations of your flameless heater design. You'll have time after testing to fill out the rubric as a team.*

Direct teams to get to work testing their designs. As teams are working, circulate to check in and be sure teams are assembling and using their devices as indicated in their designs and how-to instructions.

Provide reminders for cleanup as needed. As teams finish their tests, display **slide AA** and be sure they are collecting liquids and rinsing containers as directed.

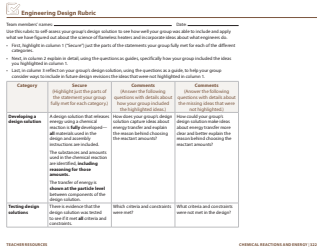
10. Self-assess engineering practices in teams. 7 MIN

Materials: *Engineering Design Rubric*, highlighters

Complete the *Engineering Design Rubric* in teams. Display **slide BB**.

Say, *Take some time with your team to assess how well your team has been able to apply what you've figured out about what engineers do. I will use this same assessment rubric to assess your work, as well. After another redesign in the future, we all will reassess our engineering work again to see the progress we've made. Remember to continue to follow our expectations for teamwork as you decide together how to rate your work.*

Give teams time to complete the rubric and hand it in as they finish for you to use, as well.



Engineering Design Rubric

Team members' names: _____ Date: _____

Use this rubric to self-assess your group's design solution to see how well your group was able to include and apply what we have figured out about the science of flameless heaters and incorporate ideas about what engineers do.

- First, highlight in column 1 ("Secure") just the parts of the statements your group fully met for each of the different categories.
- Next, in column 2 explain in detail, using the questions as guides, specifically how your group included the ideas you highlighted in column 1.
- Last, in column 3 reflect on your group's design solution, using the questions as a guide, to help your group consider ways to include in future design revisions the ideas that were not highlighted in column 1.

Category	Secure (Highlight just the parts of the statement your group fully met for each category.)	Comments (Answer the following questions with details about how your group included the highlighted ideas.)	Comments (Answer the following questions with details about the missing ideas that were not highlighted.)
Developing a design solution	A design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design and assembly instructions are included. The solutions and amounts used in the chemical reaction are identified, **including reasoning for these amounts.** The transfer of energy is **chosen at the particle level** between components of the design solution.	How does your group's design solution capture ideas about energy transfer and explain the reason behind choosing the reactant amounts?	How could your group's design solution make ideas about energy transfer more clear and better explain the reason behind choosing the reactant amounts?
Testing design solutions	There is evidence that the design solution was tested to see if it met **all** criteria and constraints.	Which criteria and constraints were met?	What criteria and constraints were not met in the design?

TEACHER RESOURCES CHEMICAL REACTIONS AND ENERGY | 522

Assessment Opportunity

Building towards: 6.A.2 Undertake a design project to construct and test a solution that meets specific design criteria and constraints, including the transfer of energy.

What to look for and listen for: Collect *Engineering Design Rubric* from teams and use *Engineering Design Rubric* to do your own formative assessment on each team's design solution.

What to do: At this point in the unit, this rubric rating should be considered a formative assessment as students will have more experiences with engineering design in upcoming lessons. For example, teams will likely all score no evidence or missing on "Combining parts of design solutions" in this lesson because they will not have had a chance to compare their design with other teams' designs until Lesson 7. Likewise, it is not expected that teams will be at the secure level for "Optimizing design solutions" until Lesson 9 when they have had a chance to redesign based on their work leading up to that lesson. When teams (and you) reassess their work in Lesson 9 using this same rubric, they should be able to show growth in these engineering design practices.

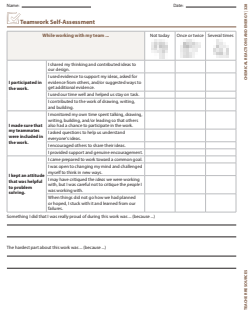
11. Self-assess teamwork individually.

3 MIN

Materials: science notebook, *Teamwork Self-Assessment*

Complete the *Teamwork Self-Assessment* individually. Display **slide CC**. Direct students to turn back in their notebook to the *Teamwork Self-Assessment* they taped in it on day 1 of this lesson. They should take the next few minutes to individually reflect on their work with their team and independently complete this self-assessment.

This assessment is intended as a space for student reflection, but if you are interested in responding to their thoughts, you might ask students to leave their notebooks open to this page at the end of class today so that you can see it.



Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I used evidence to support my ideas, asked for evidence from others, and/or suggested ways to get additional evidence.			
	I used our time well and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I limited how much time I spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged myself to think in new ways.			
	I may have critiqued the ideas we were working with, but I was careful not to critique the people who had the ideas.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

The hardest part about this work was ... (because ...)

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12. Update Progress Tracker.

10 MIN

Materials: science notebook, What We Do as Engineers board, 3" x 3" sticky notes, markers

Update Progress Trackers. Display **slide DD**. Direct students' attention to the What We Do as Engineers board and use prompts such as the following to reflect on today's work.

Suggested prompts	Sample student responses
Think about the work you did in this lesson. What did you do as engineers that's already posted on this board?	*We proposed design solutions—these designs were different from the ones we first proposed on our own at the very beginning of the unit!* *Again, we systematically tested several possible design solutions.* *But this time, we tested the whole designs and not just parts of them!*
Why several design solutions, if each group only tested their own?	*Well, no group's design was the same, so as a class we tested several possible solutions.*
And how was it systematic?	*We all were testing against the same criteria and constraints in our Design Testing Matrix.*

Say, *OK, I think we need to add something to our What We Do as Engineers board to show that we came back to proposing designs again. We already have sticky notes here, so I'm just going to add another end to this arrow to show that we've gone back and forth between developing solutions and optimizing them. And again, this systematic testing of different solutions was a big part of what we did as engineers. Take a moment to write in your Progress Tracker about what you learned from this testing—how will it help you in your designs?* Add a point to the arrow that is between "Optimize" and "Develop Solutions" so that the arrow is bidirectional.

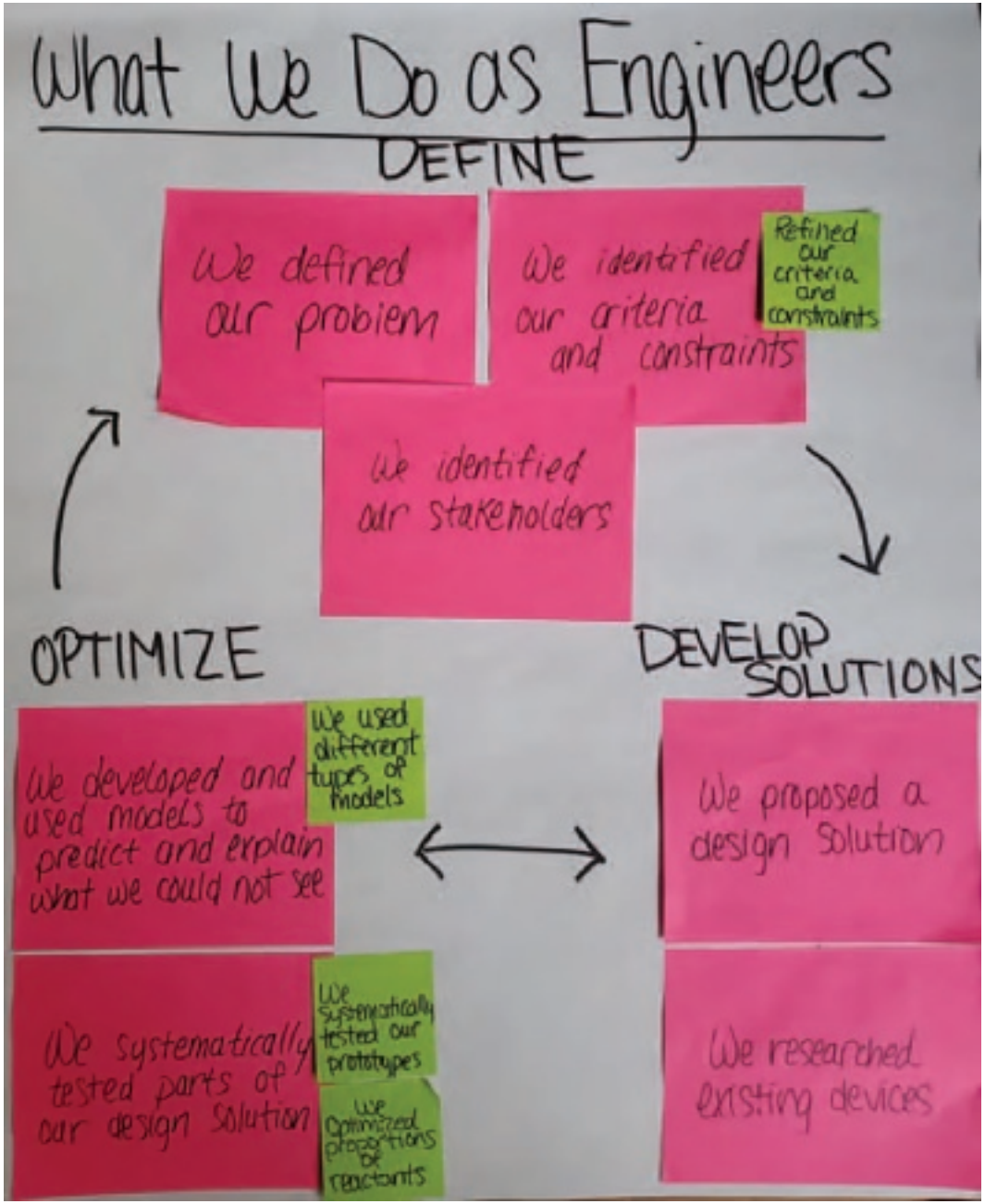
After a few minutes of writing time, continue the discussion with prompts such as these.

Suggested prompts	Sample student responses
Think back to the work we needed to do to prepare for today's testing. What did we do as engineers that may or may not already be on our board?	*We had to do a lot of planning.* *We had to get our designs approved.* *We had to draw designs before we could build prototypes.*
Do we see something like that on our board already?	*We have "We developed a model to help us plan for how we can improve our design."*
How was what we did this time different from the Energy Transfer Model we made when we wrote that on our board?	*Those were showing how the energy moved through the different systems, but the models we made this time were about the whole heater—materials, energy transfer, and how-to instructions.* *And those were just the on-paper drawn models. After that we built models to test called prototypes.*

Say, *OK, so I hear you saying that we're making models again to plan for how to improve our design, but we used different kinds of models. So let's add a smaller sticky note to the board here under the optimize category for "different kinds of models." Then you all take a moment to write in your Progress Tracker what you have figured out from using those different models that helped you with your design.*

See an example here of possible student responses in the Progress Tracker as well as an image of the updated What We Do as Engineers board.

What did we do as engineers?	What did we figure out that can help us with our designs?
We systematically tested parts of our design solution.	We have more test data to inform our next redesign. We're working repeatedly to refine and improve our design.
We developed different types of models to help us plan for how we can improve our design.	• Designs are a type of model, they create a solution to a problem using components, interactions, and mechanisms. • Modeling on paper helped us plan how things would work without using up materials. • Modeling on paper and creating instructions helped us communicate about our design to others (such as our teacher). • Building a prototype helped us test how our design actually works.


What We Do as Engineers
DEFINE
We defined our problem
We identified our criteria and constraints
Refined our criteria and constraints
We identified our stakeholders
OPTIMIZE
DEVELOP SOLUTIONS
We developed and used models to predict and explain what we could not see
We used different types of models
We systematically tested parts of our design solution
We systematically tested our prototypes
We optimized proportions of reactants
We proposed a design solution
We researched existing devices

13. Complete an exit ticket.

5 MIN

Materials: *Exit Ticket*

Reflect on design solutions using *Exit Ticket*. Say, *You all worked really hard to design and test your flameless heaters, but there are still ways we can improve them, right?* Display **slide EE**. *To help us think about how we can improve our designs we need to consider how different components or systems of our design are interacting with each other in order to transfer energy to heat up our food to 40–47 degrees Celsius. Let's return to our Energy Transfer Model to help us reflect on our designs so that next class we can begin to discuss ways of improving them.*

Pass out *Exit Ticket*. Allow time for students to map out their designs using the Energy Transfer Model. Collect *Exit Ticket* as students leave class.

Exit Ticket

This exit ticket serves two purposes: (1) to assess how students are connecting the science ideas and system interactions in their designs and (2) to provide a space for students to reflect and consider ways their designs can be improved in future redesigns. If time is running short, consider giving *Exit Ticket* for Lesson 7 since it is an important reflection and formative assessment.

Assessment Opportunity

Building towards: 6.B Apply scientific ideas, results from testing designs, and the interactions identified on system models to modify our designs in order to improve the flow of energy to food.

What to look and listen for: Students should be able to connect and compare the results from testing their designs to the Energy Transfer Model. Students should be able to identify and map the different components in their designs to the different systems in the Energy Transfer Model. Students should then be able to update their designs and explain ways to optimize the energy flow to the food. See *Exit Ticket Rubric* for additional information.

What to do: If you notice that students are struggling with finding ways to optimize and improve their designs, follow up with these students in Lesson 7 as they compare and discuss in groups the differences in designs. Ask students to think about how these differences in designs impact how energy is being transferred to the food. Students will have another opportunity in Lesson 9 to connect their final designs to the Energy Transfer Model. So you can take that opportunity to revisit this idea and ask the students how each of their different models is helping them plan and test their proposed designs.

ADDITIONAL LESSON 6 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

CCSS.MATH.CONTENT.6.RP.A.3.A Make tables of equivalent ratios relating quantities with whole-number measurements, find missing values in the tables, and plot the pairs of values on the coordinate plane. Use tables to compare ratios.

During this lesson and Lesson 9, students will scale up the amount of reactants to use in their homemade heaters but maintain the same proportion of reactants they found to be most efficient in previous testing.

CCSS.MATH.CONTENT.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."*

CCSS.MATH.CONTENT.6.RP.A.3.D Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

During this lesson and Lesson 9, students will need to calculate the correct amounts of hydrated water beads and plain water to make "water bead soup" as a proxy for food in their prototype heaters. The ratio of water beads to plain water is 1:3 (1 part water beads to 3 parts water), and students will measure the beads and water in grams.

LESSON 7

How did our design compare to others in the class?

Previous Lesson

After a discussion about packaging materials and how-to instructions, we worked in teams to revise our designs for our homemade flameless heaters. We built prototypes and tested them using a Design Testing Matrix based on our criteria and constraints. We reflected on our work with self-assessments of our engineering work and our teamwork.

This Lesson

Problematizing

1 DAY

We provide and receive critiques about our flameless heater designs with other teams and work as a class to identify the most promising design characteristics. As we do this, we realize that we don't know how to evaluate how easy our design instructions are to follow because we never had anyone else put them together. We decide to have another group test how easily they can follow our instructions in our next redesign.

Next Lesson

We will use the design characteristic ideas that are most promising to investigate if making those changes will affect other characteristics of our design and how this could impact stakeholders. Our team will use this information to decide which changes we want to implement in our final homemade heater designs.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

7.A Respectfully provide and receive critiques about design solutions to evaluate competing designs with respect to how they meet criteria and constraints and consider patterns across multiple designs to determine which design characteristics caused more-effective outcomes in performance.

What Students Will Figure Out

- We identify which design characteristics cause the best performance, and we want to optimize our flameless heater designs by incorporating different combinations of these characteristics.
- We need to systematically examine how changes in one part of our design might cause changes in another part.
- We need other groups to test our designs to see if our instructions are clear.

Lesson 7 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	2 min	**NAVIGATION** Prepare for sharing their designs with partner teams.	A	*Design Testing Matrix*
2	25 min	**EXCHANGE IDEAS WITH PARTNER TEAMS** Share designs with partner teams.	B-C	*How-to Instructions Must-Haves*, *Design Testing Matrix*, 2 tables from *Peer Feedback on Designs* cut apart, 2-3 3" X 3" sticky notes, space for partner teams to share designs
3	12 min	**SHARE IN A WHOLE-CLASS DISCUSSION THE MOST PROMISING DESIGN CHARACTERISTICS** Meet in the Engineers Circle to share and record the most promising design characteristics.	D	*Design Testing Matrix*, tables from *Peer Feedback on Designs*, instructions with sticky note feedback, chart paper, markers
4	3 min	**ADD TO OUR PROGRESS TRACKERS** Update students' Progress Trackers.	E	What We Do as Engineers board, 3" x 3" sticky notes, markers
5	3 min	**INDIVIDUALLY RANK CRITERIA AND CONSTRAINTS** Individually consider priorities among criteria and constraints and the consequences of making certain changes.	F-G	*Design Testing Matrix*, tables from *Peer Feedback on Designs*
				End of day 1
		SCIENCE LITERACY ROUTINE		Student Reader Collection 3: *Putting Ideas to Work*

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• *Design Testing Matrix* • *How-to Instructions Must-Haves* • 2 tables from *Peer Feedback on Designs* cut apart • 2-3 3" X 3" sticky notes • tables from *Peer Feedback on Designs* • instructions with sticky note feedback • science notebook	• space for partner teams to share designs • tables from *Peer Feedback on Designs*	• chart paper • markers • What We Do as Engineers board • 3" x 3" sticky notes

Materials preparation (10 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Print a copy of *Peer Feedback on Designs* for each student. Cut apart the two tables in *Peer Feedback on Designs*. Each student will get two tables.

Based on each team's design performance in Lesson 6, plan team pairings for feedback rounds.

Prepare chart paper for the Engineers Circle discussion to record the most promising design ideas for each criterion and constraint.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

In the previous lesson, students tested their flameless heater designs and collected data to inform their next redesign. The small- and whole-group discussions in this lesson allow students to identify the most promising design features of a flameless heater and begin to think about what changes they want to make to their team's design and what consequences might occur as a result of those changes. This lesson gives students opportunities for authentic scientific communication, including supporting claims about performance with evidence from investigations, providing and receiving critiques, and asking questions for clarification.

Where We Are NOT Going

Sharing current design solutions with others and engaging in reciprocal feedback is an important aspect of engineering design. Students may be very excited and have new ideas about how to optimize their designs. Although it is productive for students to be thinking about their priorities for design modifications, decisions about specific changes should wait until a systematic look at potential consequences of any change is done in the next lesson.

In the spirit of collaboration, sharing of design performance should not be a competition. Teams should stay focused on sharing what worked or didn't work and collaboratively agree on the most promising design solutions. The norm-setting step is important for reminding students that giving and receiving feedback takes vulnerability. Critiques should be focused on design performance not team members or their actions.

LEARNING PLAN FOR LESSON 7

1. Navigation

2 MIN

Materials: *Design Testing Matrix*

Motivate the need to share ideas with others. Display **slide A**. Say, *In our last lesson, we tested our prototype designs and had some exciting results. Look back at your Design Testing Matrix and think about the performance of your design against the criteria and constraints.*

Suggested prompts	Sample student responses
Is there one particular characteristic you'd like to improve? Think about this quietly for a moment.	*(Pause briefly to let students think. No need to go public with responses.)*
Many of us may not know exactly what to do, so how might it be helpful to learn about the performance of other teams' designs?	*(Allow 1 or 2 students to answer and listen for ideas about learning from each other through feedback.)*

2. Exchange ideas with partner teams.

25 MIN

Materials: *How-to Instructions Must-Haves*, *Design Testing Matrix*, 2 tables from *Peer Feedback on Designs* cut apart, 2-3 3" X 3" sticky notes, space for partner teams to share designs

Discuss norms for giving and receiving feedback.* Display **slide B**. Ask students to revisit the classroom norms and to share ideas for which norms are especially important when giving and receiving feedback. Allow a few students to quickly share their thinking with the class and listen for ideas such as the following:

- We critique ideas, not people.
- We encourage other voices that haven't been heard yet.
- We listen carefully and ask questions to help us understand.

Say, *These are all important to help us learn from one another as we share our designs with other teams. You will want to ask questions related to the team's designs and instructions. Listen carefully to learn more about their thinking and reasoning. You will respond in the same way. These are important communication skills for science and engineering as well as in all of your classes. Have any of you worked on these skills in your Language Arts classes?*

Additional Guidance

Students may respond that they have because this skill is emphasized in CCSS.ELA-LITERACY.SL.7.1.A and CCSS.ELA-LITERACY.SL.7.1.C. See the end of this teacher guide for more details. Consider talking with the students' ELA teacher about how to support this standard.

*** Supporting Students in Engaging in Argument from Evidence**

Sharing ideas clearly and persuasively is an important aspect of scientific communication. As students are engaged in cross-team discussions, circulate and encourage presenting teams to cite evidence to support the performance of different design characteristics. Partner teams should ask clarifying questions to elicit details that reveal *why* a particular design feature leads to improved performance.

Give teams time to share and compare their how-to instructions and designs with two other teams. Display **slide C** and use it to explain the process for sharing designs among teams. Explain the following:

- 2 min: Have each team exchange the instructions for building their design to scale (from Lesson 6). Each team should give feedback to their partner team's instructions by writing feedback on sticky notes and adding to the team's How-to Instructions written at the bottom of *How-to Instructions Must-Haves*. Ask clarifying questions or give feedback that will help them improve their instructions.
- 6 min: Each team will have 3 minutes to verbally share their design with their partner team. Partner teams should record information about how the presenting team's design performed.
- 4 min: Then partner teams will have 4 minutes to individually give written feedback using the guiding questions in their *Peer Feedback on Designs*. Teams may discuss the presenting team's design during this time, if needed for clarity, but groups should be mindful of the time so that each person can think about and give helpful feedback to their partner team.
- Partner teams give each other the completed feedback tables from *Peer Feedback on Designs* and return the instructions with sticky note feedback added before parting ways.
- Teams will complete two rounds of sharing using this process. Each round should take a total of 12 minutes. Determine a method for timekeeping to ensure that all teams have time to share, receive, and give feedback.

Say, *Listen carefully to the successes that other teams have experienced with their designs because we will come together in the Engineers Circle to share the most promising ideas. It may be useful for you to make notes in your science notebook about promising ideas so that you can reference them later in our whole-group discussion and when you are making decisions about the next revision of your team's design.**

Circulate and listen in as students are sharing their designs with partner teams. Push students to back up the performance of different design characteristics with evidence from their investigations and encourage students to listen to, compare, and critique the designs of partner teams.

Assessment Opportunity

Building towards: 7.A.1 Respectfully provide and receive critiques about design solutions to evaluate competing designs with respect to how they meet criteria and constraints and consider patterns across multiple designs to determine which design characteristics caused more-effective outcomes in performance.

What to look for

- Students cite evidence to support the performance of different design characteristics.
- Students share and partner teams ask clarifying questions to elicit details that reveal *why* a particular design feature causes improved performance.

What to do

- If students are struggling to back up their ideas with evidence, direct them to *Design Testing Matrix*.
- Students should also be encouraged to ask clarifying questions that reveal underlying reasons for how particular characteristics performed. Provide sentence starters, such as those listed above, to support students in this task.

Universal Design for Learning: Students may benefit from sentence starters to help them express what they know. Consider providing some sentence or question starters, such as the following:

- This characteristic of our design led to better performance because _____.
- The evidence that supports the effectiveness of this characteristic of our design is _____.
- Why do you think that characteristic of your design resulted in _____?
- How do you know that characteristic of your design was important to performance?

*** Supporting Students in Engaging in Argument from Evidence**

Students have the opportunity here to respectfully provide and receive critiques about their design solutions. Encourage students to base their critiques on how well the design solution meets the criteria and constraints. Encourage students to ask and respond to questions in their allotted time. If students are reluctant to ask questions, provide them with some sentence or question starters to help them begin the discussion. Remind students

Collaboration

To keep the focus of sharing and feedback on identifying successes, make careful decisions about which groups are paired together. Pair teams that had similar levels of success in Lesson 6 and avoid pairing teams with the highest functioning and lowest functioning designs together. To save time, determine and post partner teams before class.

that we are evaluating and critiquing the designs, not the students.

Students will have the opportunity to respond to questions and feedback provided in this activity during Lesson 8 when they are considering revisions to their designs.

3. Share in a whole-class discussion the most promising design characteristics. 12 MIN

Materials: *Design Testing Matrix*, tables from *Peer Feedback on Designs*, instructions with sticky note feedback, science notebook, chart paper, markers

Examine feedback on team designs. Teams take 2 minutes to examine the two tables of feedback from their partner teams as well as the feedback on their instructions. Ask students to highlight or annotate the feedback they find the most valuable to use in their redesign and then ask them to put the tables aside to use again at the end of the lesson. Feedback on the instructions will be used again to make specific changes to their instructions in a later lesson.

Gather the class in the Engineers Circle.* Display **slide D**. Say, *It sounds like you all learned a lot by sharing your designs with partner teams. Let's meet in the Engineers Circle now to share and record the most promising design characteristics.*

Create a record of the most promising design characteristics.* Display chart paper to record the class discussion of the most promising design characteristics. Encourage students to record revision ideas in their notebook as they listen to teams share their designs and identify the most promising design characteristics. Tell students that they will have the opportunity in Lesson 8 to consider the feedback and questions they have received as well as consider other revision ideas.

*** Supporting Students in Developing and Using Stability and Change**

As students share their ideas about promising design characteristics, they may naturally begin to think about and discuss the cascading consequences of making changes to their team design. For example, using a lower-cost container might give them more money for reactants, but using more reactants will change the mass of the system. This thinking can be leveraged in Lesson 8 when students will systematically document how changes in one part of their designed system will affect other parts. Keep the focus of this discussion on identifying the most promising design characteristics but encourage students to write down their ideas about the consequences of making changes for reference in future lessons.

Assessment Opportunity

Building towards: 7.A.1 Respectfully provide and receive critiques about design solutions to evaluate competing designs with respect to how they meet criteria and constraints and consider patterns across multiple designs to determine which design characteristics caused more-effective outcomes in performance.

What to look for

- Students cite evidence to support the performance of different design characteristics.
- Students are able to support any claims they make with evidence and reasoning.
- Students are asking questions to elicit details important to meeting the criteria and constraints.
- Students also have the opportunity to respond to clarifying questions.
- Students identify design features that cause more-effective outcomes in the performance of their MRE.

What to do

- If students are struggling to back up their ideas with evidence, direct them to *Design Testing Matrix*.
- Students should also be encouraged to ask clarifying questions that reveal underlying reasons for how particular characteristics performed.
- If students give feedback such as "sounds good" or "unclear," ask the receiver if the feedback will help them improve their design or if more specifics would be helpful. Students will likely share that this more-general feedback is not extremely helpful but that more-specific feedback about what was good or what parts were unclear would help them improve their designs. This exchange will help students give more-productive feedback and critique to their peers.
- When you question students, use questions such as "What design feature do you think caused the MRE to perform as it did?" or "What pattern do you identify in these tests that is similar, and how did that cause the MRE prototype to perform the way it did?" Emphasizing the cause-and-effect relationship that students identify by seeing patterns in the data is the CCC emphasized in this lesson.

Begin a discussion by asking, *Can someone share a design characteristic they saw or heard about from a partner team that they'd like to try in their team's design or that they think might improve the performance of their team's design?*

Some examples may include the following:

Design characteristic	What was promising? What were the trade-offs?	Why was it effective?
Reactants were in a cylinder that food surrounded.	*This really helped it get to a high temp (49°C), but it pushed the cost over $3.*	*It maximizes contact between reactants and food.*
They used all-glass containers.	*It held the temperature for a long time and didn't use that many reactants to get to temperature.*	*The glass insulated the heat so that the energy couldn't be transferred out.*
They used all plastic.	*This made the design lightweight, but heat transferred away from the food to the environment too quickly.*	*Lightweight materials would make the homemade heaters easier to carry and allow more weight to be used for food or reactants.*
The amount of food was 150 grams.	*This made less food to heat up, but it might not be enough food to fill everyone up.*	*Less food to heat up means that less energy transfer is required from the heater system to the food system.*
Images were included with each step of the instructions.	*This helped us understand the how-to instructions a lot better but will take time to do. It might push up the cost of instructions.*	*Visual images will work for any language that people use. Also, a visual helps communicate details that words cannot easily describe.*

*** Supporting Students in Developing and Using Patterns**

Students will be identifying patterns in the class data to identify cause-and-effect relationships. For example, several teams may have used a particular design that caused there to be more energy transferred to the food. Use the term *cause and effect* to highlight this relationship that students identify and ask them questions so that they link the relationship to a pattern they see in the data. Support students in using cause-and-effect relationship language as they are identifying the patterns they see in the data. This will support their development of the crosscutting concept patterns to identify cause-and-effect relationships.

Keep track of promising ideas for design characteristics on the chart paper and help students connect to the criteria and constraints on *Design Testing Matrix* by asking which criterion or constraint(s) the design characteristic addressed as they share. Highlight patterns by asking students to identify them as teams share ideas. As they identify patterns, encourage them to identify design characteristics that caused the design to perform well or meet the criteria.

After each team has an opportunity to share, review the chart and engage students in a discussion using the example dialog below.

Suggested prompts	Sample student responses	Follow-up questions
Did we address all of our criteria and constraints?	*Yeah, most of them.*	*Which ones do we have promising ideas for?*
Do we have a promising idea for cost?	*Yes, one team cut costs by using an oatmeal bowl!*	*What other promising ideas do we have?*
What about the mass?	*Not really.*	*Does anyone have a suggestion for the mass that we can add to the chart?*
Do you have suggestions to add to the chart for clear and easy-to-follow instructions?	*Well they need to make sense!* *The instructions we read were clear, but we had some suggestions.*	*So we agree that we all can make our instructions clearer.* *If our instructions weren't clear, what effect might that have on the use of these devices?*
Do we have any evidence that these instructions work?	*They were clear.* *But we didn't try them out—we really don't know if they work.*	*Do you think that is something we should do once everyone has a chance to revise their instructions?* *Do you have any suggestions for how to give this criterion a fair test?*

Explain to students that the data collected on this chart will inform our work moving forward.

4. Add to our Progress Trackers.

3 MIN

Materials: science notebook, What We Do as Engineers board, 3" x 3" sticky notes, markers

Update our Progress Trackers. Display **slide E**. Stay in the Engineers Circle and direct students to the Progress Tracker section of their science notebook. Say, *We really learned a lot by sharing and comparing our designs with one another. This is an important practice of engineers.* Say, *So, how did comparing with other teams help us in our designs? Record on the right side of your tracker what you learned from comparing designs with other teams.*

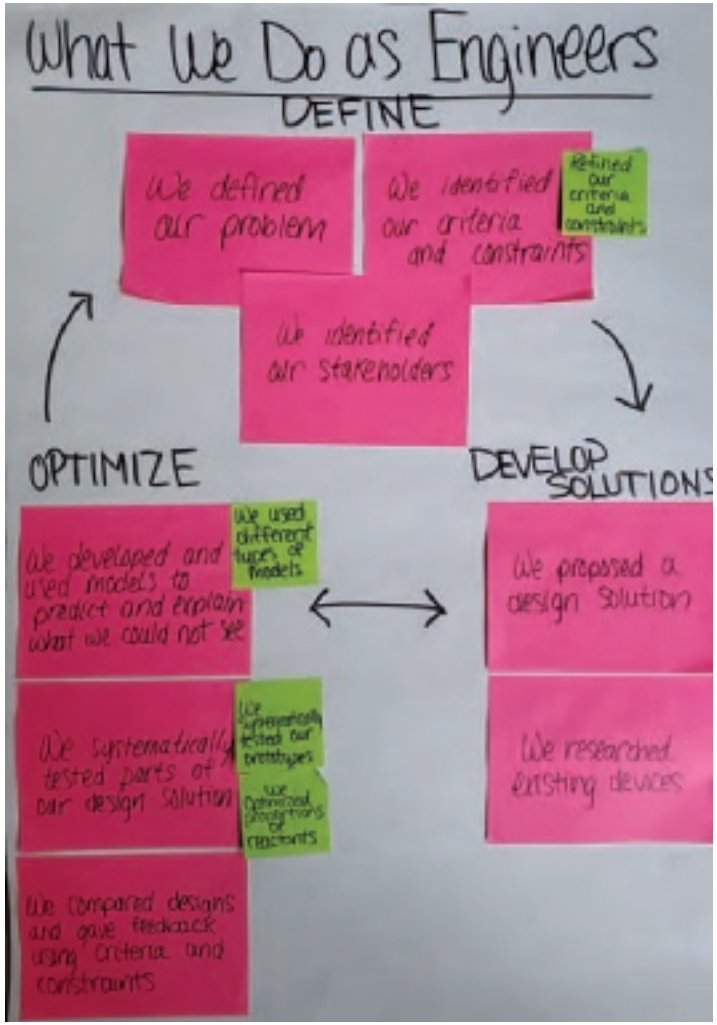
Suggested prompt	Sample student responses
What should we record in our tracker? What did team sharing look like?	*We shared how our designs performed for each criterion and constraint.* *We shared feedback with partner teams about how well their design performed for each criterion and constraint.*

Say, *OK, let's capture that on the left side of our Progress Tracker.* Write on a large sticky note or half sheet of paper the bulleted text shown on the left side in the table below to add to the What We Do as Engineers board.

What did we do as engineers?	What did we figure out that can help us with our designs?
• We compared designs and gave feedback based on the results of their performance against defined criteria and constraints.	• We have some ideas about which characteristics lead to the best performance outcomes in our designs.

Ask students to identify what they plan to do with the information they learned from sharing with partner teams.

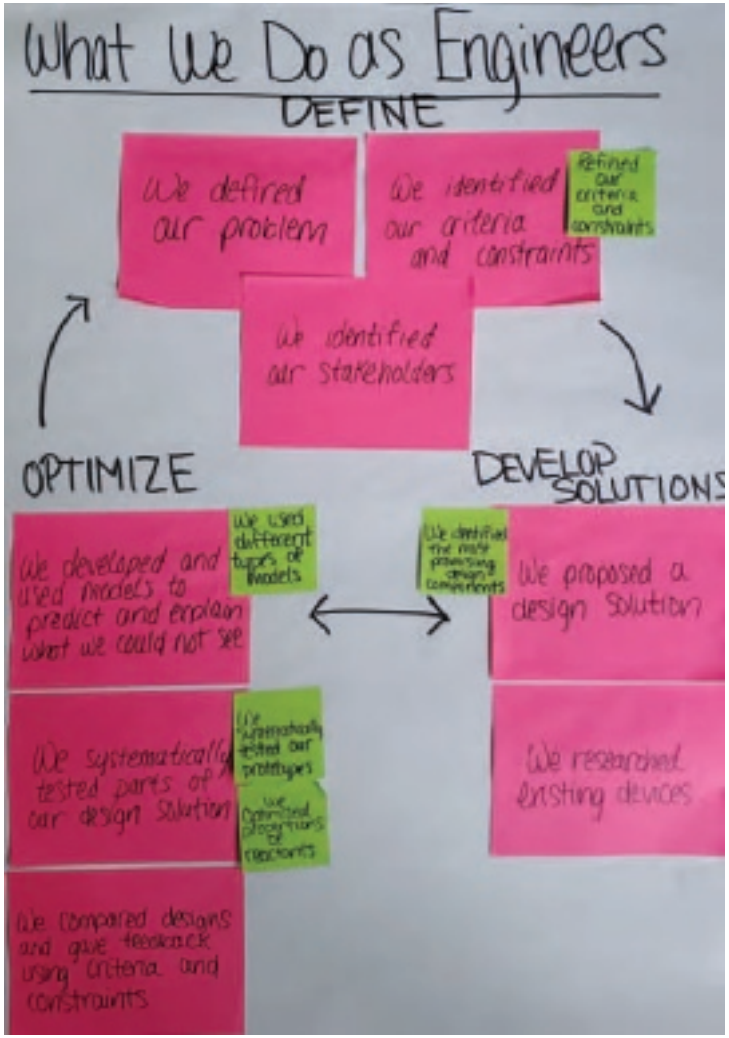
Suggested prompt	Sample student responses
How are we using the information we learned from sharing our designs with partner teams? How can we represent this on our tracker?	*We used the feedback to think about how to improve our own designs.* *We compared different designs and how they performed for each criterion and constraint and agreed on some of the most promising design characteristics.*



Write on a sticky note the bulleted text shown on the left side in the table below to add to the What We Do as Engineers board.

What did we do as engineers?	What did we figure out that can help us with our designs?
• We identified the most promising design characteristics.	• We want to make changes to optimize our designs by incorporating different combinations of characteristics in our designs to improve performance.

Say, *Let's add these ideas to our What We Do as Engineers board as well.*



5. Individually rank criteria and constraints. 3 MIN

Materials: *Design Testing Matrix*, tables from *Peer Feedback on Designs*

Rank each criterion and constraint. Display **slide F**. Say, *We have learned a lot about how different design characteristics performed, and it would be great if we could all use all the best characteristics. If we change too many things at once, we won't know which design characteristic helped or hindered performance.*

Ask students to individually look over their *Design Testing Matrix*, the feedback on the instructions they received, and the completed feedback tables from *Peer Feedback on Designs* they received from partner teams. Have them add a row to *Design Testing Matrix* and individually assign a numerical ranking (1, 2, 3 …) indicating what they think is the highest priority to change when they optimize their designs.

Motivate the need to share rankings with team members. Display **slide G**. Say, *You may be thinking about specific changes that would improve the performance of your design. Why is it important to share your rankings with your team members?* Give students the remaining time to answer the question on the slide in their notebook and remind them to be prepared to share the justification for their rankings with their team in the next lesson.

ADDITIONAL LESSON 7 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.7.1.A Come to discussions prepared, having read or researched material under study; explicitly draw on that preparation by referring to evidence on the topic, text, or issue to probe and reflect on ideas under discussion.

CCSS.ELA-LITERACY.SL.7.1.C Pose questions that elicit elaboration and respond to others' questions and comments with relevant observations and ideas that bring the discussion back on topic as needed.

During this lesson, students will listen to their partner teams share about their designs, take notes and give feedback about those designs, and then use that preparation to contribute meaningfully to a whole-class discussion about the most promising characteristics they have heard. Especially during the partner team sharing, students will be expected to pose questions about the other team's design and respond to questions about their own design using relevant observations and ideas. The teamwork expectations established in Lesson 6, for example, keeping the discussion focused on the work, also apply in this lesson.

SCIENCE LITERACY: READING COLLECTION 3

Putting Ideas to Work

1 **The Engineering Design Process**
2 **Famous Hollywood Engineers**
3 **Funky Failed Prototypes**
4 **Gathering Feedback**
5 **Engineering in Poetry**

Literacy Objectives

- ✓ Recognize the steps of a process.
- ✓ Determine how the design process is applied.
- ✓ Describe design failures that result in lessons.
- ✓ Identify methods of receiving relevant feedback.
- ✓ Interpret symbolism.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 5–7.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Write a poem that reflects the design process in response to the reading.

Instructional Resources

Student Reader

Collection 3

Science Literacy Student Reader, Collection 3
"Putting Ideas to Work"

Exercise Page

EP 3

Science Literacy Exercise Page
EP 3

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 5: How can we refine our criteria and constraints?
- Lesson 6: How can we redesign our homemade flameless heater?
- Lesson 7: How did our design compare to others in the class?

Standards and Dimensions

NGSS

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

MS-ETS1-3: (Building toward) 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.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

Science and Engineering Practices
Engaging in Argument from Evidence; Analyzing and Interpreting Data

Crosscutting Concept Cause and Effect

CCSS: English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

CCSS.ELA-LITERACY.W.7.2

Write informative/explanatory texts to examine a topic and convey ideas, concepts,

and information through the selection, organization, and analysis of relevant content.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

constraints **criteria**

engineering design process

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

quantifiable **simulate** **symbolism**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page

EP 3

2. Preview the assignment and set expectations. (Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Chemical Reactions and Energy unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.
  - *In "The Engineering Design Process," you will learn about steps in the engineering design process.*
  - *In the second selection, you'll read about Hollywood engineers that use the design process in popular movies.*
  - *"Funky Failed Prototypes" shows how design failures can lead to interesting applications.*
  - *In "Gathering Feedback,"you'll find out how engineers get and use relevant feedback.*
  - *The final selection presents poems that reinforce how the design process is important in many ways throughout time.*
- Distribute Exercise Page 3. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a poem about the engineering design process.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What is the engineering design process?	*a series of steps that engineers often take to create solutions to problems*
Pick an object in the room. How might the engineering design process have been used in creating the object?	*The chair was designed to solve the problem of providing a comfortable place for students to sit. Some criteria would be that it must be a certain height and support a range of weight. It also must be durable. A constraint may have been that the chair could only be made from metal and plastic or could only cost a certain amount of money to make.*
What can you learn from failure?	*You can learn what not to do.* *You can learn how to change your method or idea so that it does work.* *You can try to use the failed product for another purpose.*
How do you know that everything that people have made throughout time has been through an engineering design process?	*Every human-made object attempts to solve a problem. People identify a need for something before they make it. The need defines the criteria. People naturally work within certain constraints when trying to make something new.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
What are criteria?	*the standards that you use to decide whether something solves a problem or not*
What are constraints?	*limits or controls that restrict what you can do*
What might be your criteria for getting a new phone?	*high-quality camera* *lightweight* *fast speed* *face recognition* *a lot of storage space*

SUPPORT—Have students watch a video overview of the engineering design process.

Suggested prompt	Sample student responses
What might be your constraints for getting a new phone?	*money* *access to applications and websites* *adult permission*

- Refer students to the Exercise Page 3. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to create a poem about the engineering design process.*
  - *In the selections, you read about the process itself, applications of the design process, learning from failure, and getting feedback.*
  - *In the last selection, different poems expressed ideas about the importance of the design process.*
  - *Think about what you can say in a poem about the design process itself, applications of the design process, failures, or feedback.*
  - *Your poem can be rhyming or in any form.*
  - *The poem must provide information about the engineering design process.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 3

4. Facilitate discussion.

(Friday)

Facilitate class discussion about the reading collection and writing exercise.

The five reading selections help to explain what the engineering design process is and how it is applied in everything that people create to solve problems.

Pages 24–25 Suggested prompts	Sample student responses
What is the general purpose of the first selection, "The Engineering Design Process"?	*It describes each step of the design process.*
What are the three main phases of the design process?	*defining the problem, developing possible solutions, and then using testing and feedback to make the best solution*
Could you build something without criteria or constraints?	*Yes, you could aimlessly play around with materials, but it wouldn't have a clear purpose or solve a problem. Without criteria, you wouldn't know if your final product is successful or not.*

Student Reader

Collection 3

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 26–27 Suggested prompts	Sample student responses
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first selection was about defining the engineering design process. The second selection describes applications of the engineering design process in popular movies.*
Which of the films mentioned celebrates a real-life triumph of engineering problem solving?	Apollo 13 *told the real story of astronauts and engineers figuring out how to bring the crew home safely from space after damage to their spacecraft.*
What are some real-life constraints that make any of the fantasy engineering solutions described in these movies impossible?	*Students may or may not have seen the films to provide specific examples, but from the reading should be able to note that Stark's implanted arc reactor, shrinking people, and time travel in a modified car all surpass the limits of the real physical world.*

Pages 28–29 Suggested prompts	Sample student responses
What is the general purpose of the third article, "Funky Failed Prototypes"?	*It explains the importance of failure in the engineering design process.*
Describe a failure you experienced and what you learned from it.	*I put orange juice in my cereal instead of milk, and I could not eat it. I learned to check carefully before pouring liquid on cereal.* *I tried to glue the sole of my shoe back on, but the glue I used didn't stick. I learned I needed to use specific shoe glue.*
What is a prototype?	*a working or nonworking model of something that a designer and engineer create to show the look and purpose of something*

SUPPORT—Have students compare the words *criteria* and *constraint*. The word *constraint* can be broken into the prefix *con-*, meaning "with," and the root *strain*, meaning "to tie or bind." The word *constrain* means "with binding or ties." That contrasts with *criteria*, which comes from the Greek word *krites*, meaning "judge."

CHALLENGE—Have interested students research what lighting engineers do in movie production. Have them develop a demonstration to show the class the different choices and effects lighting engineers make when producing a movie.

EXTEND—Have students watch a video that shows what sound engineers do.

Pages 30–31 Suggested prompts	Sample student responses
What is the general purpose of the fourth article, "Gathering Feedback"?	*It explains the importance of getting feedback during the engineering design process and how to get reliable feedback from different sources.*
How might quantifiable feedback be more valuable than a written review?	*Being able to compare numerical scores gives you more specific feedback and tells you how well or poorly your work is received. Sometimes you can't tell from words how good your design or product really is or how your design compared to others.*
What are some benefits and disadvantages of peer reviews?	*A benefit is that peer reviews are done by people who share your knowledge and know about the type of work you do. So they can provide informative feedback.* *A disadvantage is that because peer reviews are conducted by experts, they may not have a good sense of how a product will be used by the public.*

Pages 32–33 Suggested prompts	Sample student responses
How does the last selection relate to the other selections in this collection?	*It helps you think about the achievements of engineering design in nature, in buildings, and in great public works like railroads.*
Dickinson's poem expresses the idea that once the engineer's work is done and the structure is built, it is easy to forget how much design and engineering work went into its creation. Think about a common object you use every day. How difficult was it to create?	*The poem reminds us that it takes a huge amount of effort to build anything. The lights in the room were created over decades. Engineers and inventors created light bulbs. Then they had to figure out how to bring them to buildings in cities and rural areas. Over the years, light bulbs and lighting systems have been tested and refined to provide just the right amount and kind of light at an affordable cost.*

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 3, students should write a poem about the engineering design process. It should be engaging and provide an insight into the process for others to learn from.

Use the rubric provided on the Exercise Page to supply feedback to each student.

LESSON 8

What effects might result from our design changes?

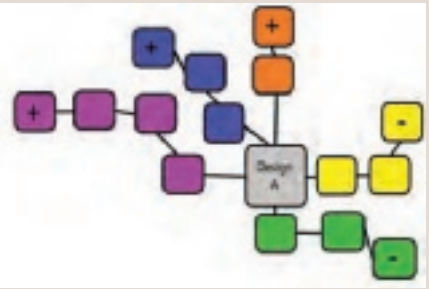
Previous Lesson

We compared our flameless heater designs with other teams and identified the most promising design characteristics. We realized that we need to make sure that we have another group test how easily they can follow our instructions in our next redesign.

This Lesson

Investigation, Putting Pieces Together

2 DAYS



We take ideas that we have about the most promising design characteristics for optimizing our designs and investigate whether making those changes will impact other characteristics of our design. We consider these downstream consequences and how they affect stakeholders differently. We use this information to come to a team consensus about the changes we want to implement.

Next Lesson

We will redesign, optimize, build, and test our homemade heaters. After we refine our instructions, we will exchange them with a partner team to test. We will reflect on how well our team works as engineers and how we meet expectations as teammates. Finally, we will revisit our DQB to address any remaining questions.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

8.A Evaluate competing design solutions based on jointly developed and agreed-upon design criteria using systematic processes to consider how small changes in one design characteristic might cause unexpected changes in other design characteristics.

8.B Prioritize criteria and consider trade-offs that occur as a result of design changes to decide which changes to incorporate for the optimal homemade heater design.

What Students Will Figure Out

- Intentional design changes result in unintentional changes to other design characteristics.
- Thinking about the ways in which stakeholders are impacted by design changes is important when making decisions about optimizing the design.

Lesson 8 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Reflect on the way students ranked criteria in the last lesson and check their justification by using data in combination with the criteria and constraints as evidence to support their rankings.	A-B	*Design Testing Matrix*
2	15 min	**BRAINSTORM WAYS TO CHANGE YOUR DESIGN** Use the Discussion Diamond protocol to share and compare our individual ideas regarding the ranked importance of criteria and constraints from Lesson 7 to come to a team decision about the changes we want to make to optimize our homemade heater design.	C-E	*Design Testing Matrix*, *Discussion Diamond Graphic Organizer*, Lesson 7 *Peer Feedback on Designs* completed by individuals from other teams, chart paper, markers
3	10 min	**BEGIN TO CONSTRUCT A CASCADING CONSEQUENCES CHART AS A CLASS** Work with the class to begin creating the first arm of the Consequences Chart to learn how to construct a Consequences Chart and to clarify any questions about the process.	F	*Design Testing Matrix*, chart paper, markers
4	20 min	**CONSTRUCT A CASCADING CONSEQUENCES CHART THAT INCORPORATES THE TOP-RANKED CHANGES FOR THE HOMEMADE HEATER DESIGNS** Work in teams to finish the Consequences Chart that incorporates the 2-3 changes on which each team came to consensus.	G	chart paper, markers
5	2 min	**NAVIGATION** Reflect on the consequences students have discovered and how they might use those to help with their design decisions.	H	
				End of day 1
6	5 min	**NAVIGATION** Discuss ideas that students have about how to use the information we learned during the last class to help us make the best design change decisions.	I	What We Do as Engineers board
7	15 min	**USE STAKEHOLDER IMPACT CHARTS TO MAKE FINAL DESIGN DECISIONS** Use a graphic organizer to compare the types of effects and the severity of the impact that students' design changes had on different stakeholders.	J	*Stakeholder Impact Chart*

8	15 min	**UPDATE PROGRESS TRACKERS AND WHAT WE DO AS ENGINEERS BOARD** Update Progress Trackers and the What We Do as Engineers board. We realize that, instead of a one-direction design "cycle," our design process is more like a web of ideas that can connect back and forth iteratively between any of the categories of the process.	K	What We Do as Engineers board, sticky notes, markers
9	15 min	**JUSTIFY PROPOSED DESIGN CHANGES** Record how students plan to change their designs and justify those decisions using knowledge of design tests, criteria and constraints, and impacts on stakeholders.	L	*Stakeholder Impact Chart* (optional)

End of day 2

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• Science Notebook • *Design Testing Matrix* • *Stakeholder Impact Chart* • *Stakeholder Impact Chart* (optional)	• *Discussion Diamond Graphic Organizer* • Lesson 7 *Peer Feedback on Designs* completed by individuals from other teams • chart paper • markers	• chart paper • markers • What We Do as Engineers board • sticky notes

Materials preparation (2 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Print one copy of *Discussion Diamond Graphic Organizer* per team. Print one copy of *Stakeholder Impact Chart* per student.

Optional: consult *Optional Extension—Cascading Consequences Practice.*

Be sure that you have materials ready to add the following term to the Word Wall: *cascading consequences*. Do not post this word on the wall until after your class has developed a shared understanding of its meaning.

Online Resources

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

Students create a Consequences Chart to think about what other design characteristics will change as a result of what we decided were some of the most promising design changes we would like to implement. Students will consider 2-3 changes to their design and investigate if there are any unintended consequences. We will evaluate the impact of the changes on stakeholders to decide what to use in our final homemade heater design.

Where We Are NOT Going

Students will be considering feedback about their designs in this lesson, but they will not yet address the feedback that was given about their instructions. When they write their final instructions in Lesson 9 they will revisit this feedback. With regard to design changes, we are not limiting students to a single change because it will likely be obvious that they should change 2-3 things based on what they learned in previous lessons. However, this is not a complete design overhaul. The idea is to use what they have learned to modify their design, not to start over from scratch.

LEARNING PLAN FOR LESSON 8

1. Navigation

5 MIN

Materials: science notebook, *Design Testing Matrix*

Navigate to today's work. Display **slide A** and ask students to individually look over their *Design Testing Matrix* on which they individually assigned a numerical ranking (1, 2, 3 …) indicating what they think is the highest priority to change when they optimize their designs. Say, *You have ranked the importance of these criteria and probably have some ideas about specific changes that you think will improve the performance of your design. Turn to the page in your science notebook where you wrote the justification for your top two rankings and look everything over to see if there is anything you would like to add or modify to your ranking or justification.*

Display **slide B**. Say, *As you check your work, make sure you are using specific data from prior investigations as evidence to explain your rankings. Use the sentence starter on the slide to test if you have included a justification for your top two choices.*

- *Our design could be improved if we change (which criterion/constraint) to (how you will change the criterion/constraint) because (how the change you propose will help your design meet the optimal criterion and fit within our constraint better).*

2. Brainstorm ways to change your design.

15 MIN

Materials: science notebook, *Design Testing Matrix*, *Discussion Diamond Graphic Organizer*, Lesson 7 *Peer Feedback on Designs* completed by individuals from other teams, chart paper, markers

Give directions for the Discussion Diamond protocol. Display **slide C**. Say, *In a moment, we will share our ideas with the rest of our team. To make it easy to compare ideas and give each person a chance to speak, we will use the Discussion Diamond protocol.* Pass out one copy of *Discussion Diamond Graphic Organizer* to each team. To begin, each team member will quickly jot in their corner of the handout the criteria and constraints they ranked as first and second most important.*

Display **slide D**. Say, *Now, one at a time, each person will have one minute to explain their ranking using specific data from past investigations as evidence to support their ideas.* Similar to the Talking Sticks protocol, no one gets to respond during round 1—each person is listening carefully to the speaker. After everyone has shared their justifications, begin round 2. In round 2, the purpose is to come to a consensus about which two or three things your team wants to modify for the final homemade heater design. The whole team has a chance to talk freely with one another, to ask questions to specific team members, and to add any ideas you may have thought of as other team members presented their ideas. Keep your Design Testing Matrix out and also consult Peer Feedback on Designs (which was completed by your partner teams) so you may use the information there to support your ideas during the discussion. The goal is for your team to be in agreement about which two or three elements to change by the end of this discussion. Record these two to three things in the center of the handout.*

Circulate to look and listen in as teams share their ideas with teammates. Stop in to ask clarifying questions to help students use specific data from their investigations in the context of the criteria and constraints as evidence to justify their choices.

*** Attending to Equity**

Universal Design for Learning: Working memory is very limited for any learner and even more-severely limited for many learners with learning and cognitive disabilities. Providing a graphic organizer, reminding students to refer to other documents for evidence, and embedding prompts for all students to use helps all students better visualize chunks of information. This will allow the pieces of information to be accessed easily, which is especially important to support *expression* during complex verbal practices like argumentation, explanation, and communication.

Assessment Opportunity

Building towards: 8.A Systematically evaluate competing design solutions based on jointly developed and agreed-upon design criteria using systematic processes to show how small changes in one design characteristic might cause unexpected changes in other design characteristics.

What to look for

- As students are explaining their top two changes in teams, listen for each team member using the data from previous investigations and how those relate to the criteria and constraints to justify their choices.
- As teams begin their consensus discussion, listen for students to surface potential negative effects of changes as they decide on which changes are best to implement.
- Look to see they are using their *Design Testing Matrix* to support their arguments.

What to do

- Circulate while teams are working to look at individual student notebook entries and listen for discussions during consensus building that are explicitly considering whether the changes will ensure the device will still align with the criteria and constraints. If students are only using the data to talk about more or less energy transfer, ask probing questions about *why* those data can be used as evidence to support their ranking to encourage them to put the data in the context of the criteria and constraints.
- If you don't hear students pushing back against others' ideas for changes during the consensus discussion, look at team members' written responses to find differences in suggested changes and set these changes up against each other while encouraging students to weigh in. Prompt them to check their *Design Testing Matrix* to consider any potential negative effects of a change (in addition to the positive effects that relate to the criteria and constraints). Use prompts similar to those below to encourage students to use evidence to be critical of choices:
  - It looks like there are some ideas for changes that are the same, but there are several ideas that are different. Are all the effects of each of these changes equal?
  - How are the other criteria and constraints affected when these changes are made?
  - Do any of these changes have some possible negative effects?
  - How can we know if a positive effect of a change outweighs the possible negative effects?

Discuss the consensus process and how to be more confident with their design choices. Ask students how they felt about the process of reaching consensus on the criteria they thought were important to change. Display **slide E**. Say, *Many of you may feel like you need more time to talk these ideas through and haven't yet come to a consensus. That is OK. We will have more time to consider these decisions, but let's take a moment to take stock of our progress. Turn and talk with a neighbor to discuss these prompts:*

- *How did you feel about the consensus process?*
- *Were there any disagreements about which of the criteria to change or how to change them?*
- *Are you sure you are making the best decision?*

*** Attending to Equity**

Universal Design for Learning: It is not always easy for students to make sense of the ideas of peers, especially when they are learning English, process language differently, lack confidence, or are uncertain. To encourage *engagement*, foster a culture in which exploring all student ideas is valued, especially those of students whose voices are not often heard. Set the expectation for all students to have areas where they are not in total agreement or have further questions. Validate students who persist in questioning the team's thinking and bring up stories of scientists who famously questioned prevailing thought. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

- *How did using your Design Testing Matrix help you have purposeful discussions?*
- *What would we need to do to be confident we were making the decisions that would optimize our design?*

Suggested prompt	Sample student responses
As I walked around the room during the team discussions, I noticed that some teams came to consensus relatively easily, while others had a harder time making a decision about which criteria or constraints to change. I heard similar patterns during this discussion as well. What did you all talk about in your teams?	*Our team pretty much had the same two things that we all wanted to change, but we just wanted to change it slightly differently.* *Our team couldn't really decide; some people thought certain criteria were a lot more important than others.* *It was hard to make a decision sometimes because some people just cared about certain parts of the design more than other parts.* *It's hard to make a final decision without seeing exactly if the design will work better or if there is something that we won't expect.*

3. Begin to construct a cascading consequences chart as a class. 10 MIN

Materials: science notebook, *Design Testing Matrix*, chart paper, markers

Reflect on how to be confident about the decisions we make. Say, *This is really hard work. Even if everyone on the team agrees on the changes you want to make, do we know for sure that these are the best decisions? Have we considered all of the consequences that will result from the changes we want to make?*

Display **slide F** and add a piece of blank chart paper to the wall and label it "Consequences Chart." Say, *Getting really organized and being systematic about keeping track of how one change will affect other criteria or constraints will be important to be confident about the decision we make. We can design a Consequences Chart to keep track of these changes and what happens as a result.*

Alternate Activity

If you think your students would benefit from extra practice considering cascading consequences or understanding the purpose of this chart, an optional 10-minute extension is provided in *Optional Extension—Cascading Consequences Practice*, and **optional slide F1** is provided to support the activity.*

Facilitate the construction of the Consequences Chart. Say, *OK, If your team said that you need to improve your instructions as part of the redesign, raise your hand.* Look around to notice that all the teams (or at least most) agree that they need to improve their instructions. Say, *Wow, it looks like we all feel like we need to change our instructions. That's great, let's begin this chart together to help us understand how organizing our work this way can be helpful.*

Additional Guidance

If the focus on creating instructions for stakeholders hasn't been explicit leading up to this, there is a chance that no teams will raise their hands to agree that they need to revise their instructions. Should this happen, you may ask questions to help remind students that the product we are designing is the instructions. We are not making these kits for our stakeholders, we are providing instructions so they can make them at home. Then in this context ask students if they agree it is important that we carefully consider how we create our instructions.

Write "Design A" in a box in the center of the Consequences Chart. Say, *The reason we are writing "Design A" here is that this is one of our revision options. If your team hasn't come to a consensus about what things are important to change, you could break up for this activity and part of your team could create this chart for a Design B as well.*

Lead a discussion asking for the possible consequences in terms of our criteria and constraints for this option. Complete an arm of the chart together related to changing instructions in some way. Since all teams will need to work on their instructions it makes sense to work on this together (and will help teams think about things they might do to change their instructions—even if they didn't initially agree they needed to). As we work on this first part together, be sure to give appropriate time for students to be working along with you on their own charts—and look around to be sure that teams are working on their charts—so when the teams are released to complete the rest of their chart they all have this first arm finished.

Suggested prompts	Sample student responses
Let's begin one together so that we can all be confident in how to get started. Since so many of us agreed we need to update our instructions, let's work on that all together. What is a possible change you could make to your instructions?	*We could be more clear about each step.* *We could record a video.* *We could write the instructions in another language or several languages.* *We could simplify and label our drawings so they are very clear.* *We could add photos of the steps of the instructions so there won't be any confusion in case our drawings aren't very clear.*
OK, since there are several options to update the instructions, teams will likely have different plans for what they want to do. Are there any of the ideas we mentioned that all teams agree would be a good idea for the instructions?	*Adding photos or very simple pictures to the instructions seems like it helps the most people, with the least amount of extra work on our part.* *Making a video would also be good, but pictures on the instructions is even better because someone can still use the directions if they don't have access to a device to watch a video.*

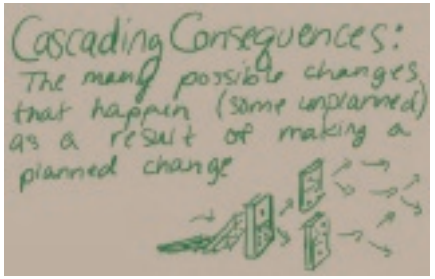
*** Attending to Equity**

Universal Design for Learning: Consider giving students the alternate example to provide an additional way to increase comprehension. All students may initially struggle to understand the purpose of this activity; having a concrete example using a decision that students in the class are likely familiar with will help internalize the purpose, which in turn will help students feel that this process is authentic as they transfer the task to decisions about their team's design changes.

Suggested prompts	Sample student responses
OK, let's work with that idea first. What would be some possible effects that result from including photographs in our instructions?	*People who can't read will still be able to make the homemade heater by following the photos in the directions.* *Even if a person doesn't speak the same language the instructions are written in, they can still see how to make a heater.* *People might be able to make their heaters more quickly because the photos would make the instructions easier to follow.*
Are there any less desirable outcomes of adding pictures to the instructions?	*It might be challenging to create the photographs so that they are clear.* *If the instructions are not printed in color it might be difficult to see some of the detail with photos.* *If we zoom in on a part to be clear, it might be too hard to know what we are talking about.* *If the photos are confusing, too complicated, or too hard to see details, it might make it even harder to follow the instructions.* *If the instructions are hard to follow it will cause stress and frustration. We are trying to help people, not make them more frustrated.*
Could you add even more consequences? For example, if people might not understand the directions, what might happen?	*If the photos or pictures are not clear enough, they might not follow the instructions as we intended and they could hurt themselves if they use the wrong amounts of substances to mix together.*
Could we add more changes about changing the instructions? If we did, how would we add them to this chart?	*We could branch off a second option for instructions to see if the change we trace on that branch would have a similar effect.*

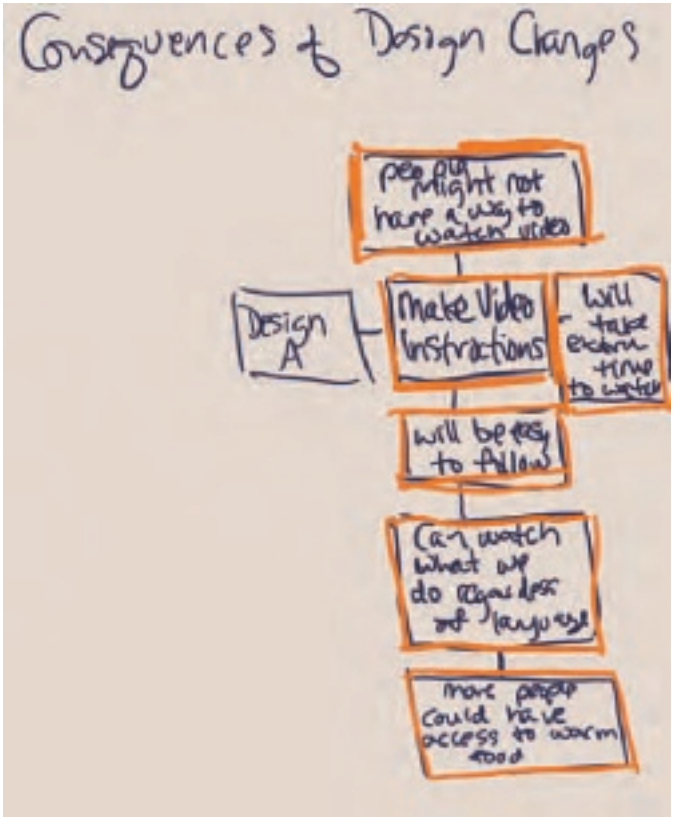
As students are suggesting the effects of this change, add them as connected boxes arranged as one arm or branch off of the center box.

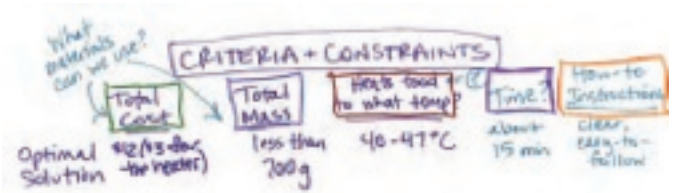
Add "cascading consequences" to our Word Wall. Say, *Wow! There are consequences here that seem unrelated but they are definitely affected by our changes! Making that one change affected a lot of other things that we might not have even thought about. When we think through consequences like this we call it "cascading consequences"—like how tipping one domino in a row of standing dominos affects a lot of other dominos. This is definitely an idea we should add to our Word Wall.*



Organize the Consequences Chart using color. After completing this arm, pause and say, *Wait, with all of these cascading consequences, this is going to get messy. Maybe if we color-code these, we can keep track of them better. Go back to the Design Testing Matrix and add colors to your criteria and constraints categories, and I will do the same on our class chart.*

Add to your Design Testing Matrix the corresponding color you plan to use (e.g., put purple around the boxes that relate to the amount of time it takes) so that you will be able to make the arms in those colors to keep everything more organized.





4. Construct a cascading consequences chart that incorporates the top-ranked changes for the homemade heater designs.

20 MIN

Materials: science notebook, chart paper, markers

Finish developing the Cascading Consequences Chart for the 2-3 design changes each team plans to make. Display **slide G**. Say, *It looks like you all are ready to finish your team's Consequences Chart. Does anyone have clarifying questions about the process?* Answer any lingering questions about the process and direct students to refer to the process on the slide.

Give students time to finish the chart with the rest of their team. Teams will work to complete their Consequences Chart(s). If teams are still in strong disagreement about which changes to make, encourage teams to split and each subgroup make a Consequences Chart for the proposed changes they support, which will help the team decide on a final design using the charts as evidence.

Additional Guidance

The chart arms will start with ideas present on the matrix, but as the class works, they will realize that there are other cascading consequences resulting from those changes that may not have been represented on their Design Testing Matrix and they will need to add those to the chart as well. There is no right or wrong answer here as long as the ideas are relevant. If students want to put consequences in more than one category, that is also OK (this would be shown on their chart as a box that has more than one color highlighted).

Annotate the chart to show positive and negative consequences that resulted from the changes they made. As students are finishing their charts, ask them to look at each of the effects of their decision.

Say, *Are all of these changes equal in their potential impact? Let's look at each box that changed as a result of the changes we made.*

Get students to give input as you add "+" and "–" signs to the boxes you created together for the "How-to instructions" arm (depending on if the consequence would generally be considered a positive or negative impact). Then give students time to add the "+" and "–" signs to the rest of their consequences boxes. Then do a quick whole-class share to see if there are any patterns to the kinds of consequences that were common. See the example provided to get an idea of what this might look like after students finish all arms.

Additional Guidance

Students may notice that a consequence could be considered both positive and negative, depending on whose point of view you are using. If they bring this up, let them know that they can use "+" and "–" markings and that they will have a chance to explain that later. If students do not bring this up, it is not necessary to do so ahead of time. This is meant to be a relatively quick exercise to start, and they will still have more time to think about the impacts in the next part of the lesson.

Assessment Opportunity

Building towards: 8.A Evaluate competing design solutions based on jointly developed and agreed-upon design criteria using systematic processes to show how small changes in one design characteristic might cause unexpected changes in other design characteristics.

What to look for: As students are constructing the charts, listen for teams using cause-and-effect relationships to predict outcomes that are not on their Design Testing Matrix. Look for arms in the organizer to branch (a cause having more than one effect) and for there to be a series of boxes more than just one step removed from the cause (cascading consequences).

What to do: Circulate while teams are working to look and listen for discussions that are explicitly mentioning cause-and-effect relationships. Encourage this practice with prompts, such as the following:

- Help me understand what I'm seeing—what things did you change? What was affected by that change?
- How did such a small change to ___ have such a big effect on ___?
- Does this change cause a positive, negative, or neutral consequence?

5. Navigation

2 MIN

Materials: science notebook

Navigate to next time's work. Say, *It looks like teams are noticing a variety of possible consequences resulting from the changes they proposed, but are all consequences equal? We will continue this decision-making work tomorrow.*

Show **slide H** and ask students to turn to their next open page in their science notebook.

Say, *In the meantime, think about ways we could decide which of these consequences is the most important to pay attention to. Jot down some thoughts you have about the following questions so that we are prepared to talk about them next time.*

- Are all consequences equal?
- Even if there are some negative consequences, can we still live with them if they make our design that much better?
- How can we be confident about our decision?

End of day 1

6. Navigation

5 MIN

Materials: science notebook, What We Do as Engineers board

Discuss student ideas about making design decisions. Display **slide I**. Say, *Open your science notebook to where you recorded your ideas about decision-making at the end of the last class. We were trying to think about ways to use our Consequences Charts to help us make the best decision. We noticed that there were some positive consequences and some negative consequences when we made a change, but are all consequences equal? Even if there are some negative consequences, can we still live with them if they make our design that much better?*

Suggested prompts	Sample student responses
How do we go about deciding if the consequences are something we can live with?	*You need to try to see if the positive effects outweigh the negative consequences.*
It seems like we've tried to do that by creating this chart, but I'm still not seeing any clear answers. It also seems like people still have some pretty strong opinions about the "right" answer. Let's look back at our What We Do as Engineers board and see if that can help us think about how to move forward on our decision. Is there anything here that can help us?	*When we were trying to make decisions before, we thought about who our stakeholders were and what they would need or want.* *Maybe we need to look back at our stakeholders again?*

Say, *Oh, that's right, these designs aren't really for us—at least not for everyday use. We want to be able to help people who need to use these in an emergency. Let's go back to our Progress Trackers and look at who we listed as our stakeholders.*

Ask students to turn to the page in their student notebook where the Progress Tracker was updated to identify our stakeholders. Invite students to share the identities of the stakeholders we defined.

Our stakeholders are the following:

- people in our community who might need to have to warm up food this way:
  - people caught in snow storms or other natural events
  - people who may not have access to a stove
  - a person buying supplies and making the heaters
  - a person eating the food heated up by the heater
- the Red Cross, FEMA, or other organizations that might be buying supplies for people to have ahead of time
- recycling centers or landfills
- places that sell the root killer, like gardening places
- companies that make root killer
- the environment (if students have been bringing it up—not critical if they haven't brought this up at this point)

7. Use stakeholder impact charts to make final design decisions.

15 MIN

Materials: science notebook, *Stakeholder Impact Chart*

Organize the impacts on stakeholders by recording them in a chart. Pass out *Stakeholder Impact Chart* and ask students to list in the left column the stakeholders we just mentioned. Then ask students to individually assess the impact of the proposed design changes on those stakeholders by completing the other columns on the table.

Share stakeholder impact charts and weigh impacts on stakeholders to decide which changes teams will make for the heater redesign. After students have filled in their *Stakeholder Impact Chart*, show **slide J** and ask students to discuss the following questions with their team to help them decide on the changes they will ultimately implement in their final design:

- How important to you are the interests of this stakeholder?
- If the effect on this stakeholder is negative, do you feel that it is directly offset by greater good elsewhere?

Additional Guidance

In this stage, students specify how important the interests of each stakeholder are to them and whether they believe negative impacts on a particular stakeholder are balanced by positive impacts on them or other stakeholders. This is the stage in the process when students bring in their personal values and see how different values can lead to different decisions.

8. Update Progress Trackers and What We Do as Engineers board. 15 MIN

Materials: science notebook, What We Do as Engineers board, sticky notes, markers

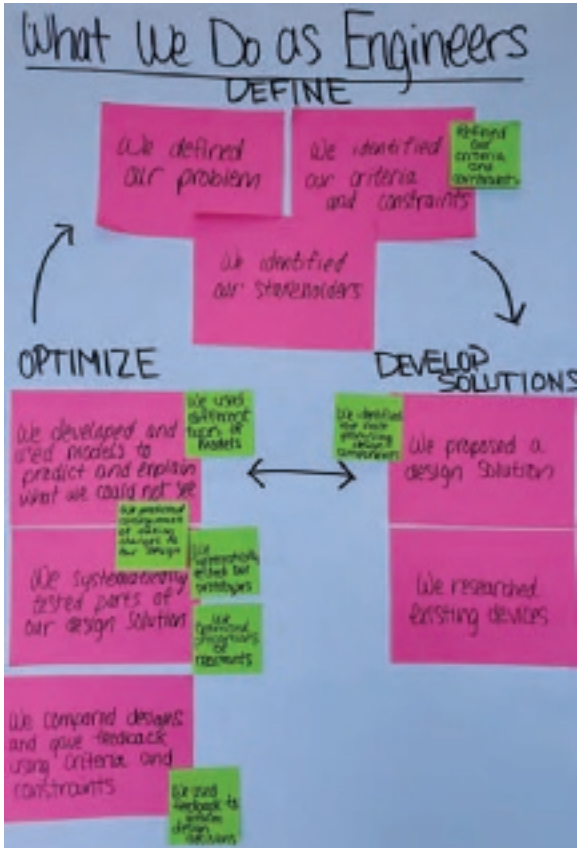
Update the Progress Trackers in student notebooks and update the What We Do as Engineers board. Display **slide K** and ask students to complete the trackers in their science notebooks as we add small sticky notes to our What We Do as Engineers board and update the arrows to be bidirectional between "Optimize" and "Define" and between "Develop Solutions" and "Define." Say, *We did a lot of engineering work today, so let's take a look at our What We Do as Engineers board and see where our actions fit into the design cycle.*

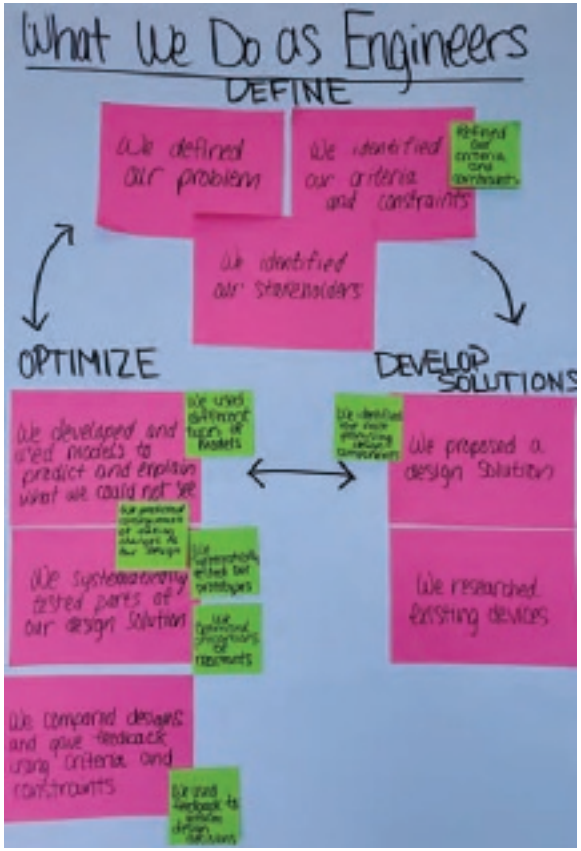
Suggested prompts	Sample student responses
Let's start by considering what we did right before we started our work today. Check your Progress Tracker—will someone share what we added to our board last time?	*We identified the most promising design components.*
Great, how did we categorize that with regard to what engineers do?	*We added it as a small yellow sticky in the "Develop Solutions" category.*
Was there anything else in that lesson that we needed to use today and would be important to consider?	*We ranked our design ideas based on how our designs performed compared to the optimal criteria and constraints.*
Great, did we use that information for our work today?	*Yes, we needed to use the most promising design ideas to predict the consequences of making those changes.*

Suggested prompts	Sample student responses
As we built the Consequences Charts, we incorporated a lot of information—did we only use the ideas about what to change to create our charts? What else did we need to consider at the same time? For example, if another characteristic changed, what did we have to check to make sure it still worked?	*We used feedback from other teams to help us make some decisions.* *We also had to consider whether the unplanned changes still fit within our constraints and met our criteria to be able to make a decision.* *We will have to go back to that sticky note every time we make any changes.*
We are able to use our Consequences Chart to make predictions about whether our changes would give us an optimal design. Is it fair to say that these charts helped us systematically evaluate our design? Which category should it go in?	*There is a sticky note in the "Optimize" category about using models, so we should add our small sticky note to that category.*

Add two sticky notes in the "Optimize" category. Add two small sticky notes to the board: one that says "We used feedback to inform design decisions" next to the pink "We compared designs and gave feedback using criteria and constraints" sticky note, then another small sticky note that says "We predicted consequences of making changes to our design" next to the "We developed and used models …" sticky note in the "Optimize" category.

Add an arrowhead pointing from "Define" to "Optimize." Say, *So we were using this* (point to the pink sticky note in the "Define" category that says "We identified our criteria and constraints") *to give feedback to our partner teams about how our designs performed* (point to the pink sticky note under the "Optimize" category that says "We compared designs and gave feedback using criteria and constraints"). *In addition, we were also using this* (point to the small sticky note in the "Develop Solutions" category that says "We identified the most promising design characteristics"). *We added these actions to the "Optimize" category, which must mean that these arrows flow in both directions.* Draw in an arrowhead pointing to "Optimize" from "Define" so there is a bidirectional arrow between the categories.





Suggested prompt	Sample student response
As we looked at our predictions from the Consequences Chart, we again looked at the changes we wanted to make to our designs (point to the small sticky note in the "Develop Solutions" category). I'm not going to add another sticky note because, like the criteria and constraints sticky note, we will likely be returning here several times. What did we do next?	*We considered how the changes (and the effects of those changes) impacted specific stakeholders.* *So we need to add the next sticky note next to the stakeholder sticky note under the "Define" category.*

Add an arrowhead pointing from "Develop Solutions" to "Define." Add a small sticky note that says "We considered the impact of different solutions on stakeholders" next to the large sticky note that says "We identified our stakeholders". Say, *So just like with our last sticky note, we were using more than one part of this process to help us move forward—the predictions from our Consequences Chart* (point to the small sticky note in the "Optimize" category) *that says "We predicted consequences of making changes to our design" and this* (point to the small sticky note in the "Develop

Solutions" category) *that says "We identified the most promising design characteristics" to help us consider how these changes would impact different stakeholders. If we are adding this action to the "Define" category, that means that these arrows go in both directions.* Draw an arrowhead pointing from "Develop Solutions" to "Define."

Say, *Interesting. I've heard this called a design cycle often, but we are seeing that this isn't just a one-way cycle. It appears more like a complex interacting web of ideas that are always connecting back to one another!*

See an example here of possible student responses in the Progress Tracker.

What did we do as engineers?	What did we figure out that can help us with our designs?
We used feedback to inform design decisions.	Partner teams helped us notice parts of our instructions that were not clear. We also could see good ideas from other team's designs which gave us ideas to improve our designs.
We predicted the consequences of making changes to our design.	We played out the effects that the changes we wanted to make had on other design characteristics to help us understand all the consequences our changes had on our design.
We considered the impact of different solutions on stakeholders.	We considered our stakeholders and the impacts that the consequences of the changes we could make to our designs might have on them.

9. Justify proposed design changes.

15 MIN

Materials: science notebook, *Stakeholder Impact Chart* (optional)

Make and justify a decision. Give students time to have a discussion to finalize what they plan to change.

When teams have decided which of the changes they want to implement, conclude the decision-making process by asking students to individually report in their science notebook the constraints, criteria, and stakeholder impacts that were considered as they justify their decisions. Display **slide L** and ask students to turn to the next free page in their science notebook to complete the following prompt:

- Describe the changes you will make to your design and justify those changes—include an explanation of how both positive and negative impacts on stakeholders were considered in your decision.

Assessment Opportunity

Building towards: 8.B Prioritize criteria and consider trade-offs that occur as a result of design changes to decide which changes to incorporate for the optimal homemade heater design.

What to look for

- During the team discussion to come to consensus on design changes, listen for students weighing the costs and benefits of making specific design changes and how the improvement in the design would outweigh any other negative impacts to stakeholder interests. Listen for how teams are coming to consensus in the event that they still don't agree on which criteria to change.
- Look for individual student responses justifying the choices they made to modify their design. They should include mention of how design features perform with respect to the criteria and constraints we defined, an explanation of the stakeholders who were affected by the changes, and a discussion of how the impacts on stakeholders weighed into their final decision.

What to do

- During the team discussion, ask probing questions, such as the following:
  - In what ways does _____ change _____?
  - What evidence from the Consequences Chart helped you come to consensus?
  - Which stakeholders are most impacted by the change? In a positive, negative, or neutral way?
  - Does everyone agree which stakeholder interests are most important?
  - How did you navigate which criteria and constraints to change when your whole team didn't agree? What was the strongest argument made for or against a certain change?
- For individual responses, consider providing parallel examples to help struggling students see what a complete justification looks like with each required part of the parallel justification identified. Encourage students to highlight on the *Stakeholder Impact Chart* the important ideas that they want to include in their response. You may find or create sentence stems to help students get started with each section of the justification.

ADDITIONAL LESSON 8 TEACHER GUIDANCE

Supporting Students in Making Connections in ELA

CCSS.ELA-LITERACY.SL.7.1.B Follow rules for collegial discussions, track progress toward specific goals and deadlines, and define individual roles as needed.

CCSS.ELA-LITERACY.SL.7.1.D Acknowledge new information expressed by others and, when warranted, modify their own views.

During this lesson, students will continue to follow expectations for teamwork, with the added challenge of making decisions about how to modify their designs. Students will work together to discuss and construct a chart of cascading consequences, which will provide a way to track their thinking about each proposed design change toward the goal of an improved design. The team will have to come to a consensus about the changes they will enact, which will require them to acknowledge the ideas of their teammates and possibly modify their own views about what ideas will best improve their design.

LESSON 9

What is our optimal design for a homemade flameless heater?

Previous Lesson

We used ideas about the most promising design characteristics and investigated whether making those changes would impact other characteristics of our design. We considered these downstream consequences and how they would affect stakeholders differently. We used this information to come to a team consensus about the changes we wanted to implement.

This Lesson

Investigation

3 DAYS

We redesign and optimize our homemade flameless heaters to target our highest priority criteria and constraints using the most promising design features. We build and test our heaters using a Design Testing Matrix based on our criteria and constraints. We refine our how-to instructions and give them to our partner team to build our heater and test them. We reflect to evaluate our work as engineers and how well we individually meet expectations as teammates. Then, we revisit our Design Questions Board to address any remaining questions.

Next Lesson

Students will demonstrate their understanding on a summative assessment transfer task involving sea turtle incubators. In this assessment they will evaluate different designs and develop an argument for which sea turtle incubator design or combination of design features would work best based on relevant criteria and constraints.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

9.A Communicate technical information in writing about how to transfer energy through a system that was designed to perform better than any of its predecessors by using parts of different solutions.

9.B Optimize performance of a design that represents systems and energy flows between systems by revising and retesting to incorporate characteristics of the most promising solutions.

What Students Will Figure Out

- Design performance needs to be optimized by revising and retesting.
- Parts of different solutions can be combined to create a solution that is better than any of its predecessors.
- Peer testing of designs and instructions can inform modifications that lead to a better solution.

Lesson 9 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Consider ideas from the last class for updating designs and review how designs have been systematically tested.	A	What We Do as Engineers board, sticky note, marker
2	40 min	**UPDATE OUR DESIGN PLANS IN TEAMS**	B-E	*How-to Instructions Must-Haves* with sticky-note feedback (from Lesson 6), *Design Testing Matrix* (from Lesson 6), *Teamwork Self-Assessment* (from Lesson 6), *Materials Cost List* (from Lesson 6), chart paper or butcher paper, markers, initial class consensus model, extra white paper (optional), Planning and Modeling Optimized Homemade Heaters Lab *End of day 1*
3	30 min	**BUILD AND TEST OUR OPTIMAL DESIGNS** Build and test teams' optimized designs and record data on their Design Testing Matrix.	F-K	*Design Testing Matrix* (from Lesson 6), team designs, how-to instructions, Building and Testing Optimized Homemade Heaters Lab
4	5 min	**PREPARE TO HAVE ANOTHER TEAM TEST HOW-TO INSTRUCTIONS** Do a quick revision of the how-to instructions for teams' optimized heaters and prepare *How-To Instructions Must-Haves* for another team to test their designs.	L	*Design Testing Matrix* (from Lesson 6), *Partner Info Sheet for Final Design*
5	10 min	**EXCHANGE DESIGNS WITH ANOTHER TEAM** Begin building a partner team's design using their how-to instructions. Record data on *Partner Info Sheet for Final Design*.	M	computer or other device to view video instructions (optional), Partner Testing Homemade Heaters *End of day 2*
6	20 min	**FINISH BUILDING ANOTHER TEAM'S DESIGN TO HEAT UP FOOD AND TEST IT** Continue building and testing a partner team's design. Record data on *Partner Info Sheet for Final Design* and exchange testing data when complete.	N-P	Partner Testing Homemade Heaters
7	5 min	**COMPLETE ENGINEERING DESIGN RUBRIC IN TEAMS** Work in teams to assess their final designs and their work as engineers.	Q	*Engineering Design Rubric*
8	5 min	**SELF-ASSESS TEAMWORK INDIVIDUALLY** Self-assess independently by comparing the expectations for teamwork they used first in Lesson 6 and that they reviewed earlier in the lesson.	R	*Teamwork Self-Assessment*, transparent tape

Part	Duration	Summary	Slide	Materials
9	15 min	**REFLECT ON WHAT WE HAVE ACCOMPLISHED** Revisit the DQB with the whole class and take stock of all the questions we have now answered. Ask new questions to help clarify class models in preparation for the summative assessment in the next lesson.	S-U	transparent tape, *Questions from Our DQB*, 5 sticky dots, Design Questions Board, chart paper for Take-aways board (optional)
10	2 min	**NAVIGATION** Close today's work by considering all the things we have figured out and survey others to gain additional feedback on our instructions.	V	

End of day 2

Lesson 9 • Materials List

	per student	per group	per class
Planning and Modeling Optimized Homemade Heaters Lab materials **Student Procedure Guide** **Student Work Pages**		• 1 digital scale • various containers • plain water • *Design Must-Haves* • *How-To Instructions Must-Haves*	
Building and Testing Optimized Homemade Heaters Lab materials	• indirectly vented chemical splash goggles • 1 nonlatex apron • nitrile gloves	• 1 digital scale • various containers • 300 mL of plain water • 100 grams hydrated water beads • 1 8-oz. Styrofoam cup containing 5 grams of shredded aluminium • 1 8-oz. Styrofoam cup containing 55 grams of copper sulphate • 2 pieces of 4" x 4" parchment paper • 400 mL of saltwater • 1 tray • 2 plastic spoons • *Design Must-Haves*	

	per student	per group	per class
Partner Testing Homemade Heaters materials	• indirectly vented chemical splash goggles • 1 nonlatex apron • nitrile gloves	• 1 digital scale • various containers • 300 mL of plain water • 100 grams of hydrated water beads • 18-oz. Styrofoam cup containing 5 grams of shredded aluminium • 18-oz. Styrofoam cup containing 55 grams of copper sulphate • 2 pieces of 4" x 4" parchment paper • 1 tray • 2 plastic spoons • optimized design how-to instructions • *Partner Info Sheet for Final Design* • 400 mL of saltwater • partner team how-to instructions	
Lesson materials	• Science Notebook • *How-to Instructions Must-Haves* with sticky-note feedback (from Lesson 6) • *Design Testing Matrix* (from Lesson 6) • *Teamwork Self-Assessment* (from Lesson 6) • *Materials Cost List* (from Lesson 6) • *Teamwork Self-Assessment* • transparent tape • *Questions from Our DQB* • 5 sticky dots	• chart paper or butcher paper • markers • initial class consensus model • team designs • how-to instructions • *Partner Info Sheet for Final Design* • computer or other device to view video instructions (optional) • *Engineering Design Rubric*	• What We Do as Engineers board • sticky note • marker • extra white paper (optional) • Design Questions Board • chart paper for Take-aways board (optional)

Materials preparation (90 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Prepare the handouts:

- Print one copy for each student of each of these handouts: *Questions from Our DQB* (print after updating the document per the instructions below), *Teamwork Self-Assessment*.
- Print one copy for each team of each of these handouts: *Design Must-Haves*, *How-To Instructions Must-Haves*, *Engineering Design Rubric*.
- Print four copies of *Partner Info Sheet for Final Design* per class and cut them in half so you have one half-sheet per team.
- Trim the *Questions from Our DQB* and *Teamwork Self-Assessment* handouts to fit science notebooks.

Create the *Questions from Our DQB* handout for your class: Use the digital copy of this handout as a template. List on the handout all the questions that students developed on the Design Questions Board. For ease of reference you can number each of the questions on the DQB and make sure the handout has the corresponding number next to that question.

Check to be sure students have *Design Testing Matrix*, and *Teamwork Self-Assessment* from Lesson 6 in their science notebooks or print additional copies. You may choose to invite students to bring in additional materials they'd like to use to build their homemade heaters, and/or you might collect other locally supplied materials, such as cardboard, packing peanuts, differently shaped bottles or containers. If you do add other materials to those available for design construction, use the estimated costs of those materials that were determined in Lesson 6. Students will refer to *Materials Cost List* from Lesson 6.

As an optional suggestion, you might create a handout checklist of the testing procedures (on **slides G** and **J-L**, including steps specific to your classroom) for each team so that they can self-monitor their progress and sustain the effort and concentration needed to build and test their redesign.

You may want to take time to intentionally plan which teams will exchange how-to instructions to build and test each other's designs in days 2 and 3. Use the observations you've made about the successes and challenges that design teams are facing to inform how you pair partner design teams. List partner teams on **slide M** or on the board or a piece of chart paper.

Decide how you will arrange your classroom to allow for four pairs of teams to work together.

Reminder: *Prepare all substances and solutions, including hydrated water beads, at least a day before students conduct their investigations and allow them to come to room temperature overnight.* Since students will be measuring the temperature changes caused by the chemical reaction, it is critical that all substances and the saltwater solution have fully come to room temperature. Avoid storing substances and solutions near windows or HVAC equipment that may be hotter or colder than the rest of the room.

Review the survey and create a copy to use with your classes (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

Make sure the lab has engineering controls—eyewash station and shower—available.

Day 1: Planning and Modeling Optimized Homemade Heaters Lab

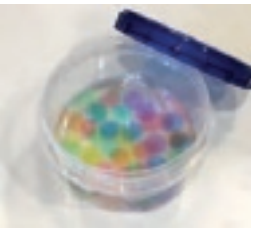
- **Group size:** 8 teams of 3-4 students
- **Setup**
- Have a variety of containers and lids available for teams to use in their designs, such as plastic food-storage containers and various sizes of ziplock bags. You may also choose to provide insulating packaging, such as cardboard or bubble wrap, or invite students to bring in boxes, bottles, or other materials they would like to use in their designs.
- Have 8-10 liters of water available for students to use as a proxy for the saltwater they will use during testing—they should be able to plan how much saltwater they will want in their designs without actually running the reaction. Since it will not be used in testing, this water need not be at the same temperature as the other materials.
- Be sure each team has access to a scale.
- Saltwater at room temperature will be needed on days 2 and 3. It is highly recommended that you prepare the saltwater at least a day in advance so it has ample time to equilibrate to room temperature. Prepare 6,500 mL of saltwater per class; this allows a class to use 3,250 mL on day 2 and day 3. This may be more easily done in 13 batches of 500 mL each by adding 3 grams of table salt to a container of 500 mL of water. Stir to make sure all the table salt dissolves. Be sure to leave the saltwater out at least a day in advance to come to room temperature. Keep the saltwater in pitchers or beakers that are easy to pour from so teams can measure what they need into their own containers.
- **Notes for during the lab:** Teams may explore with various packaging materials, amounts of water (as a proxy for the saltwater they'll use in their design), and masses as they plan and draw models for their designs. They will not be constructing their prototypes in this lab.
- **Safety:** Safety recommendations for students and teacher(s)

Ensure that the lab has engineering controls (eyewash station and shower) available.

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.
- Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.

- **Disposal:** At the end of the day, the plain water can be poured down the drain. Do not dispose of any other materials as teams will continue to use them on days 2 and 3 of this lesson.
- **Storage:** Make a plan for how teams will keep their designs safe and out of the way while other classes use the room. Consider making space on a back table, a counter, or bookshelves to collect the teams' designs.

Days 2 and 3: Building and Testing Optimized Homemade Heaters Lab



- **Group size:** 8 teams of 3-4 students
- **Setup**
- Teams will test designs twice. The first test will be their own test of their optimal design, and the second will be when teams switch instructions with a partner team and test the partner team's optimal design. The amounts of materials listed here are enough for both tests.
- Have a variety of containers and lids available for teams to use in their designs, such as plastic food-storage containers and various sizes of ziplock bags. You may also choose to provide insulating packaging, such as cardboard or bubble wrap, or invite students to bring in boxes, bottles, or other materials they would like to use in their designs.
- Each team may want to use up to 100 grams of hydrated water beads in addition to the water they're using for their "food" per test (their own revision on day 2 and a partner team's test on day 3). Exact water bead absorbency will vary by brand, but for approximately 1,600 grams of hydrated water beads, add a teaspoonful (about 16 grams) of dry water beads to 1,600 mL of water. Cover the container to reduce evaporation and allow the water beads to stand for 8-12 hours to fully hydrate. See photos here of the water beads added to the water to start and after 10 hours of soaking.
- Plan how you'd like to distribute hydrated water beads to students. You may choose to keep them all in one place with a cup as a scoop for students to measure into their containers, or you may choose to supply each team with a smaller container of their own to measure from. (Reminder: Teams will be combining 1 part hydrated water beads with 3 parts plain water to create the "water bead soup" they will use as a proxy for food during testing.) Keep the hydrated water beads covered when not in use so that they don't begin to dry out.
- Teams will need access to plain water at room temperature to add to their hydrated water beads to create the "water bead soup" they will use as a proxy for food during testing. Have 4 large containers of water from which students can measure the quantity of room temperature water they need.
- Prepare 64 grams of shredded aluminum foil per class by running ~8" x 11" pieces of aluminum foil through a paper shredder. A crosscut paper shredder is preferred since it cuts the aluminum into small pieces (~2 cm x 0.5 cm) whereas strip-cut paper shredders produce long strips that will then need to be cut into smaller pieces. You may need to run a few pieces of aluminum foil through the shredder to remove any paper bits before you collect foil to use in class. Note: This is the last time you will use shredded aluminum foil. Fill 8 8-oz. Styrofoam cups per class with about 5 grams of shredded aluminum foil each for day 2. Teams can bring a cup to their work area to measure out the amount they need for their design, then return whatever they don't use that is still in the cup. Refill the cups as needed for day 3.

- Fill 8 8-oz. Styrofoam cups per class with about 55 grams of copper sulfate per cup for day 2. Teams can bring a cup to their work area to measure out the amount they need for their design, then return whatever they don't use that is still in the cup. Refill the cups as needed for day 3.
- On days 2 and 3, each team will need a scale and 4" x 4" parchment paper on which to mass their materials (unless they are measuring directly into a container).
- **Safety:** Safety recommendations for students and teacher(s)

Ensure that the lab has engineering controls (eyewash station and shower) available.

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.
- Follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate* in case of accidental exposure to copper sulfate.
- During the design step, confirm that teams will use:
  - *no more* than 55 total grams of reactants (copper sulfate + aluminum) and
  - *no less* than 250 mL of saltwater in order to keep the reaction from getting dangerously hot.
- Be sure to confirm that students are venting the containers where the reactions are happening to avoid build-up of hydrogen gas or having them pop open and cause a splash.
- **Disposal:** After teams have built and tested their own design on day 2, you may want to collect and put away any remaining saltwater since teams will not actually test a partner team's design until day 3.
- After designs are tested, dispose of solid wastes (including pieces of aluminum and copper) in the garbage and dispose of liquid waste as directed in the teacher reference *Safety Information for Copper Sulfate Pentahydrate*. Hydrated water beads can be disposed of in the garbage or dehydrated for reuse next year (see "Storage" below for instructions on doing this). Wash containers and leave out to dry and reuse next year. The leftover aluminum and copper sulfate should be retained for future lessons; keep and refill the cups for testing on day 3. After day 3, unused saltwater can be poured down the drain.
- **Storage:** Make a plan for how teams will keep their partner team designs from the end of day 2 safe and out of the way while other classes use the room. Consider setting each design on blank paper labeled with the team's name on

a back table, a counter, or bookshelves. Unused aluminum foil and copper sulfate can be retained for future lessons. Hydrated water beads can be dehydrated and reused next year. If you choose to do this, wash the water beads with soap and water or a vinegar solution before letting them dry on paper towels until they are fully dehydrated. If the water beads develop dark spots or mold, dispose of them in the garbage. Note that it will take several days for the water beads to fully dry out. Store dehydrated water beads in an airtight container for next year. All containers and cups can be retained for future lessons.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, student teams apply their thinking from Lessons 7 and 8 around promising design features, ranking of criteria and constraints, and associated consequences to a redesign of their homemade flameless heater. Teams build and test their redesign to gauge the effectiveness of their improvements and revise their how-to instructions. Teams then trade how-to instructions with a partner team and build and test each other's final designs. The majority of the class period on day 1 is dedicated to allowing teams to redesign their homemade flameless heaters, and this is their opportunity to incorporate significant changes if needed. After they test their redesign on day 2, they will only have enough time to revise their how-to instructions unless you decide to provide them with additional time to do another redesign iteration.

As in Lesson 6, any time students redesign their homemade flameless heater, you will need to check their plans before they begin building and testing to make sure that their plans

- include a way to vent the container,
- use *no more* than 55 total grams of reactants (copper sulfate + aluminum), and
- use *no less* than 250 mL of saltwater.

Where We Are NOT Going

In the spirit of collaboration, design performance should not be a competition. Teams should stay focused on identifying what worked or didn't work and focus on the impact of their design improvements based on what they learned from their peers and the Consequences Chart.

LEARNING PLAN FOR LESSON 9

1. Navigation

5 MIN

Materials: What We Do as Engineers board, sticky note, marker

Turn and talk to navigate to today's work. Display **slide A**. Direct the students to look at the What We Do as Engineers board and then discuss the questions on the slide with a partner.

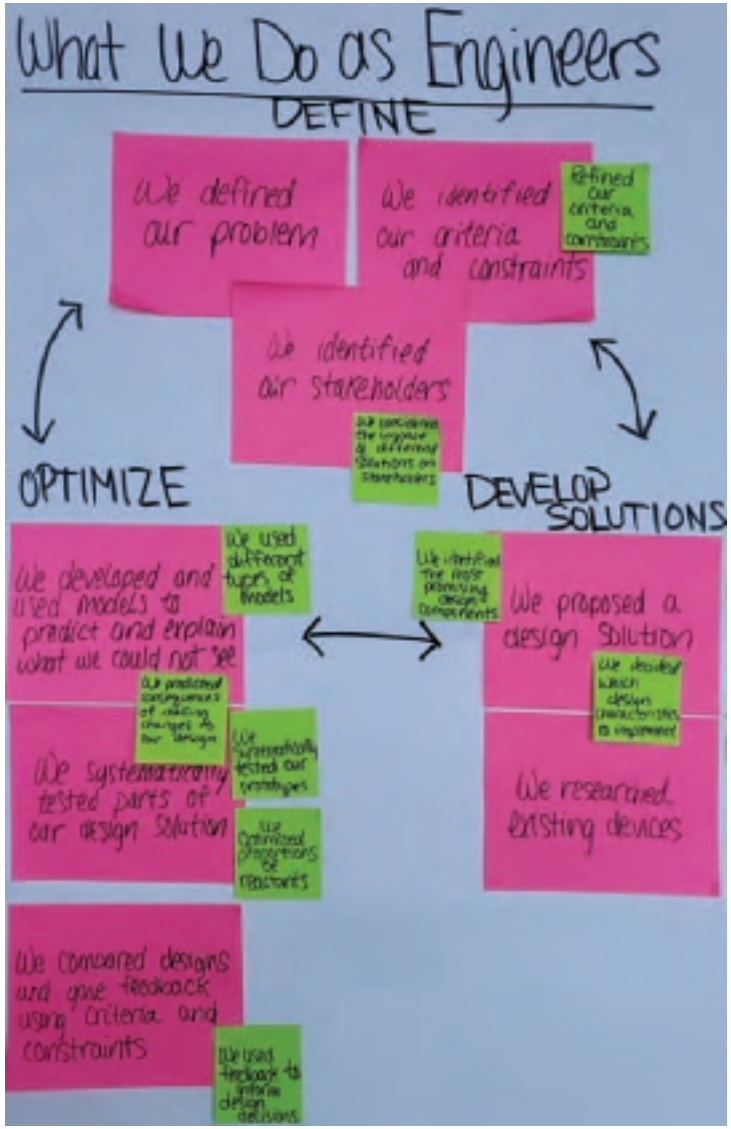
After a few minutes conduct a brief, whole-group share out.

Suggested prompts	Sample student responses
What did we figure out in our last class?	*We figured out how changes we wanted to make in our designs could impact other parts of our design.*
What else did we consider when deciding on what changes to make?	*We considered our stakeholders and thought through the effects of cascading consequences of our decisions.* *Sometimes we thought a decision was only going to have one effect, but after we thought about it more it actually had five effects we did not originally consider.*
At the end of class you used this information to make some final decisions. How did that go? Was your team able to come to a consensus on which changes to implement?	*We decided which design characteristics to implement.* *We used the feedback from our partner teams as well as the consequences chart and the stakeholder impact chart to support our arguments for which design was best.*

Update the Progress Trackers in student notebooks and update the What We Do as Engineers board. Ask students to complete the trackers in their science notebooks as we add the last yellow sticky note to our What We Do as Engineers board.

See examples of possible student responses in the Progress Tracker as well as an image of the updated What We Do as Engineers board.

What did we do as engineers?	What did we figure out that can help us with our designs?
We decided which design characteristics to implement.	We made our design decisions based on the idea that we want to incorporate the changes that have the most positive impact and the least negative impact on stakeholders.

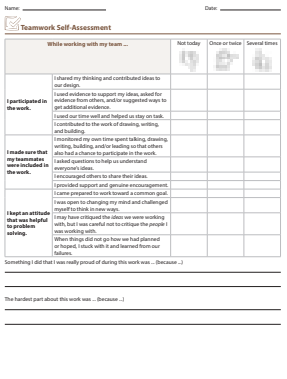


2. Update our design plans in teams.

40 MIN

Materials: Planning and Modeling Optimized Homemade Heaters Lab, science notebook, *How-to Instructions Must-Haves* with sticky-note feedback (from Lesson 6), *Design Testing Matrix* (from Lesson 6), *Teamwork Self-Assessment* (from Lesson 6), *Materials Cost List* (from Lesson 6), chart paper or butcher paper, markers, initial class consensus model, extra white paper (optional)

Reflect on the self-assessment from Lesson 6. Display **slide B**. Say, *We want to improve on being part of a design team, so let's look in our science notebooks at our* Teamwork Self-Assessment *sheet from Lesson 6 and reflect on how you are doing as a team member.* Give students a few minutes to reflect on what they want to improve and write a goal in their science notebook.


Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I used evidence to support my ideas, asked for evidence from others, and/or suggested ways to get additional evidence.			
	I used our time well and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I monitored my own time spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged myself to think in new ways.			
	I may have critiqued the ideas we were working with, but I was careful not to critique the people I was working with.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

The hardest part about this work was ... (because ...)

TEACHER RESOURCES

Plan redesign on paper. Display **slide C**. Say, *We aren't starting from scratch because we have evidence that our classmates shared which we can use to create a better solution than the design we tested before. Let's look at our* Design Must-Haves *for our optimized design.*

Hand groups *Design Must-Haves*; they will turn this in at the end of this class period and use it again next class period.**

Display **slide D**. Hand out blank chart or butcher paper to groups and tell them that these tests will be done at full scale. Say, *We know that we will have to combine different parts of previous designs to work towards an optimal solution that will be better than we had before. Remember that last time we tested, we wanted to conserve our materials so we used one-quarter amounts. This time we will be testing everything at full scale so we can make sure that our instructions and designs work for our user-stakeholders.*

Remind students to update their how-to instructions. After about 10 minutes of design planning work, say, *We've worked hard to optimize the design of our prototype, so now we can finally create the final version of our products: the instructions that will help people make these heaters at home! When we update and rewrite our how-to instructions, we must keep in mind that another team will be responsible for following them, so we want to make sure they are complete.*

Distribute a copy of *How-To Instructions Must-Haves* to each group and remind teams to review and use the following as they revise their instructions: the partner-team sticky-note feedback they received on *How-to Instructions Must-Haves* in Lesson 7, their science notebook final entry from Lesson 8 describing their changes, and their *Design Testing Matrix*. Previously students have used the Lesson 8 materials to optimize their designs, but here they should use those materials in addition to the Lesson 7 partner-team sticky-note feedback to revise *their instructions*.

Say, *Though Design Must-Haves and How-To Instructions Must-Haves are very similar, we have to remember which pieces are important to us and which pieces are important to someone building our designs. Follow How-To Instructions Must-Haves to make sure we have everything we need for our instructions.*

Allow time for students to revise their instructions that they wrote on *How-to Instructions Must-Haves* and on which they received sticky-note feedback. Tell students that they can use the back of the handout if they need more room. As they are working, walk around the room and check that each team completes their how-to instructions.

Assessment Opportunity

Building towards: 9.A Communicate technical information in writing about how to transfer energy through a system that was designed to perform better than any of its predecessors by using parts of different solutions.

* Supporting Students in Developing and Using Energy and Matter

Design Must-Haves provides opportunities for students to model energy flow at the system level and the particle level. Students used Energy Transfer Models in Lessons 3 and 6 to explain energy transfer between systems, and Lesson 10 will require students to use an Energy Transfer Model in a new context. Students draw a particle level model here to allow more practice before they draw models for their assessment in Lesson 10. Prompt students to think about how the energy transfer and particle models for their optimized designs differ from those for their earlier designs. Groups may choose to draw their energy and particle models on a separate sheet of paper if they don't have enough room on their design paper.

* Attending to Equity

Universal Design for Learning: *Design Must-Haves* can be used as a checklist to help students manage their *actions* with this multistep task of revising their design. Additionally, frequent check-ins using engineering talk moves can help students stay focused and engaged. For example, you can ask a group the following:

- How does changing _____ make your design even better?

What to look for and listen for: Teams' how-to homemade heater instructions that are intended for stakeholder-users should be clear and easy to follow and should include, but are not limited to, the following items listed on *How-To Instructions Must-Haves*: amounts of reactants, types of materials to be used, and how to vent the gases.

What to do: If a team's how-to instructions do not include the items listed above, remind the team to go back and add those. If a team is struggling to write clear instructions, suggest that they number their instructions, think about instructions they have used before, and address the sticky-note feedback they received on the first iteration of their *How-to Instructions Must-Haves* in Lesson 7. If a team is still struggling, have them watch how-to videos as an example of helpful instructions. Once you approve the teams' instructions, place your initials on *How-To Instructions Must-Haves* to indicate what parts you have approved.

- What might you add next to your redesign?
- Can you tell me about your design?
- How did you modify the _____ criterion based on prior testing?

Alternate Activity

If possible, students may want to create a video or type their how-to instructions (especially if that would be an improvement in the ease of use for their design from a previously handwritten version of the directions). If you choose to allow students the video option, they would film their video during the trial run on day 2, but then they may need extra time to edit the video before another team tests the design on day 3.

Approve updated plans. Display **slide E** and remind teams that their design should include a way to vent the hydrogen gas out of their heater. Specifically look for this safety feature and the total amount of reactants as you approve groups' updated plans. Collect and review *Design Must-Haves*.

Safety Precautions

It is critical that students' designs: use *no more* than 55 total grams of reactants (copper sulfate + aluminum), use *no less* than 250 mL of saltwater, and include a way to vent the container holding the reactants.

Designs that do not meet these requirements could get dangerously hot and have the potential to "pop" and release hot liquid or gas. Direct students to design to meet these criteria before building their heaters. Students will be able to successfully heat at least 250 grams of "food" with less than 55 total grams of reactants in 250 mL or more of saltwater if they use the most efficient ratio and their packaging is well designed.

The following safety guidelines should be followed at all times:

- Ensure that the lab has engineering controls (eyewash station and shower) available.
- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.

- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

Assessment Opportunity

Building towards: 9.B Optimize performance of a design that represents systems and energy flows between systems by revising and retesting to incorporate characteristics of the most promising solutions.

What to look for and listen for: Teams' designs should include all the characteristics listed on *Design Must-Haves*. This includes, but is not limited to:

- justification for amounts of reactants used
- reasons for any changes in materials
- trade-offs considered when calculating cost and so forth
- trade-offs based on Consequences Chart
- an Energy Transfer Model
- a particle-level model

What to do: If a team's redesign does not include reasoning for their changes, remind the team to go back and look at their Consequences Chart from Lesson 8. Suggest that they base their changes on prior test results (theirs or another group's). If any team is struggling to show the transfer of energy from the reaction system to the food system on their Energy Transfer Model or the particle-level model of their design, refer to the initial consensus model you made as a class (which shows how the MRE heater's particles were moving) and the Energy Transfer Model from Lesson 3 (which includes a particle-level model) and ask the team to consider how those might be similar to their models. Teams could also think about how their material and reactant changes impacted their Energy Transfer Model from Lesson 6. If these students experienced *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*, referring to the models that they drew of the energy transfer happening with their cups may also be helpful.

End of day 1

3. Build and test our optimal designs.

30 MIN

Materials: Building and Testing Optimized Homemade Heaters Lab, science notebook, *Design Testing Matrix* (from Lesson 6), team designs, how-to instructions

Navigate into today's work. Say, *Last class, we spent a lot of time optimizing our homemade flameless heaters. I bet you are all anxious to build and test them out, so let's get going! Remember, our tests from here on out are at full scale.* Redistribute *Design Must-Haves*.

Safety Precautions

If you were not able to approve each team's optimized design on day 1, be sure to finish doing so before allowing teams to begin building. Confirm that all optimized designs

- use *no more* than 55 total grams of reactants (copper sulfate + aluminum),
- use *no less* than 250 mL of saltwater, and
- include a way to vent the container holding the reactants.

The following safety guidelines should be followed at all times:

Ensure that the lab has engineering controls (eyewash station and shower) available.

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and take-down segments of the activity.
- Immediately wipe up any spilled water on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- Safety guidelines need to be in place for the hydrogen gas that is generated by these reactions (root killer). Guidelines should include the use of vented containers to avoid the build up of pressure and the elimination of potential ignition sources like sparks and flames. The amounts of hydrogen generated by these reactions do not pose an inhalation hazard. Use appropriate lab ventilation.

Review directions for building prototypes. Display **slide F** and review the types of things teams will do as they follow their how-to instructions to build their optimal homemade heater.* These include

- massing their copper sulfate and aluminum,
- measuring and packaging 1 part water beads to 3 parts water to make their "soup" for food,
- putting together their packaging and massing those components, and
- cutting lids or implementing other types of venting for the reactant container.

To avoid students confusing the plain water used for their "soup" with the saltwater, ask them to hold off on measuring out their saltwater until they are finished building their design and are ready to test it.

Prepare to test full-scale designs. Display **slide G**. Have everyone turn to their *Design Testing Matrix* from Lesson 6 in their science notebook and write "My team's optimal design" in the first column of the next blank row. Ask students to be ready to record today's test data in that row.

Display **slide H** and invite students to set up a simple data table (such as the one shown on the slide) to collect the time and temperature data for their optimal design as well as record any observations they make during testing.

*** Attending to Equity**

Universal Design for Learning: Use this opportunity to encourage students' *action* and *expression* by having team members take on certain roles as they build and test their optimized homemade heaters. Possible roles include but are not limited to

- massing reactants,
- packaging the "food,"
- assembling containers and making the vent,
- reading temperatures from the thermometer,
- monitoring time, and
- recording data.

To allow everyone a chance to participate in the different aspects of building and testing designs, you can encourage team members to take turns conducting different tasks.

*** Attending to Equity**

Supporting Universal Design for Learning: If you think it would help support your students' *action* and *expression* by self-regulation, you might create a handout checklist of these procedures (on **slides G** and **J-L**, including steps specific to your classroom) for each team so that they can self-monitor their progress and sustain the effort and concentration needed to build and test their redesign.

Review steps for testing designs. Display **slide I** and briefly review the reminders for testing designs that were followed in Lesson 6. Remind teams to begin watching the clock as soon as the saltwater is combined with the dry reactants and collect temperature data for at least 10 minutes (until the food temperature starts to decrease). As in Lesson 6, teams should record temperature at least every 5 minutes if they are opening a lid to place the thermometer in the "food." If teams choose to leave the thermometer in the "food" for the entire time, they can collect temperature data more frequently.

Review safety guidelines. Display **slide J**. If needed, remind students that the tray and vent are also there for safety purposes.

Direct teams to assemble and test their designs. As teams are working, circulate to check in and be sure teams are assembling and using their heaters as indicated in their designs and how-to instructions. Prompt teams to look for and note places where they find their own how-to instructions to be confusing. Remind team members to record data in the "My team's optimal design" row in *Design Testing Matrix* when they are not actively involved in testing.

Remind students to follow cleanup procedures. As teams finish testing their designs, display **slide K** and draw their attention to the cleanup procedures.*

Update the table of contents. As a reminder, have students periodically update the table of contents in their science notebook.

4. Prepare to have another team test how-to instructions.

5 MIN

Materials: science notebook, *Design Testing Matrix* (from Lesson 6), *Partner Info Sheet for Final Design*

Prepare to exchange how-to instructions. Hand out one half-sheet of the *Partner Info Sheet for Final Design* to each team and display **slide L**. Instruct teams to fill out their team name on the "Design team" line, class period, and the total cost of the heater in their optimized design (this should be in *Design Testing Matrix* in their science notebooks under "My team's optimal design").

Direct teams to make quick revisions to their how-to instructions. Tell teams that they have 5 minutes to make quick revisions to their how-to instructions. Ask them to focus on areas where they found their own instructions to be confusing so that they can clarify them for their partner team. Ideally, their instructions should be clear enough for their partner team to meet or exceed the test results that they obtained. Emphasize that the instructions must still follow the design that was approved at the end of day 1 and that they are modifying instructions for clarity and are *not* to modify any design specifications.

Alternate Activity

After teams test their own optimized design, you may want to give them more time to undergo another round of redesign and testing. Students will probably need another class period to make and test meaningful design modifications. This decision is up to your discretion and should be based on available time and student interest. This option might be helpful for teams that have failed to meet the temperature criterion or if you want groups to have more time for smaller adjustments. Be sure to provide teams with fresh copies of *Design Must-Haves* and *How-To*

Instructions Must-Haves and remind students to back up whatever modifications or tweaks they make with evidence and data they collected. You will need to approve their new designs, and teams will also need to create another row on *Design Testing Matrix* to record their test results.

Additional Guidance

You can use the time during which teams are revising their how-to instructions to assign partner teams. Consider pairing teams that had similar levels of success in Lesson 6 and avoid pairing teams with the highest functioning and lowest functioning designs together. To save time, determine partner teams before class and post them either to **slide M** or on chart paper or on the board as indicated in the "Materials Preparation" section.

5. Exchange designs with another team.

10 MIN

Materials: Partner Testing Homemade Heaters, science notebook, computer or other device to view video instructions (optional)

Share partner team assignments. Say, *We are ready to see if our instructions and designs hold up when another team is asked to build our homemade flameless heaters.*

Show **slide M** (or chart paper or the board) listing the team pairings. Ask the paired teams to exchange their partially filled-out *Partner Info Sheet for Final Design* half-sheets and their optimized heater how-to instructions. Ask testing teams to fill in their team name on the *Partner Info Sheet for Final Design* that they received from their partner team.

Additional Guidance

If any of the teams chose to do a video for their how-to instructions rather than written instructions, have computers or other devices available to view their videos.

Begin assembling partner team's heater. Ask teams to read through their partner team's how-to instructions and begin assembling their heater. Let teams know that there will not be enough time for them to test designs today, so they will not have access to saltwater until the next class. Show the class how they will store their unfinished heaters in the classroom before testing next time so that, when building time is over for today, they will know how to label their work and keep it out of the way until the next class.

End of day 2

6. Finish building another team's design to heat up food and test it.

20 MIN

Materials: Partner Testing Homemade Heaters, science notebook

Build and test partner team's design. Project **slide N**. Direct students to finish building their partner team's design according to their how-to instructions using the supplies from the end of the last class. Partner teams should verify that the device will vent properly and complete the "Total mass of food + reactants + packaging" box on *Partner Info Sheet for Final Design* before moving into the testing phase. Project **slide O** to remind students of safety guidelines.

As teams are working, circulate to check in and be sure teams are assembling and using the designs as indicated in their partner team's how-to instructions. Hand out saltwater to teams that have finished building and are ready to test, directing them to follow all previous safety protocols. Partner teams should complete *Partner Info Sheet for Final Design* as they are testing; the last column of the handout should include specifics about why their partner team's instructions were easy or hard to use.

Exchange partner data and compare testing results. Display **slide P**. When both partner teams are finished collecting data, they should exchange their *Partner Info Sheet for Final Design* with each other. Students should locate *Design Testing Matrix* that is attached in their science notebooks and enter "Partner-team test of our optimal design" in the next blank row of the table. Teams should then enter into this new row the data from *Partner Info Sheet for Final Design* that they received from their partner team. Allow groups to ask each other clarifying questions about the data collected on *Partner Info Sheet for Final Design*. Now all three rows of data on *Design Testing Matrix* are of the same team's designs (My team's prototype, My team's optimal design, and Partner-team test of our optimal design).

Remind teams to compare the results that their partner team generated for testing their device to their own as evidence of how clear their how-to instructions were to follow.

Provide reminders for cleanup as needed. As teams finish their tests, be sure they are collecting liquids and washing containers as directed. If students finish early, direct teams to begin completing *Engineering Design Rubric* that is listed in the next activity.

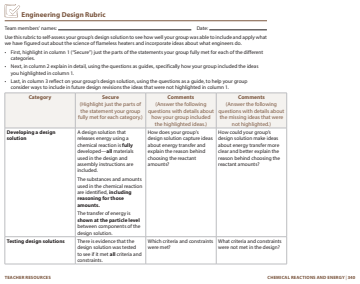
7. Complete Engineering Design Rubric in teams.

5 MIN

Materials: *Engineering Design Rubric*

Complete the *Engineering Design Rubric* in teams. Display **slide Q**. Distribute one copy of *Engineering Design Rubric* to each team.

Say, *Let's see what kind of progress we've made on our engineering work. Take some time with your team to assess how well you've been able to apply what you've figured out about what engineers do. I will use this same rubric to assess your work, as well. Continue to follow our expectations for teamwork as you decide together how to rate your work, and remember, it's not assessing how successful our design was but how well we were able to apply what we've learned about what engineers do.*



Engineering Design Rubric

Team members' names: _____ Date: _____

Use this rubric to self-assess your group's design solution to see how well your group was able to include and apply what we have figured out about the science of flameless heaters and incorporate ideas about what engineers do.

- First, highlight in column 1 ("Secure") just the parts of the statements your group fully met for each of the different categories.
- Next, in column 2 explain in detail, using the questions as guides, specifically how your group included the ideas you highlighted in column 1.
- Last, in column 3 reflect on your group's design solution, using the questions as a guide, to help your group consider ways to include in future design revisions the ideas that were not highlighted in column 1.

Category	Secure (Highlight just the parts of the statement your group fully met for each category.)	Comments (Answer the following questions with details about how your group included the highlighted ideas.)	Comments (Answer the following questions with details about the missing ideas that were not highlighted.)
Developing a design solution	A design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design and assembly instructions are included. The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts.** The transfer of energy is **shown at the particle level** between components of the design solution.	How does your group's design solution capture ideas about energy transfer and explain the reason behind choosing the reactant amounts?	How could your group's design solution make ideas about energy transfer more clear and better explain the reason behind choosing the reactant amounts?
Testing design solutions	There is evidence that the design solution was tested to see if it met **all** criteria and constraints.	Which criteria and constraints were met?	What criteria and constraints were not met in the design?

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Give teams time to complete the rubric and hand it in as they finish for you to use, as well.

Assessment Opportunity

Building towards: 9.B Optimize performance of a design that represents systems and energy flows between systems by revising and retesting to incorporate characteristics of the most promising solutions.

What to look for and listen for: As teams reflect on their work in Lesson 9 to complete *Engineering Design Rubric*, make sure students are referring to their optimal design and the associated test results recorded on *Design Testing Matrix* in their science notebooks. At this point in the unit, this rubric rating can be considered a summative assessment, as students have had more experience with engineering design in this lesson and previous lessons.

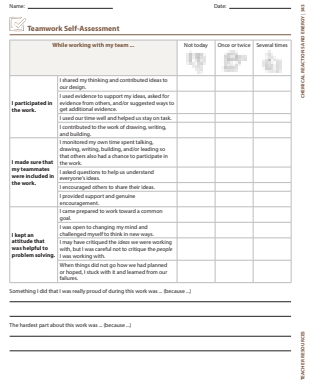
What to do: If students are struggling to identify where their team is on *Engineering Design Rubric*, ask them to point to specific evidence of a category and level of mastery on their optimal design and/or the partner-tested data on *Design Testing Matrix*. Ask them how they incorporated the most promising design components (Lesson 7) and thought through the consequences of design changes in Lesson 8. Push them to make an evidence-based argument for why they highlighted certain statements.

8. Self-assess teamwork individually. 5 MIN

Materials: science notebook, *Teamwork Self-Assessment*, transparent tape

Complete the teamwork self-assessment individually. Display **slide R**. Hand out *Teamwork Self-Assessment* and have students attach it to the next clean page in their notebooks. Cue students to look back at the goal they set at the beginning of the lesson for working as a team. Then direct students to think about how they worked with their teams in Lesson 9. They should take the next few minutes to individually reflect on their work and independently complete this self-assessment. If you are running short on time, assign the self-assessment as home learning.

This assessment is intended as a space for student reflection, but if you are interested in responding to their thoughts, you might ask students to leave their notebooks open to this page after class today so that you can see it.


Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I used evidence to support my ideas, asked for evidence from others, and/or suggested ways to get additional evidence.			
	I used our time well and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I monitored my own time spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged myself to think in new ways.			
	I may have critiqued the ideas we were working with, but I was careful not to critique the people I was working with.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

The hardest part about this work was ... (because ...)

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Alternate Activity

If there is time, you may wish to have students compare their team *Teamwork Self-Assessment* from Lesson 6 to that of *Teamwork Self-Assessment* from Lesson 9. These handouts are in the students' notebooks. This is an excellent opportunity for students to reflect on growth in their design team's thinking about engineering practices and their ability to execute them within their revised heaters. Improvement in their designs in one or more matrix categories can be seen as evidence that they applied what they learned from previous tests to their optimal designs in Lesson 9.

Similarly, you may wish to have students compare their *Engineering Design Rubric* from Lesson 6 to that of *Engineering Design Rubric* from Lesson 9. If so, direct students to compare their Lesson 9 copy to that of Lesson 6 that you have collected.

9. Reflect on what we have accomplished. 15 MIN

Materials: science notebook, transparent tape, *Questions from Our DQB*, 5 sticky dots, Design Questions Board, chart paper for Take-aways board (optional)

Direct students to our Design Questions Board to reflect on what we've accomplished. Say, *Wow, we've figured out so many different pieces to help answer our big question, "How can we use chemical reactions to design a solution to a problem?" Let's take some time to revisit our DQB to see if we've answered any of our own questions.*

Work in pairs to evaluate what questions the class has answered from the DQB. Display **slide S**. Provide students with *Questions from Our DQB*, which you created to contain all the student questions from the DQB, and have students tape it into their science notebook. Have pairs of students work to mark questions with how they think the class has answered them.

*** Attending to Equity**
Revisiting the Design Questions Board is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed (it's more likely that 60–75 percent will be at least partially

- We did not answer this question or any parts of it yet: **O**
- Our class answered *some parts* of this question, or I think I could answer *some parts* of this question: ✓
- Our class answered this question, or using the ideas we have developed, I could now answer this question: ✓+

Mark questions on the DQB with sticky dots, individually. Display **slide T**. Students should walk up to the DQB and put 5 sticky dots on the questions that they think the class made progress on.* Then have students move into their Engineers Circle.

Look for patterns using the dot stickers. In the Engineers Circle, focus on the questions that have the highest numbers of sticky dots.

Discuss as a class the questions the class can now answer. Present **slide U.** Pick a few questions that have the most dots and have the class discuss the answers to these questions as a group. If you have space, you might make a "Take-Aways" board that has a record of the answers the class provides.*

Encourage students to ask questions to help clarify the models the class has built. Work through these questions together to clear up the partial understandings.

10. Navigation

2 MIN

Materials: None

Close today's work and assign home learning. Remind students that they made great progress in the unit by figuring out how to help people create a flameless heater through understanding what we do as engineers. Project **slide V**. Have students survey friends and family about their homemade flameless heater instructions using the form (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**). You may want to direct your students to take a picture of their group's instructions so that they can use it when they survey people. Say, *Let's check with others who aren't in our class to see if they understand our instructions, and let's think about how we might apply what we've figured out to another context. Before next time, survey two or more people. One can be your age, but the other should be an adult. You'll have to describe your heater and show them your instructions, so make sure you have what you need before you go!*

Home Learning Opportunity

Students can share the survey with stakeholders in a variety of ways, including sharing the link, recording responses on their own device, or recording responses on a paper copy of the survey.

You may want to make multiple versions of the survey if you want each class's data to be separate. Refer to *Student Electronic Surveys: Why + How-To* from Lesson 1 to create a Flameless Heater Instructions Survey for your classes.

answered), this helps students see that they have done this hard work to answer many of their own questions.

*** Supporting Students in Engaging in Asking Questions and Defining Problems**

Revisiting the DQB at the end of the unit helps students see the progress they have made toward answering questions that were important to them at the onset of the unit. Students were tasked with asking questions that require sufficient and appropriate evidence to answer. Through the investigations in the unit and individual and whole-group sensemaking, they can now answer many of the questions.

This final visit to the DQB also allows students to ask additional questions to seek clarity about the models that the class has built over the unit to answer the driving question, "How can we use chemical reactions to design a solution to a problem?" This is an opportunity to help students with partial understandings as they prepare for the summative assessment in the next lesson.

ADDITIONAL LESSON 9 TEACHER GUIDANCE

Supporting Students in Making Connections in Math

CCSS.MATH.CONTENT.7.G.B.6 Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.

Students may want to redesign their homemade heaters to increase the surface area of the reactant system that is in contact with the food system. While mathematical calculation of surface area will not be necessary for these design improvements, it may be helpful if students understand the concept of surface area.

CCSS.MATH.CONTENT.6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

Students may change the total amount of reactants in their homemade heaters and will need to use the optimal proportion (from Lesson 4) to recalculate the needed amounts of each individual reactant.

CCSS.MATH.CONTENT.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities. *For example, "The ratio of wings to beaks in the bird house at the zoo was 2:1, because for every 2 wings there was 1 beak." "For every vote candidate A received, candidate C received nearly three votes."*

As in Lesson 6, students will need to calculate the correct amounts of water beads and plain water to make "water bead soup" as a proxy for food in their flameless heaters. The ratio of water beads to plain water is 1:3 (1 part water beads to 3 parts water), and students will measure the beads and water in grams.

LESSON 10

How can we decide between competing designs?

Previous Lesson

We redesigned, optimized, built, and tested our homemade heaters using a Design Testing Matrix. We refined our instructions and exchanged with a partner team to build and test heaters. We reflected on how well our team worked as engineers and how we met expectations as teammates. We revisited our Design Questions Board to address any remaining questions.

This Lesson

Putting Pieces Together

1 DAY

Students demonstrate their understanding on a summative assessment transfer task involving sea turtle incubators. In this assessment they evaluate different designs and develop an argument for which sea turtle incubator design or combination of design features would work best based on relevant criteria and constraints. Then the class celebrates their designs by thinking of other applications for their homemade heaters.

Next Lesson

There is no next lesson.

Building Toward NGSS

MS-PS1-6, MS-ETS1-2, MS-ETS1-3, MS-ETS1-4

What Students Will Do

10.A Make a written argument that supports or refutes the advertised performance of a sea turtle incubator based on evidence concerning whether the incubator meets relevant criteria and constraints, such as transferring the right amount of energy to the sea turtle eggs.

10.B Apply the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the system containing the turtle eggs.

What Students Will Figure Out

- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

- 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 the characteristics may be incorporated into the new design.
- Some chemical reactions release energy.
- Increasing the amount of reactants in an exothermic reaction corresponds to an increase in energy transferred out of that system.

Lesson 10 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	5 min	**NAVIGATION** Review survey results with feedback about our homemade heaters and other ways people could use them.	A	Results from Stakeholder Survey
2	5 min	**REVIEW PROGRESS TRACKERS** Review Progress Trackers with a partner and as a class field any remaining questions that students have.	B	Progress Tracker
3	30 min	**DEMONSTRATE UNDERSTANDING ON AN ASSESSMENT TASK** Demonstrate understanding individually on an assessment about sea turtle incubators.		*Form A: Sea Turtle Assessment*, *Design Testing Matrix for Sea Turtle Assessment*
4	5 min	**PROPOSE OTHER APPLICATIONS FOR DESIGNS ON GRAFFITI BOARDS** Review the survey and discuss other applications that their homemade heaters might have besides heating up food. Students share their ideas on "graffiti boards" around the classroom and celebrate their designs.	C-E	marker, 4 graffiti boards hung around the classroom
				End of day 1
		SCIENCE LITERACY ROUTINE		Student Reader Collection 4: *Good, Better, Best*

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials **Student Procedure Guide** **Student Work Pages**	• Science Notebook • Progress Tracker • *Form A: Sea Turtle Assessment* • *Design Testing Matrix for Sea Turtle Assessment* • marker		• Results from Stakeholder Survey • 4 graffiti boards hung around the classroom

Materials preparation (20 minutes)

Online Resources

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Print a copy for each student of the *Form A: Sea Turtle Assessment* and *Design Testing Matrix for Sea Turtle Assessment* handouts.

Create a link to the survey results from Flameless Heater Instructions Survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**) and add it to **slide A** to be ready to discuss the results as a class.

Prepare at least four "graffiti boards" by hanging pieces of chart paper around the classroom with the question—"How else could our homemade heaters be useful?"—written in the center.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This is the last lesson in this unit. Students will have an opportunity to demonstrate understanding on a summative assessment transfer task about sea turtle incubators. Over the course of the unit students have been building understandings of the four key DCIs that this assessment targets: (1) PS1.B Some chemical reactions release energy; others store energy; (2) ETS1.B There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem; (3) ETS1.B Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors; and (4) ETS1.C 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 the characteristics may be incorporated into the new design.

Where We Are NOT Going

Parts of this assessment are not able to explicitly target DCIs included in this unit, such as the following: (1) ETS1.B A solution needs to be tested and then modified on the basis of the test results in order to improve it and (2) ETS1.B Models of all kinds are important for testing solutions.

These DCIs were addressed throughout the course of the unit and culminated in Lesson 9 with students' final optimal designs.

LEARNING PLAN FOR LESSON 10

1. Navigation

5 MIN

Materials: Results from Stakeholder Survey

Review survey results as a class. Say, *For homework you were asked to fill out this survey yourself, but also to find at least one other person in your community to take the survey as well.* Show **slide A**, which lists the questions that were asked on the survey.

1. Do you think most people would be able to follow these instructions to build a flameless heater to successfully heat food?
2. What suggestions for improvement do you have for these instructions?
3. Do you think you could use this heater to do other things? List your ideas.

Link to the survey results and have a short discussion asking individual students to share about the responses the class collected, conversations they had with people in their family or community about their heater, and whether they were surprised at anything they learned from the survey.

2. Review Progress Trackers.

5 MIN

Materials: science notebook, Progress Tracker

Review Progress Trackers with a partner. Show **slide B**. Say, *Let's pull out our Progress Trackers, talk with a partner about any new ideas we recorded on our Progress Trackers, and ask our partner any final questions we have before we demonstrate our learning on a final assessment. Compare your Progress Tracker with our Design Questions Board. Did we leave any big questions unanswered? Did any new big questions arise from what we figured out in this unit?*

Give students 3-5 minutes to talk with a partner about the questions on **slide B**.

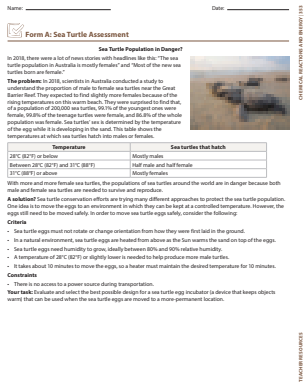
1. What new ideas or insights did you add to your Progress Tracker?
2. What remaining questions do you have?

Answer any remaining questions that students have as a whole class. Allow students to ask in a whole-class discussion any final questions that are unresolved. Answer questions with the class as time allows.

3. Demonstrate understanding on an assessment task. 30 MIN

Materials: *Form A: Sea Turtle Assessment*, *Design Testing Matrix for Sea Turtle Assessment*

Administer *Form A: Sea Turtle Assessment* individually to students. This assessment will take students at least 30 minutes to complete. To ensure students are able to demonstrate their understanding, give students as much time as they need to complete—even if this means pausing and allowing students to complete the rest of the assessment at home or during another class period.


Name: _____ Date: _____

Form A: Sea Turtle Assessment

Sea Turtle Population in Danger?

In 2018, there were a lot of news stories with headlines like this: "The sea turtle population in Australia is mostly females" and "Most of the new sea turtles born are female."

The problem: In 2018, scientists in Australia conducted a study to understand the proportion of male to female sea turtles near the Great Barrier Reef. They expected to find slightly more females because of the rising temperatures on this warm beach. They were surprised to find that, of a population of 200,000 sea turtles, 99.7% of the youngest ones were female, 99.8% of the teenage turtles were female, and 86.8% of the whole population was female. Sea turtles' sex is determined by the temperature of the egg while it is developing in the sand. This table shows the temperatures at which sea turtles hatch into males or females.

Temperature	Sea turtles that hatch
28°C (82°F) or below	Mostly males
Between 28°C (82°F) and 31°C (88°F)	Half male and half female
31°C (88°F) or above	Mostly females

With more and more female sea turtles, the populations of sea turtles around the world are in danger because both male and female sea turtles are needed to survive and reproduce.

A solution? Sea turtle conservation efforts are trying many different approaches to protect the sea turtle population. One idea is to move the eggs to an environment in which they can be kept at a controlled temperature. However, the eggs still need to be moved safely. In order to move sea turtle eggs safely, consider the following:

Criteria

- Sea turtle eggs must not rotate or change orientation from how they were first laid in the ground.
- In a natural environment, sea turtle eggs are heated from above as the Sun warms the sand on top of the eggs.
- Sea turtle eggs need humidity to grow, ideally between 80% and 90% relative humidity.
- A temperature of 28°C (82°F) or slightly lower is needed to help produce more male turtles.
- It takes about 10 minutes to move the eggs, so a heater must maintain the desired temperature for 10 minutes.

Constraints

- There is no access to a power source during transportation.

Your task: Evaluate and select the best possible design for a sea turtle egg incubator (a device that keeps objects warm) that can be used when the sea turtle eggs are moved to a more-permanent location.

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TEACHER RESOURCES

Distribute both *Form A: Sea Turtle Assessment* and *Design Testing Matrix for Sea Turtle Assessment* to students. They will record their criteria and constraints on *Design Testing Matrix for Sea Turtle Assessment*.

Assessment Opportunity

Building towards: 10.A Make a written argument that supports or refutes the advertised performance of a sea turtle incubator based on evidence concerning whether the incubator meets relevant criteria and constraints, such as transferring the right amount of energy to the sea turtle eggs.

Building towards: 10.B Draw and use an Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the system containing the turtle eggs.

What to look for and listen for

- See detailed responses in *Key for Sea Turtle Assessment*.

What to do: This is a summative assessment. However, if students need extra support, you can choose to allow them to use the classroom consensus model, their science notebooks, as well as their responses to the Exit Ticket from Lesson 6 to help them complete the sea turtle transfer task. Since the phenomenon they will be exposed to will be new, they will not find exact answers to the assessment in their notes, and allowing this support may help students make explicit connections to the work they did in class.

Attending to Equity

This assessment encourages students to demonstrate their understanding of key skills and concepts from the unit multiple modalities, including writing to explain and drawing models. There have been several opportunities to assess many of these elements throughout the unit. If any students have already demonstrated security in their ability to use systems and system models to describe the transfer of energy, consider providing those students *Form B: Sea Turtle Assessment*. The standard assessment (*Form A*) has some scaffolds in place to help students begin their models. The alternate version (*Form B*) does not have any framed model starters.

4. Propose other applications for designs on graffiti boards. 5 MIN

Materials: science notebook, marker, 4 graffiti boards hung around the classroom

Reflect on the application of the heater on the assessment. Display **slide C**. Ask students the following questions:

Suggested prompts	Sample student responses
The heaters we made could be used for other applications. For example, we just completed a task that used a chemical reaction for another purpose. What was it used to do?	*They used the heater as an incubator for sea turtles.*
We also surveyed people in our community about other possible uses of our homemade heater designs. What are some of the best ideas?	*(Answers will vary based on survey results and student ideas.)*

Transition to a quick-write prompt in science notebooks. Display **slide D**. Allow students 2 minutes of quiet time to brainstorm ideas in their science notebooks about the following questions:

- We also surveyed people in our community about other possible uses of our homemade heater designs. What are some of the best ideas?
- How else could our homemade heaters be useful besides just heating up food?
- Do you have any other ideas for how someone might use chemical reactions to solve other problems?

Post ideas for application of designs on graffiti boards. Display **slide E**. Instruct students to find the poster they were assigned to and write one idea that they came up with for how our homemade heaters might be applied in another context. Then students can go around to other graffiti boards and view the ideas other students came up with. If they see an idea that inspires them to think of another idea, they can write more than one. There is no need for these ideas to be organized. Students can write anywhere on the chart paper.

Discuss and celebrate as a class the ideas shared on the graffiti boards. Ask students to share some of the interesting applications they saw for the homemade heaters from their classmates. This should be a time to celebrate the broad applications of their devices that they designed!

Additional Guidance

The purpose of this graffiti board strategy is to help students hear one another's ideas. It also helps students who may not be comfortable sharing ideas in a whole-group discussion engage in the conversation. For more information about implementing graffiti boards in classrooms, see: Facing History & Ourselves Graffiti Boards (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**).

SCIENCE LITERACY: READING COLLECTION 4

Good, Better, Best

1 **Who Are Stakeholders?**
2 **Design Test Matrix**
3 **Science Interviews Podcast**
4 **Toothpaste to Smile About!**
5 **A Survey of Food Poisoning Victims from MREs**

Literacy Objectives

- ✓ Identify different stakeholder interests.
- ✓ Distinguish between supported and unsupported claims.
- ✓ Describe a comprehensive method for product testing.

Literacy Exercises

- Read varied text selections related to the topics explored in Lessons 8–10.
- Evaluate the reading selections according to provided prompts and criteria.
- Compare and contrast information gained from reading text with information gained from class investigation.
- Write a description of the different stakeholders in the development of a product in response to the reading.

Instructional Resources

Student Reader

Collection 4

Science Literacy Student Reader, Collection 4
"Good, Better, Best"

Exercise Page

EP 4

Science Literacy Exercise Page
EP 4

Prerequisite Investigations

Assign the Science Literacy reading and writing exercise *after* class completion of this lesson group:

- Lesson 8: What effects might result from our design changes?
- Lesson 9: What is our optimal design for a homemade flameless heater?
- Lesson 10: How can we decide between competing designs?

Standards and Dimensions

NGSS

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

MS-ETS1-3: (Building toward) 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.

Disciplinary Core Ideas

ETS1.B: Developing Possible Solutions

Science and Engineering Practices
Engaging in Argument from Evidence; Analyzing and Interpreting Data

Crosscutting Concept Cause and Effect

CCSS: English Language Arts

RST.6-8.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

RST.6-8.6: Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text.

RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.

CCSS.ELA-LITERACY.W.7.2
Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.

Core Vocabulary

Core Vocabulary: Core Vocabulary terms are those that students should learn to use accurately in discussion and in written responses. During facilitation of learning, expose students repeatedly to these terms. However, these terms are not intended for isolated drill or memorization.

stakeholder

Language of Instruction: The Language of Instruction consists of additional terms, not considered a part of Core Vocabulary, that you should use when talking about any concepts in this exercise. Students will benefit from your modeling the use of these words without the expectation that students will use or explain the words themselves.

effective **efficient**

feedback **optimize** **test**

A Glossary at the end of the Science Literacy Student Reader lists definitions for Core Vocabulary and selected Language of Instruction.

1. Plan ahead.

Determine your pacing to introduce the reading selections, check in with students on their progress, and discuss the reading content and writing exercise. If you are performing Science Literacy as a structured, weekly routine, you might implement a schedule like this:

- Monday: Designate a ten-minute period at the beginning of the week to introduce students to the assignment.
- Wednesday: Plan to touch base briefly with students in the middle of the week to answer questions about the reading, to clarify expectations about the writing exercise, and to help students stay on track.
- Friday: Set aside time at the end of the week to facilitate a discussion about the reading and the writing exercise.

You'll proceed with the in-class lesson investigations during this week.

Exercise Page

EP 4

2. Preview the assignment and set expectations.

(Monday)

- Let students know they will read independently and then complete a short writing assignment. The reading selection relates to topics they are presently exploring in their Chemical Reactions and Energy unit science investigations.
- The reading and writing will be completed outside of class (unless you have available class time to allocate).
- Preview the reading. Share a short summary of what students can expect.

- *In "Who Are Stakeholders?" you will find out how many different people have an interest in the development of a product.*
- *In the second selection, you'll review a model that demonstrates how a product is thoroughly tested.*
- *"Science Interviews Podcast" explains how to set criteria for judging a pie baking contest, which supports the notion that parts of the engineering design process can be applied to just about any industry.*
- *In "Toothpaste to Smile About," you'll discriminate between advertising based on real testing and advertising based on hype.*
- *The final selection gives you ways to determine whether the flameless heater you read about in the beginning of this unit is reliable enough to cook meat and avoid food poisoning.*

- Distribute Exercise Page 4. Preview the writing exercise. Share a summary of what students will be expected to deliver. Emphasize that Science Literacy exercises are brief. The focus is on thoughtful quality of a small product, not on the assignment being big and complex.
  - *For this assignment you will be expected to generate a description of different stakeholders in the development of a product or service.*
- Remind students of helpful strategies they can employ during independent reading. Offer the following advice:
  - *The reading should take approximately 30 minutes to complete.* (Encourage students to break reading into smaller sections over multiple short sittings if their attention wanders.)
  - *A good reading strategy is to scan through the collection first to see the titles, section headers, graphics, and images to see what the selections are going to be about before fully reading.*
  - *Next, "cold read" the selections without yet thinking about the writing assignment that will follow.*
  - *Then, carefully read the Exercise Page to understand the expectations for the writing part of the assignment.*
  - *Revisit the reading selections to complete the writing exercise.*
  - *Jot down any questions for the midweek progress check in class.* (Be sure students know, though, that they are not limited to that time to ask you for clarification or answers to questions.)

3. Touch base to provide clarification and address questions. (Wednesday)

Touch base midweek with students to make sure they are on track while working independently. You may choose to administer a midweek minute-quiz to give students a concrete reason not to postpone completing the reading until the last minute. Ask questions such as these, and have students jot answers on a half sheet of paper:

Suggested prompts	Sample student responses
What is a stakeholder?	*a person who is affected by the failure or success of a product or service*
What would be the first sign that a new app you just installed doesn't work?	*You can't log in to the app.* *Nothing happens when you try to open a link.* *It looks chaotic.*

Suggested prompts	Sample student responses
Whom would you blame if a new app you bought does not work?	*the person who told me about it* *the person who designed it* *the person who tested it* *the person who released it*
What is a fair way to judge a cooking contest?	*Establish criteria for things like taste, texture, appearance, and smell. Then judge the dish on each of those criteria.*
How do you know when a product advertisement is not true?	*It uses a lot of adjectives.* *It makes extraordinary claims that don't seem realistic.*

Ask a few brief discussion questions related to the reading that will help students tie the text content to students' classroom investigations.

Suggested prompts	Sample student responses
How could stakeholder interests be in conflict?	*A designer or engineer might want to take more time to improve or change the design, but the marketing and sales people want the product as soon as possible.*
What are some unfair ways to choose between two designs or products?	*picking one even if the designer didn't follow the rules* *choosing one because you like the person who designed/made it*

SUPPORT—Have students watch a short video of the criteria for a pie baking contest. (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

- Refer students to the Exercise Page 4. Provide more specific guidance about expectations for students' deliverables due at the end of the week.
  - *The writing expectation for this assignment is to create a description of stakeholder interests in a chosen product or service.*
  - *In the selections, you read about stakeholder interests and ways that products are tested.*
  - *Think of a product or service you like or would like to have.*
  - *Make a list of all the stakeholders who have or had an interest in that product or service.*
  - *Write a short description of each different stakeholder. Include why they would care about the success of that product or service. The criterion for the writing is that it must describe the different interests of at least five stakeholders.*
- Answer any questions students may have relative to the reading content or the exercise expectations.

Exercise Page

EP 4

4. Facilitate discussion.

(FRIDAY)

Facilitate class discussion about the reading collection and writing exercise.

The five reading selections help to explain who is interested in the success of a product and how it can be fairly tested to make sure it works regardless of claims about it.

Student Reader

Collection 4

SUPPORT—If you are using the recommended word envelope convention, check the envelope to see if it contains any words, phrases, or sentences that students need help understanding. Read key sentences aloud, and provide concise explanation.

Pages 34–35 **Suggested prompts**	**Sample student responses**
How could an engineer be affected if their product doesn't work as promised?	*The engineer's reputation could be ruined.* *The engineer could be fired from their job.* *The engineer could lose credibility as an expert.*
How could a customer be affected if a product they bought doesn't work as promised?	*The customer would be angry and frustrated.* *The customer would feel as though the product was a waste of money.*
How could a company and its brand be affected if a product they made didn't work as promised?	*The company could lose business.* *The company could lose money.* *The company could get a negative public image.* *The company would have to recall the product.*
What common interest do all stakeholders in a product have?	*They all have an interest in the product being successful.*

Pages 36–37 **Suggested prompts**	**Sample student responses**
How does the second selection help you build knowledge on top of what you learned in the first selection?	*The first selection was about the different people who have a stake in a product. The second selection shows how important it is that a product be tested thoroughly and fairly so that all the stakeholders are satisfied.*
What could happen if a software product were not tested thoroughly before it was brought to market?	*Customers would be unhappy and frustrated.* *The company might have to return the customers' money and fix the product, which takes time and money.* *The company's reputation would be damaged.*
Would it be acceptable if a company tested some parts of a product but not others because they didn't have enough time?	*No. Customers have the right to purchase products that work properly and are tested for safety. If only certain parts of a product are tested, then the design itself may not work as intended. Not testing something properly could be unsafe and have catastrophic effects.*

Pages 38–39 Suggested prompts	Sample student responses
What is the general purpose of the third article about the pie contest?	*It explains the importance of setting criteria for any competition so you can judge rationally and fairly.*
Why is it important that both the contestants and the judges understand the criteria in a contest?	*The contestants know what they will be judged on, and the judges know what to evaluate.*
How is this description of judging a pie contest similar to being an umpire or referee in a sports game?	*Everyone has to know the rules or criteria so that the game is fair and the best team wins.*

Pages 40–41 Suggested prompts	Sample student responses
What is the general purpose of the fourth article, "Toothpaste to Smile About"?	*This selection discusses how to identify outrageous and unsupported product claims.*
How might advertising that uses claims with statistics, like "100% satisfaction," be misleading?	*It depends on the study being cited and the number of people who were involved in the study. For example, if the study only involved three people, then having "100% satisfaction" doesn't mean as much as a study that involved 1,000 people.*
What can the consequences of false advertising claims be?	*People can lose money.* *Company reputations could be lost.* *In serious cases, false health product claims can make people sick or injured.*

Pages 42–43 Suggested prompts	Sample student responses
How does the last selection relate to the other selections in this collection?	*It ties the unit together by exploring tests and claims of flameless heaters, like the one in the beginning of the unit.*
How do you know which product claims are true and which are false?	*The product can't seem too good to be true and unrealistic.* *The supporting evidence should be based on fair tests that involve a lot of people.* *You should learn about the advertiser's motivation and consider that when reading product claims.*

SUPPORT—Have students break the compound word *stakeholder* into its two parts. Discuss that *stake* can be defined as a pointed piece of wood to be a marker or support. But in this sense, *stake* means something valuable that is wagered in a contest. If you are a *stakeholder,* you have something valuable at risk if you win or lose,

CHALLENGE—Have interested students research real-life examples of products that were not adequately tested and failed as a result. This can include airplane crashes; cell phones that catch fire; or toys, cars, and baby products that are recalled for safety reasons. Ask them to share their findings with the class.

EXTEND—Have students watch a video that discusses how misleading advertising works.

5. Check for understanding.

Evaluate and Provide Feedback

For Exercise 4, have students write a description of at least five stakeholders for a particular product or service. It should be engaging and demonstrate an understanding that many people are involved and interested in the development and success of a product or service.

Use the rubric provided on the Exercise Page to supply feedback to each student.

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Acknowledgments

ASSESSMENT SYSTEM OVERVIEW

Each unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial models in science notebooks Progress Tracker update Initial design solutions in science notebooks Design Questions Board	**Pre-Assessment** The student work in Lesson 1 available for assessment should be considered a pre-assessment. It is an opportunity to learn more about the ideas that your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 1 about the question—"How does a flameless heater heat up food just by adding room-temperature water?"—is a good opportunity to pre-assess student understanding of all three dimensions: chemical reactions and transfer of thermal energy at the particle level. On day 2 students develop an initial design solution and compare it with classmates, which is a good time to pre-assess student understanding of engineering design. Also, on day 2 students work together as a class to make entries in their Progress Trackers to explain in their own words how they have defined the problems with prepackaged MREs, proposed a design solution, and listed initial criteria and constraints. The Design Questions Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions, and to post to the board. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions as they relate to the investigations underway. Students' questions for the DQB should be connected to the observations that they had previously made and be directed at seeking additional information about how they could design a device that will heat food without electricity or flame (possibly using a chemical process).
Lesson 3	*Energy Transfer Models Answer Key for Models and Captions*	**Formative Assessment Check** Lesson 3 does a lot to ground student thinking in energy transfer between parts of a system. To demonstrate understanding of the necessary pieces to move forward with productive ideas for design solutions, it is important to check in to ensure students are comfortably using and are able to build on disciplinary core ideas and cross cutting concepts they secured in *Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 6	Team designs with 1. *Design Must-Haves* and 2. *Engineering Design Rubric* *Teamwork Self-Assessment* *Exit Ticket* *Exit Ticket Key*	**Formative and Student Self-Assessment** Teams of students will submit their design solutions. Their designs should include all of the characteristics listed on *Design Must Haves*. Then teams self-assess for how well they did as a team using *Engineering Design Rubric*. Teachers should also use this rubric to give feedback to teams. This should be considered an important opportunity to learn as this point in the unit. They will have opportunities to improve their engineering design work as the unit progresses. Using *Teamwork Self-Assessment*, students will individually self-assess their teamwork. This assessment is intended as a space for student reflection, but if you are interested in responding to their thoughts, you might ask students to leave their notebooks open to this page after class today so that you can see it. **Exit Ticket** This exit ticket builds on what students were asked to do in Lesson 3. Students are asked to map the idea for their specific design solution to the Energy Transfer Model. This check is to see that not only do they understand how energy is transferred to different parts of a system, but that they can apply these ideas directly from their actual design to this model.
Lesson 7	*Peer Feedback on Designs*	**Peer Feedback** After exchanging designs, students will individually give written feedback to their partner team using the guiding questions in *Peer Feedback on Designs*.
Lesson 8	*Peer Feedback on Designs*	**Peer Feedback** Students use the feedback they received in the previous lesson while considering the changes they will make to their design.
Lesson 9	Team designs with 1. *Design Must-Haves* and 2. *Engineering Design Rubric* *Teamwork Self-Assessment*	**Summative and Student Self-Assessment** Similar to Lesson 6, teams of students will submit their revised design solutions. Their designs should include all of the characteristics listed on *Design Must-Haves*. Then teams self-assess their group work using *Engineering Design Rubric*. Teachers should also use this rubric to assess the revised designs. This can be considered a summative assessment for their engineering designs, and teachers should be looking for improvement between the Lesson 6 and Lesson 9 team designs. **Peer Feedback** In Lesson 7 partner teams gave specific feedback about the team's written instructions. This feedback is used in Lesson 9 to help inform the revisions to the design instructions. Students will again individually self-assess their teamwork using *Teamwork Self-Assessment*. This assessment is intended as a space for student reflection, but if you are interested in looking at student growth, you might ask students to turn this in to compare their responses between Lesson 6 and Lesson 9.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 10	*Form A: Sea Turtle Assessment* *Key for Sea Turtle Assessment* Progress Tracker Design Questions Board	**Summative Assessment** This is the last lesson in this unit. Students will have an opportunity to demonstrate understanding on a summative assessment transfer task about sea turtle incubators. They will also have a chance to demonstrate understanding and surface any unanswered or new questions as they review their Progress Trackers in combination with the Design Questions Board with a partner.
During and/or after each lesson	Lesson Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	Progress Tracker	**Formative and Student Self-Assessment** The Progress Tracker is a thinking tool that was designed to help students keep track of important discoveries that the class makes while investigating phenomena and to figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment in time. In this way, the Progress Tracker can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker is meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative "grade" other than for completion.
Anytime after a discussion	Student Self-Assessment Discussion Rubric	**Student Self-Assessment** The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive.
After Students Complete Substantial, Meaningful Work	Peer Feedback Facilitation: A Guide	**Peer Feedback** There will be times in your classroom when facilitating students to give each other feedback will be very valuable for their three-dimensional learning and for learning to give and receive feedback from others. We suggest that peer review happen at least two times per unit. This document is designed to give you options for how to support this in your classroom. It also includes student-facing materials to support giving and receiving feedback along with self-assessment rubrics through which students can reflect on their experience with the process. Peer feedback is most useful when there are complex and diverse ideas visible in student work and not all work is the same. Student models or explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work; rather, peer feedback will be more valuable to students if

When	Assessment and Scoring Guidance	Purpose of Assessment
		they have time to revise after receiving peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities, which they can then use as evidence for their feedback.

For more information about the approach to assessment and general program rubrics, visit the Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross-cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Ask questions that arise from careful observation of a flameless heater that is able to heat food (effect) using a chemical process (cause). **1.B** Define a design problem that can be solved through the development of a homemade flameless heater with multiple criteria and constraints that uses a chemical process (system 1) to heat up food (system 2). **1.C** Apply scientific ideas to design a solution for a flameless heater that heats food by a chemical process that transfers energy.	**1.A Asking Questions and Defining Problems; Cause and Effect** **When to check for understanding** 1. Day 1 when students list their wonderings 2. Day 3 when students generate and share questions for the Design Questions Board **What to look and listen for** 1. Students' wonderings should be based on their careful observations of the flameless heater used in class and as seen in the video and should show that they are curious about or want to predict the cause of the food being heated. 2. Students' questions for the DQB should be connected to the observations that they had previously made and be directed at seeking additional information about how they could design a device that will heat food without electricity or flame (possibly using a chemical process). **1.B Asking Questions and Defining Problems; Systems and System Models**

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		When to check for understanding: Day 2, when students work together as a class to make entries in their Progress Trackers **What to look and listen for:** Take note of which students are able to contribute to the class discussion about what to record in their Progress Trackers. As students add entries to their Progress Trackers, look to see that they are able to explain in their own words how they have defined the problems with prepackaged MREs, proposed the solution of a homemade flameless heater that could help solve those problems, and listed initial criteria and constraints. **1.C Constructing Explanations and Designing Solutions; Energy and Matter** **When to look for it:** Day 2, when students create their initial designs for a homemade flameless heater and/or when they share them in small groups **What to look and listen for:** Since this is the first lesson in the unit, this is a pre-assessment opportunity to see where students are in designing solutions and whether they are beginning to incorporate the transfer of energy flow and/or prior knowledge about chemical processes into their models.
Lesson 2	**2.A** Conduct an investigation to serve as the basis for evidence to confirm that the devices are undergoing a chemical reaction when the temperature increases as energy is transferred from the substances in the devices to its surroundings (what the thermometer measures). **2.B** Develop a model to describe how energy is transferred between different parts of our reaction system to inform the next steps of the design process.	**2.A Planning and Carrying Out Investigations; Systems** **When to check for understanding** Day 1: when planning and revising the investigation Day 2: during the Building Understandings Discussion **What to look and listen for:** Listen for these ideas: 1. Day 1: We want to find out how hot each of the devices gets, but we also need to collect evidence during our investigation to show that new matter is present (change in color, mass, gas escaping, and so forth). 2. Day 2: The evidence we collected supports the idea that a chemical reaction happened when we measured an energy transfer. • The data that the class generated showed a temperature increase when each device (flameless heater and air-activated hand warmer) was working. • Other changes that occurred (change in mass, production of a gas, change in color) while each of the devices was working indicated a chemical reaction was taking place. **2.B Modeling; Energy and Matter** **When to check for understanding** 1. Day 2: creating the Energy Transfer consensus model 2. Day 2: Progress Tracker update

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		What to look and listen for: Listen for these ideas: 1. Day 2: Chemical reactions were happening when the temperature increased for both of the solutions we tested. • Energy flows from the system of atoms that are rearranging during the chemical reaction to the particles that surround the reacting molecules (the reaction system). • Energy flows from the reaction system to many other parts of the system. • We want to minimize energy transfer to other parts of the system and maximize energy transfer to the food system. • We need to keep our food separate from the chemical reaction (our system has subsystems or parts). 2. Day 2: Data we collected from investigating possible solutions served as evidence that chemical reactions were happening when both devices we tested warmed up. • These solutions are not appropriate (one doesn't get hot enough, the other has safety issues), but we can look for other chemical reactions to use in our design. • We need to consider safety with the materials we use (toxicity, flammability, extreme temperatures). • We need a reaction that will get warm enough in a short enough amount of time so that enough energy can be transferred to our food to make it warm.
Lesson 3	**3.A** Collect data that support choosing the chemical reaction that can transfer the most energy to the food system. **3.B** Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.	**3.A Plan and Carry Out an Investigation; Energy and Matter; Systems** **When to check for understanding** • on day 1 as students are collecting data and completing the class data chart and • on day 1 as students are responding to the questions on *Class Data for Chemical Reactions Lab* and as the class discusses the energy transfers between systems from their data **What to look for and listen for** • Students work effectively as a team to measure and record temperature data vs. time by staying focused on their roles. Students calculate the maximum temperature changes for each amount of substances. • Students propose moving forward with the root killer and aluminum foil in saltwater as the best candidate for trying in their homemade flameless heater because it causes the greatest temperature increase. • Students identify the direction of energy flow in reactions that produce an increase in temperature and in the reaction that produces a decrease in the temperature.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		• Students think about the reaction as a system from which energy transfers out of or into depending on the temperature change of the reaction system. **3.B Developing and Using Models; Energy and Matter** **When to check for understanding** • on day 2 when students are adding energy to their particle-level Energy Transfer Models • on day 2 when students are working in pairs to begin their Energy Transfer Models for doubling the reactants • on day 3 when students finalize their Energy Transfer Models on *Energy Transfer Models* and write captions for their models **What to look and listen for** • Energy is transferred from the root killer and aluminum system, including to saltwater within the reaction system, the thermometer system, and the food system. • When more substances (root killer and aluminum foil) were used, we measured a larger increase in temperature as the substance molecules were breaking apart and rearranging. • More energy is transferred from reaction systems with more mass. • If energy is transferred from a reaction system to a food system with greater mass, the temperature will not increase as much. • Using the observable phenomenon of the amount of temperature change, the unobservable direction and relative amounts of energy transferred can be predicted and explained.
Lesson 4	**4.A** Evaluate and use accurate methods of data collection to define an optimal proportion of reactants that result in the greatest temperature change and least amount of reactants left over. **4.B** Analyze data to identify patterns in numerical relationships and images to define an optimal proportion of reactants that result in the greatest temperature change and least amount of reactants left over.	**4.A Planning and Conducting Investigations; Scale, Proportion, and Quantity** **When to check for understanding** 1. As partners are filling out *Analyzing Our Data Collection Methods* on day 1 before the investigation 2. When you collect *Analyzing Our Data Collection Methods* after the investigation on day 1 **What to look for and listen for** 1. Refer to *Key for Analyzing Our Data Collection Methods*. 2. Look for revisions or new additions that have been starred on *Analyzing Our Data Collection Methods*. **4.B Analyzing and Interpreting Data; Patterns** **When to check for understanding:** • Day 2 during the Building Understandings Discussion

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		What to look for/listen for: • Students should identify the combination of 0.5 g of aluminum and 5.5 g of copper sulfate as the optimal amounts, since these provided the greatest temperature change and there was the least amount of aluminum and copper sulfate left over. This optimal proportion of reactants is 8% Al and 92% $CuSO_4$. Students should suggest using a similar proportion of Al to $CuSO_4$ in our design solutions.
Lesson 5	**5.A** Analyze data by identifying patterns to define an optimal operational range for our homemade flameless heater designs that best meets criteria for success because 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.	**5.A Analyzing and Interpreting Data; Patterns** **When to check for understanding** 1. When individual students annotate their reading, and as small groups are sharing information from those readings 2. During the Consensus Discussion about the optimal target food temperature range **What to look and listen for** 1. Students recognize patterns in data about the temperature at which food tastes best and combine this information with safety considerations about food temperature to define the optimal target temperature range. 2. See Key Ideas for the Consensus Discussion.
Lesson 6	**6.A** Undertake a design project to construct and test a solution that meets specific design criteria and constraints, including the transfer of energy. **6.B** Apply scientific ideas, results from testing designs, and the interactions identified on system models to modify our designs in order to improve the flow of energy to food.	**6.A Constructing Explanations and Designing Solutions; Energy and Matter** **When to check for understanding** 1. Days 1-2 when students submit their designs on paper 2. Day 3 with *Engineering Design Rubric* **What to look and listen for** 1. Teams' models should include all the characteristics listed on *Design Must-Haves*. 2. Teams' self-assessment and your own teacher rating of their work using *Engineering Design Rubric* should be considered formative at this point in the unit—they will have opportunities to engage in other engineering design work as the unit progresses. **6.B Constructing Explanation and Designing Solutions; System and System Models** **When to check for understanding** • Day 3 in *Exit Ticket* entries

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		What to look for and listen for • Students on their *Exit Ticket* should identify the components of different systems, mapping their designs on an Energy Transfer Model and evaluate what part of their designs need to be improved in order to optimize systems interactions to meet the criteria and constraints.
Lesson 7	**7.A** Respectfully provide and receive critiques about design solutions to evaluate competing designs with respect to how they meet criteria and constraints and consider patterns across multiple designs to determine which design characteristics caused more-effective outcomes in performance.	**7.A Engaging in Argument from Evidence; Patterns** **When to check for understanding** 1. As we share our designs with partner teams for peer feedback 2. As we identify promising design characteristics in the Engineers Circle discussion **What to look and listen for** • We support the performance of our design characteristics with evidence from investigations. • We evaluate and critique the performance of design characteristics with respect to criteria and constraints. • We give and receive feedback respectfully. • We identify patterns across all designs that cause designs to meet our criteria.
Lesson 8	**8.A** Evaluate competing design solutions based on jointly developed and agreedupon design criteria using systematic processes to consider how small changes in one design characteristic might cause unexpected changes in other design characteristics. **8.B** Prioritize criteria and consider trade-offs that occur as a result of design changes to decide which changes to incorporate for the optimal homemade heater design.	**8.A Engaging in Argument from Evidence; Stability and Change** **When to check for understanding** 1. When students are justifying their planned changes using the prompts in their notebook and the Discussion Diamond tool 2. When students are connecting causes and effects of design changes while working in teams to build their Consequences Chart **What to look and listen for** 1. As students are completing the justification for the changes in their notebooks, look for students to list the changes and the positive effects the changes will have. When they are using the Discussion Diamond tool and their *Design Testing Matrix* during the team consensus discussions, listen for students explaining their positive changes and for students with other ideas arguing against some changes by mentioning potential unintended effects of certain changes. Students should refer to their *Design Testing Matrix* for evidence to support their arguments. 2. As students are constructing the charts, listen for teams using cause-and-effect relationships to predict outcomes that are not on their Design Testing Matrix. Look for arms in the organizer to branch (a cause having more than one effect) and for there to be a series of boxes more than just one step removed from the cause (cascading consequences).

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
		8.B Constructing Explanations and Designing Solutions; Cause and Effect **When to check for understanding:** Teams come to consensus about the changes they will make to their homemade heater designs. • Students respond individually to a prompt by identifying their design changes and justifying the changes by ◦ relating to how the design performs with regard to criteria and constraints, ◦ explaining the different effects on stakeholders, and ◦ giving an explanation showing how a variety of stakeholder impacts were considered and weighed. **What to look and listen for:** Students' justifications should include mention of how design features perform with respect to the criteria and constraints the class defined, an explanation of the stakeholders who were affected by the changes, and a discussion of how the impacts to stakeholders weighed into their final decision.
Lesson 9	**9.A** Communicate technical information in writing about how to transfer energy through a system that was designed to perform better than any of its predecessors by using parts of different solutions. **9.B** Optimize performance of a design that represents systems and energy flows between systems by revising and retesting to incorporate characteristics of the most promising solutions.	**9.A Obtaining, Evaluating, and Communicating Information; Energy and Matter** **When to check for understanding** • Day 1 when students revise their how-to instructions **What to look for and listen for** • Teams' how-to instructions should be clear and easy to follow and should include but are not limited to the following items from the handout: ◦ amounts of reactants ◦ types of materials to be used ◦ how to vent the gases **9.B Constructing Explanations and Designing Solutions; Systems and System Models** **When to check for understanding** 1. Day 1 when students submit their designs on paper with *Design Must-Haves* 2. Day 3 with *Teamwork Self-Assessment* **What to look for and listen for** 1. Teams' designs should include all the characteristics listed on *Design Must-Haves*. 2. Teams' self-assessment and your own teacher rating of their work using *Teamwork Self-Assessment*

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 10	**10.A** Make a written argument that supports or refutes the advertised performance of a sea turtle incubator based on evidence concerning whether the incubator meets relevant criteria and constraints, such as transferring the right amount of energy to the sea turtle eggs. **10.B** Apply the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the system containing the turtle eggs.	**10.A Engaging in Argument from Evidence; Energy and Matter** **When to check for understanding:** during the summative assessment on *Form A: Sea Turtle Assessment* **What to look for and listen for:** See detailed responses in *Key for Sea Turtle Assessment* and scoring guidance in *Rubric for Sea Turtle Assessment*. **10.B Developing and Using Models; Systems and System Models** **When to check for understanding:** during the summative assessment on *Form A: Sea Turtle Assessment* **What to look for and listen for:** See detailed responses in *Key for Sea Turtle Assessment* and scoring guidance in *Rubric for Sea Turtle Assessment*.

Student Electronic Surveys: Why + How-To

Why student electronic surveys?

Student electronic surveys are a great tool to connect students with different stakeholders within the local community. Having students ask family and friends to participate in surveys helps provide feedback on the work that students are doing in the classroom. Having students give these surveys electronically helps to quickly aggregate data so that students can analyze the results to guide and inform the direction of their future work.

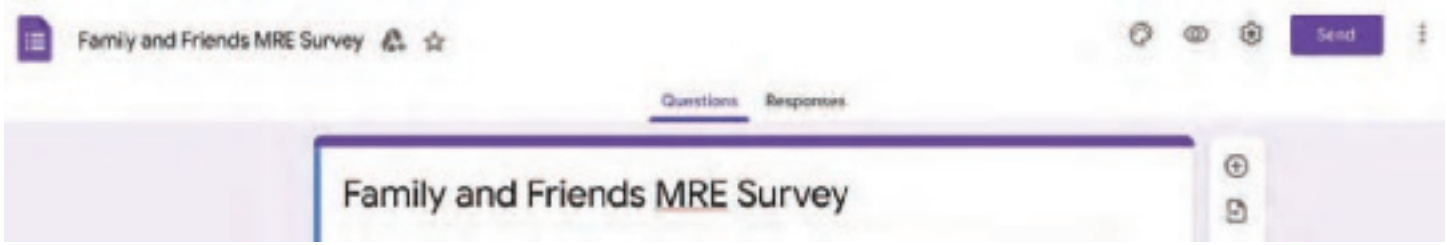
How to use student electronic surveys

1. Select the link for the survey that corresponds with the lesson you are teaching. In Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit) unit there are surveys for day 1 of Lesson 1, at the end of Lesson 4, and at the end of Lesson 9.

- Family and Friends MRE Survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
- Example Flameless Heater Stakeholder Survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
- Flameless Heater Stakeholder Survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)
- Flameless Heater Instructions Survey (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources**)

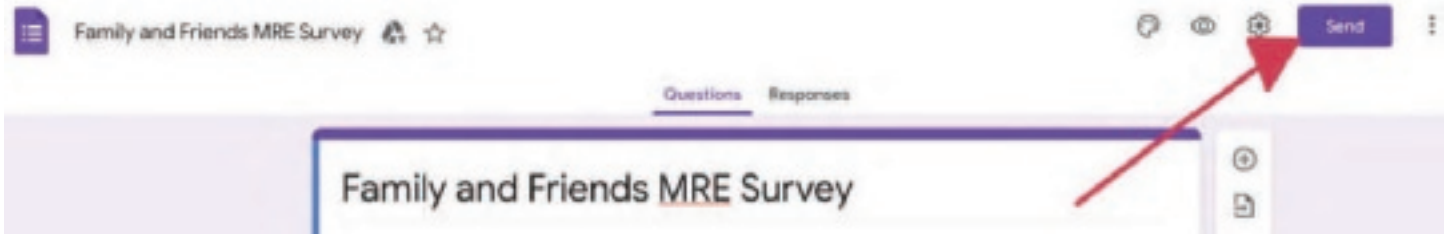
2. When you select the link, it will ask you to make a copy in your own Google Drive.

3. The student survey will open in your own Google Drive.

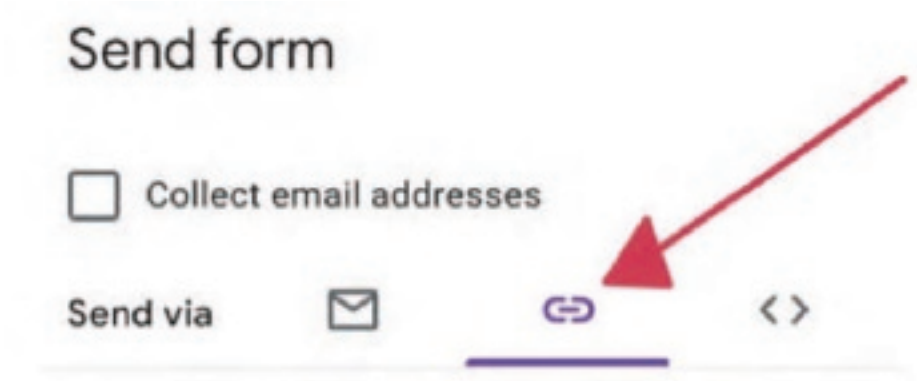


4. Select the gear icon at the top right side of the screen. Check to make sure that the survey is not restricted to certain users.

5. Select the "Send" button in the upper right corner to get a link to give to students.

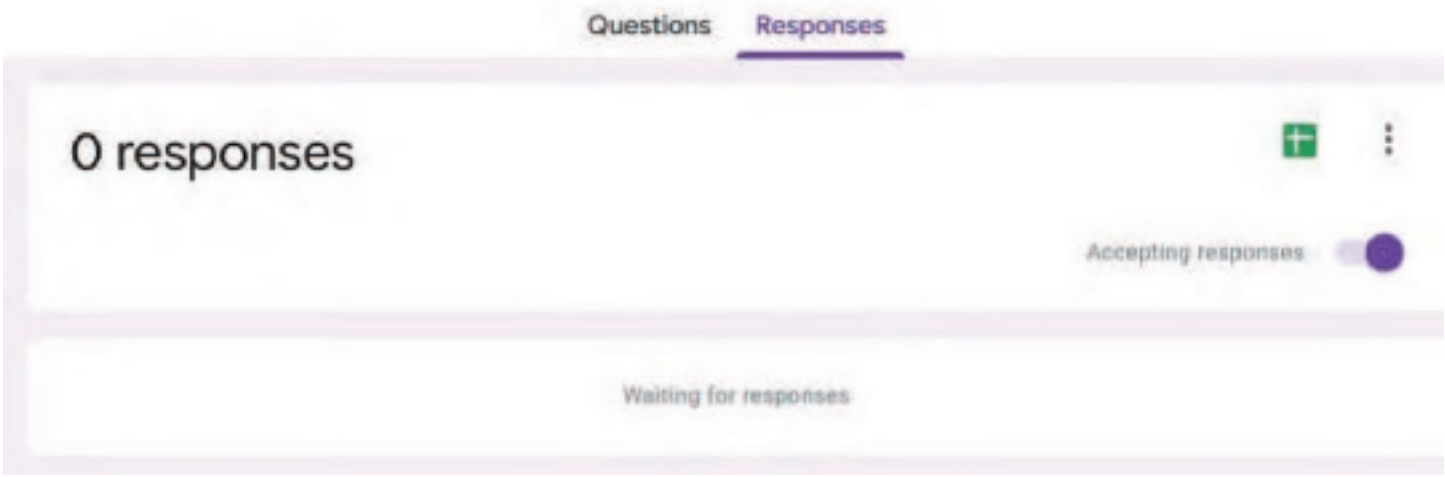


6. In the "Send via" panel select the middle icon in order to choose to send the survey via a link.



7. Copy the link it provides you or select the "Shorten URL" box then copy the link. This second option creates a link that will be easier for students to type.

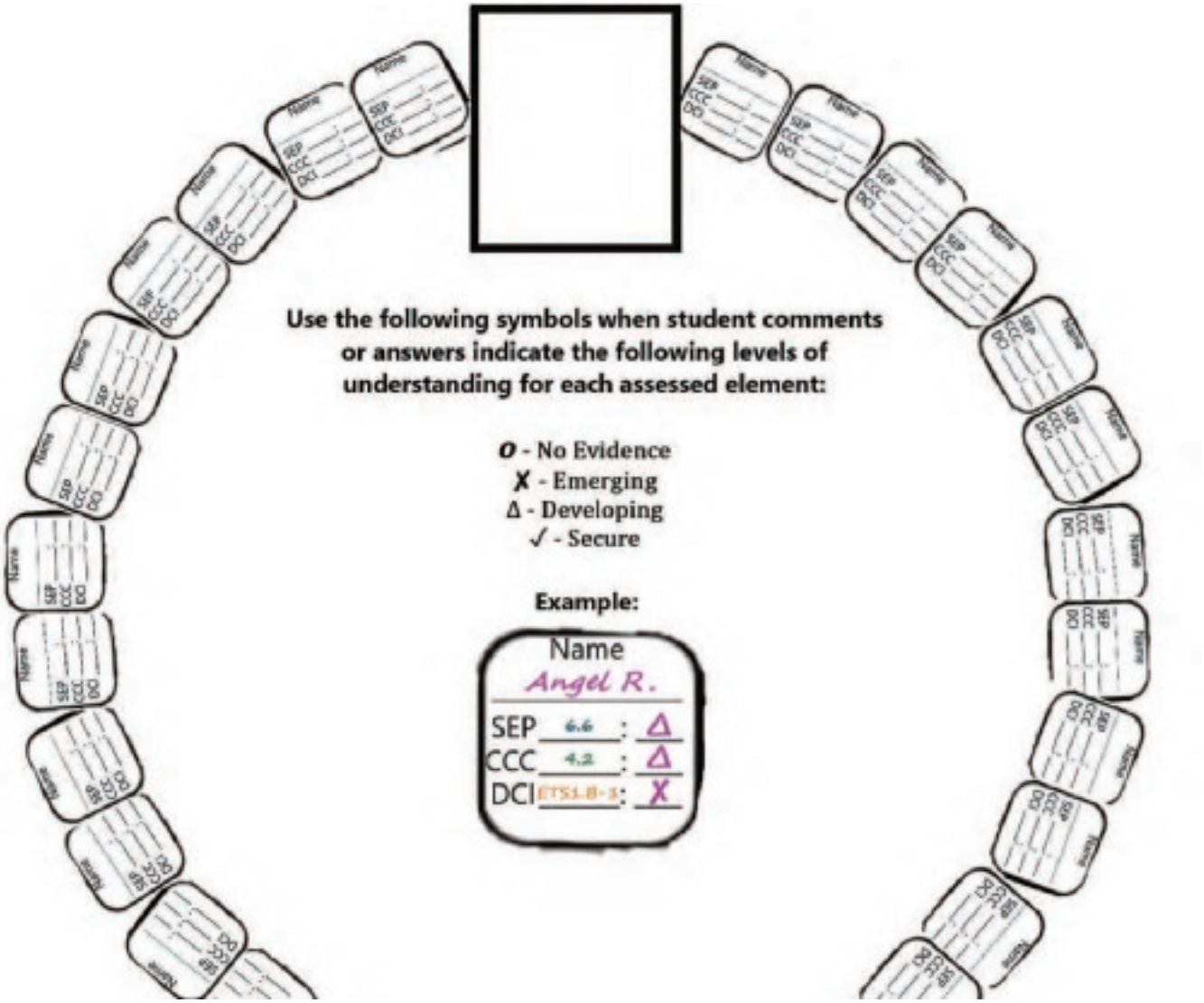
8. Have students' family and friends take the survey.
9. Once people submit responses they will show up in your Google Form under "Responses". Google will automatically provide you with some visualizations of these responses.



10. If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the survey.
11. For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes or choose to have one survey for all your classes.

Template for Discussion Mapping and Individual Student Assessment

2.A Conduct an investigation to serve as the basis for evidence to confirm that the devices are undergoing a chemical reaction when the temperature increases as energy is transferred from the substances in the devices to its surroundings (what the thermometer measures).



Use the following symbols when student comments or answers indicate the following levels of understanding for each assessed element:

O - No Evidence
✗ - Emerging
Δ - Developing
✓ - Secure

Example:

Name
SEP
CCC
DCI
Name
SEP
CCC
DCI
Name
SEP
CCC
DCI

Name
SEP
CCC
DCI
Name
SEP
CCC
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Name
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CCC
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Name
SEP
CCC
DCI
Name
SEP
CCC
DCI
Name
SEP
CCC
DCI

LESSON 2: TEACHER REFERENCE

Example observations for investigations

Time (min)	MRE heater temperature (degrees C)	Hand warmer temperature (degrees C)
0	24.4	25.2
5	64.8	27.1
10	82.7	29.3
15	82.4	29.7

Time (min)	MRE heater set-up mass (g)	Hand warmer set-up mass (g)
0	77.9	77.8
5	75.3	77.8
10	74.2	77.9
15	73.9	78.0

Time (min)	MRE heater observations	Hand warmer observations
0		Contents feel like sand
5		
10	Can see steam or something coming out of the heater	
15		Contents feel hardened or clumped

Time (min)	Comparison of substance in the MRE heater before and after	Comparison of substance in the hand warmer before and after
Before	Small silvery or gray grains with some shiny flecks mixed in	Small black grains with some shiny flecks
After	Looks more powdery and less shiny; grains are smaller	Color is more red/orange; grains have clumped up

Safety Information for Copper Sulfate Pentahydrate

The safety information presented in this reference follows the format used in the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) for identifying both the hazards and risks associated with chemicals. This system has been adopted by the EPA, OSHA, and the US Department of Transportation for use in the United States, and science teachers are expected to be familiar with the symbols, signal words, hazard statements, and precautionary statements. The information presented here for copper sulfate pentahydrate has been compiled from Safety Data Sheets that are readily available online.

Globally Harmonized System (GHS) Symbols	
	Irritant • Acute toxicity (oral, dermal, inhalation), category 4 • Skin irritation, category 2 • Eye irritation, category 2A • Note: The lower the number assigned to a given hazard category, the greater the severity.
	Environmentally Damaging • Acute hazards to the aquatic environment, category 1 • Chronic hazards to the aquatic environment, category 1 • Note: The lower the number assigned to a given hazard category, the greater the severity.
GHS Signal Word: Warning	

Hazard statements

- Harmful if swallowed
- Causes skin irritation
- Causes serious eye irritation
- Very toxic to aquatic life
- Very toxic to aquatic life with long-lasting effect

Precautionary statements	
• If medical advice is needed, have product container or label at hand. For specific treatment, refer to product label or seek medical attention.	• Keep out of reach of children. • Read label before use. • Wash hands thoroughly after handling.
• Wear protective gloves, protective clothing, eye protection, face protection.	• Avoid release to the environment. • Rinse mouth. • Collect spillage.
• Take off contaminated clothing and wash before reuse.	• IF SWALLOWED: Call a poison center or doctor or physician if you feel unwell.
• IF ON SKIN: Wash with soap and water.	• If skin irritation or a rash occurs: Get medical advice or attention.
• IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses if present and easy to do–continue rinsing.	• If eye irritation persists: Get medical advice or attention.
• IF INHALED: Move exposed individual to fresh air. Loosen clothing as necessary and position individual in a comfortable position.	• If breathing is difficult: Give oxygen. • Seek immediate medical attention or advice.

Disposal directions for copper sulfate solutions generated in Lesson 3 and later lessons

To minimize pollution of the aquatic environment, collect all liquids from the copper sulfate and aluminum reaction mixtures and react them with excess aluminum so that all copper sulfate will be converted to aluminum sulfate (in solution) and copper metal (a solid). Use the blue color of the solution as a visual estimate of how much copper sulfate remains in the solution; the less blue the solution, the less copper sulfate remaining. After a reaction with excess aluminum, the solution containing sodium chloride and aluminum sulfate can be poured down the drain with running water (since aluminum sulfate is not an environmental hazard), and the aluminum and copper solids can be disposed of in the trash.

Sources

1. American Chemical Society (2016). *Guidelines for Chemical Laboratory Safety in Secondary Schools* from 2016. Retrieved from: Guidelines for Chemical Laboratory Safety in Secondary Schools (See the **Online Resources Guide** for a link to this item. **www.coreknowledge.org/cksci-online-resources)**
2. AquaPhoenix Scientific (2014). Copper sulfate pentahydrate safety data sheet. Retrieved from: Data sheet

LESSON 3: TEACHER REFERENCE 2

Sample Temperature vs. Time Data

Bolded and underlined values are the minima or maxima that students should circle and use to calculate the maximum temperature change as indicated in *Class Data for Chemical Reactions Lab*. All temperatures are measured in degrees Celsius.

Group: Baking soda and vinegar **My role:** Varies by student

Substances used:

A. Baking soda

B. Vinegar

C.

Time (min)	Low amounts used: A. 1.0 g B. 50 mL C.	Temperature data (°C) for medium amounts Amounts used: A. 2.0 g B. 50 mL C.	Temperature data (°C) for high amounts Amounts used: A. 3.0 g B. 50 mL C.
0-0 (start temp)	19.2	19.0	19.1
0.5	17.8	16.8	15.8
1.0	**17.5**	16.2	14.5
1.5	17.5	**16.2**	**14.4**
2.0	17.7	16.3	14.5
2.5	17.8	16.3	14.5
3.0	18.0	16.5	14.7
3.5	18.0	16.6	14.7
4.0	18.1	16.6	14.8
4.5	18.1	16.8	14.8
5.0	18.2	16.9	14.9

Observations: Baking soda looks like a white solid—like a powder—and vinegar is a clear and colorless liquid that has an odor. When mixed there is fizzing and foaming.

Group: Vinegar-dipped steel wool in air **My role:** Varies by student

Substances used:

A. Steel wool

B. Air

C.

Time (min)	Temperature data (°C) for low amounts Amounts used: A. 4.4 g B. C.	Temperature data (°C) for medium amounts Amounts used: A. 7.2 g B. C.	Temperature data (°C) for high amounts Amounts used: A. 15.9 g B. C.
0 (start temp)	20.6	21.1	21.4
0.5	21.9	23.9	26.4
1.0	22.8	25.4	28.7
1.5	23.6	26.7	30.6
2.0	24.1	27.7	32.3
2.5	24.5	28.5	33.6
3.0	24.9	29.0	34.5
3.5	25.1	29.4	35.0
4.0	25.3	**29.5**	**35.2**
4.5	**25.4**	29.5	35.2
5.0	25.4	29.4	34.9

Observations:

Steel wool in vinegar has little bubbles on it and is a silvery color. When we opened up the cup at the end, we saw some rust color on the steel wool, and it smelled like rotten eggs.

Group: Root killer and aluminum foil in saltwater **My role:** Varies by student

Substances used:

A. Root killer

B. Aluminum foil

C. Saltwater

Time (min)	Temperature data (°C) for <u>low</u> amounts Amounts used: A. 1.0 g B. 1.0 g C. 60 mL	Temperature data (°C) for <u>medium</u> amounts Amounts used: A. 2.0 g B. 2.0 g C. 60 mL	Temperature data (°C) for <u>high</u> amounts Amounts used: A. 3.0 g B. 3.0 g C. 60 mL
0 (start temp)	17.6	19.7	17.6
0.5	17.9	17.9	17.5
1.0	18.7	18.8	18.3
1.5	19.9	20.9	20.4
2.0	21.1	23.2	23.7
2.5	22.2	25.1	26.9
3.0	23.1	26.5	30.2
3.5	23.8	27.7	33.0
4.0	24.2	28.5	34.3
4.5	24.5	29.3	35.2
5.0	**<u>24.7</u>**	**<u>29.8</u>**	**<u>35.7</u>**

Observations:

The root killer looks like pretty blue crystals, and the aluminum foil looks like aluminum foil cut into little pieces. The saltwater just looks like water. After mixing, the blue color is totally gone and there is some reddish-brown powder in there. There are still aluminum foil pieces. For the Medium and High cups, we could feel the cup getting warm through the Styrofoam.

Group: Cabbage juice and vinegar **My role:** Varies by student

Substances used:

A. Cabbage juice

B. Vinegar

C. Water

Time (min)	Temperature data (°C) for low amounts Amounts used: A. 5.0 g B. 5.0 g C. 50 mL	Temperature data (°C) for medium amounts Amounts used: A. 10.0 g B. 10.0 g C. 40 mL	Temperature data (°C) for high amounts Amounts used: A. 20.0 g B. 20.0 g C. 20 mL
0 (start temp)	19.7	20.1	19.8
0.5	19.8	20.1	19.9
1.0	19.8	20.2	20.0
1.5	19.9	20.2	20.0
2.0	19.9	20.2	20.0
2.5	20.0	20.3	20.1
3.0	20.0	20.3	20.1
3.5	20.0	20.3	20.2
4.0	**20.1**	20.4	20.2
4.5	20.1	20.4	20.2
5.0	20.1	**20.5**	**20.3**

Observations:

To start, the cabbage juice looked like a dark blue-purple liquid that kind of smelled like cabbage. The vinegar is a clear, colorless liquid that smells like vinegar. There was not much of a color change when we added the cabbage juice to the water, but as soon as we added the vinegar, it turned a bright pink color.

Rubric for Models and Captions

3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

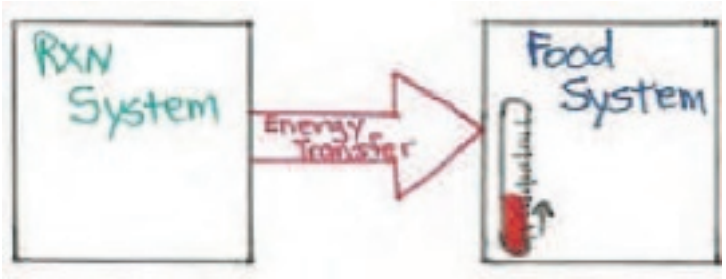
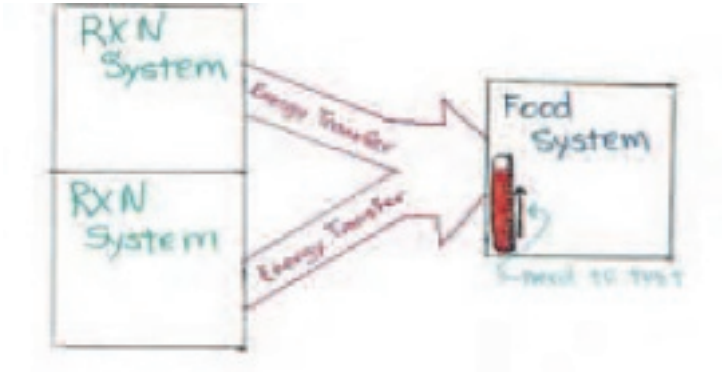
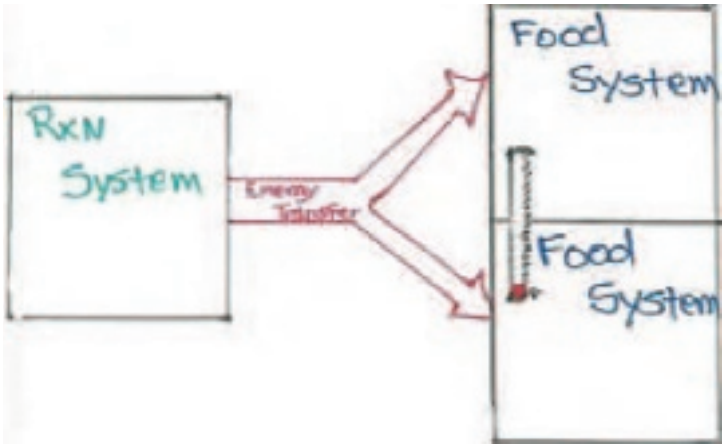
Targeted SEP, CCC, and DCI elements

SEP 2.4	Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
CCC 5.4	The transfer of energy can be tracked as energy flows through a designed or natural system.
PS1.B-3	Some chemical reactions release energy; others store energy.

Opportunities to show growth in these elements

SEP 2.2	Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.
PS1.B-1	Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
PS3.B-2	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)

Targeted SEP, CCC, and DCI elements				
Elements of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
SEP 2.4				
CCC 5.4				
PS1.B-3				

Systems description and data	Model	Caption
1X R×n **1X Food** **Δ Food temp** **2.9°C**		The breaking apart and rearrangement of particles in the reactants to produce the products transfers a certain amount of energy from the reaction system to the surroundings (the food). This energy is transferred to the food system that includes the thermometer and makes the particles in this system speed up. The thermometer shows a higher temperature. The video of this test gave us evidence that energy was transferred from the reaction system (exothermic reaction) to the food system. We developed this model to explain the energy transfer from the reaction system to the food system.
2X R×n **1X Food** **Δ Food temp** **4.8°C**		This model shows a certain amount of energy coming from 2X the amount of reactants in an exothermic reaction and transferring to the food system and thermometer, which are part of the surroundings. Since the amount of energy transferring from a reaction system is caused by the number of particles breaking apart and rearranging in an exothermic reaction, when we double the amount of the reactants in the reaction system, we double the number of particles. More energy is transferred out of the 2X reaction system. This energy transfers to the food system that contains the thermometer and raises the temperature more than the 1X/1X system. The temperature goes up more because more energy is transferred between the systems and the particles of the food system speed up more than in the 1X/1X system.
1X R×n **2X Food** **Δ Food temp** **2.0°C**		A certain amount of energy transfers from a 1X reaction system, and when that energy transfers to a 2X food system, the energy transferred from the exothermic reaction system is spread out more because there is more food. The average speed of the particles is less than the other two systems. (Students may also say because the energy is shared between more particles.) Our model shows this by thinner arrows when the energy divides—the energy is divided more among all the food particles.

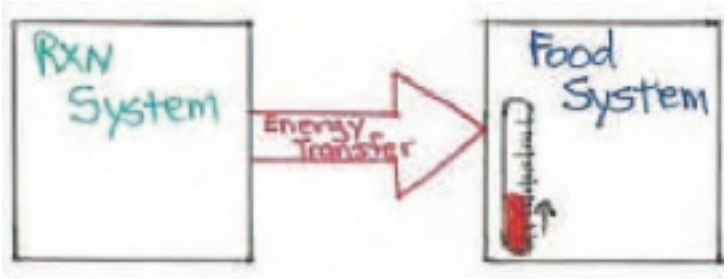
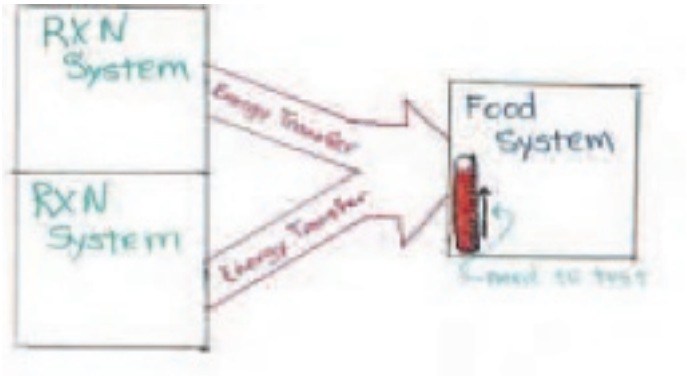
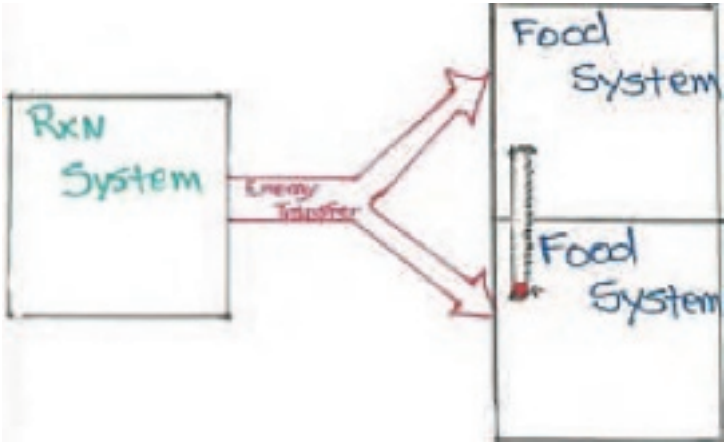
Answer Key for Models and Captions

This assessment can be used to evaluate student progress on the following LLPE. The LLPEs are an integration of elements from the three dimensions, so look for these three aspects working together across the students' models and captions.

3.B Develop a model to describe and/or explain the unobservable mechanism related to chemical reactions and the flow of energy to or from the reaction system and its surroundings.

SEPs	DCIs	CCCs

Develop and/or revise a model to show the relationships among variables, including those that are not observable but predict observable phenomena.
 	
Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.
 	
Student models (and the captions explaining each model) should include:
• A way to show that a chemical reaction has taken place
  ◦ Model should show or explain that the arrangement of atoms in the reactants is different than in the products
• A way to show that different amounts of energy is transferred between parts of the system
  ◦ Arrows may indicate direction
  ◦ Size or thickness of arrow may indicate amount of energy being transferred
• A way to show that if the the amount of reactants changes, the amount of energy that is transferred from the system also changes
• A way to show that the mass of the food will affect the temperature change of the food when energy is transferred to the food system
  ◦ If the same amount of energy is transferred to the food system, but there is less food, the temperature change will be greater.
  ◦ If the same amount of energy is transferred to the food system, but there is more food, the temperature change will be less.
  ◦ It is possible to get a similar temperature change by increasing both the food and the reactants (or decreasing the amount of food and the amount of reactants).
	Some chemical reactions release energy; others store energy.
	
	Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.
	
	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)
	
	The tasks on the assessment require students to use ideas about energy transfer to explain their thinking using models and the captions for each model. Additionally, this task requires students to use ideas learned in previous units about what is happening to the arrangement of atoms during a chemical reaction and the relationship between amount of matter and change in temperature due to energy transfer.
		The transfer of energy can be tracked as energy flows through a designed or natural system.
		
		The primary crosscutting concept lens on this assessment is that of Energy and Matter and specifically, how models can be used to track the flow of energy through a designed system. Look for students to include ways to show the direction and amount of energy that is transferred from one part of a system to another.

Systems description and data	Model	Caption
1X R×n **1X Food** **Δ Food temp** **2.9°C**		The breaking apart and rearrangement of particles in the reactants to produce the products transfers a certain amount of energy from the reaction system to the surroundings (the food). This energy is transferred to the food system that includes the thermometer and makes the particles in this system speed up. The thermometer shows a higher temperature. The video of this test gave us evidence that energy was transferred from the reaction system (exothermic reaction) to the food system. We developed this model to explain the energy transfer from the reaction system to the food system.
2X R×n **1X Food** **Δ Food temp** **4.8°C**		This model shows a certain amount of energy coming from 2X the amount of reactants in an exothermic reaction and transferring to the food system and thermometer, which are part of the surroundings. Since the amount of energy transferring from a reaction system is caused by the number of particles breaking apart and rearranging in an exothermic reaction, when we double the amount of the reactants in the reaction system, we double the number of particles. More energy is transferred out of the 2X reaction system. This energy transfers to the food system that contains the thermometer and raises the temperature more than the 1X/1X system. The temperature goes up more because more energy is transferred between the systems and the particles of the food system speed up more than in the 1X/1X system.
1X R×n **2X Food** **Δ Food temp** **2.0°C**		A certain amount of energy transfers from a 1X reaction system, and when that energy transfers to a 2X food system, the energy transferred from the exothermic reaction system is spread out more because there is more food. The average speed of the particles is less than the other two systems. (Students may also say because the energy is shared between more particles.) Our model shows this by thinner arrows when the energy divides—the energy is divided more among all the food particles.

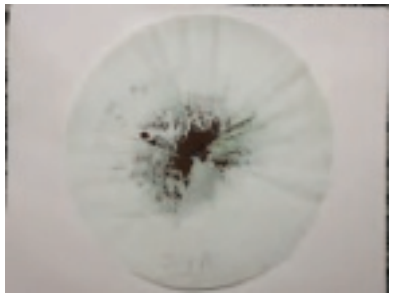
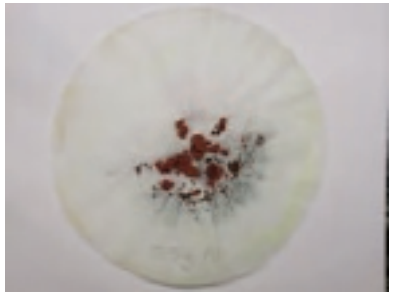
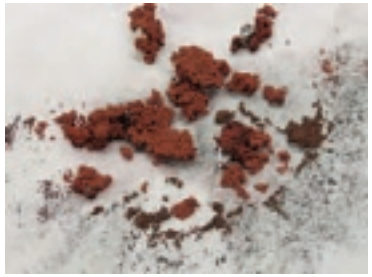
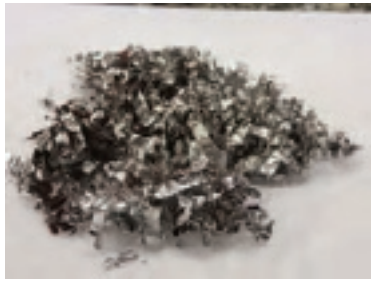
Sample Data for Proportion of Reactants Investigation

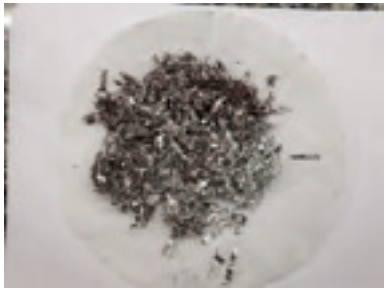
Sample temperature vs. time data are shown below. The maximum temperatures are bolded and underlined and are what students should use to calculate the maximum temperature change.

Note: The data for 3.0 g of aluminum and 3.0 g of copper sulfate, a combination that is investigated in Lesson 3, are included for reference.

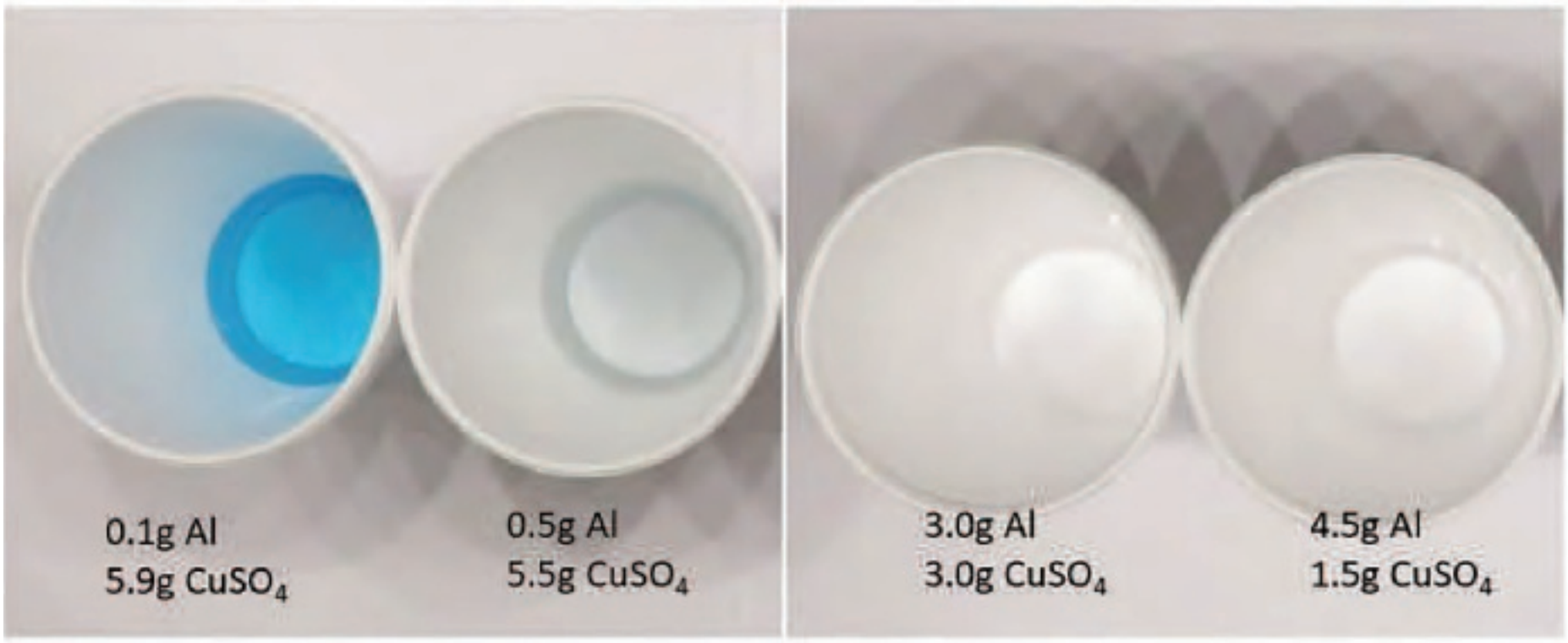
Time (min)	Temp data (°C) for Groups A and B Amounts used: Al: 0.1 g $CuSO_4$: 5.9 g Saltwater: 60.0 g	Temp data (°C) for Groups C and D Amounts used: Al: 0.5 g $CuSO_4$: 5.5 g Saltwater: 60.0 g	Temp data (°C) from Lesson 3 Amounts used: Al: 3.0 g $CuSO_4$: 3.0 g Saltwater: 60.0 g	Temp data (°C) for Groups E and F Amounts used: Al: 4.5 g $CuSO_4$: 1.5 g Saltwater: 60.0 g
0 (Starting temp.)	19.6	19.1	19.3	19.1
0.5	19.6	19.5	20.2	19.6
1.0	19.7	20.8	23.3	21.3
1.5	20.2	23.7	27.5	23.6
2.0	21.0	28.1	32.5	25.5
2.5	22.1	32.8	36.3	26.6
3.0	23.3	36.6	37.8	27.5
3.5	24.5	39.7	38.5	28.2
4.0	25.3	42.0	**38.7**	28.8
4.5	25.8	43.9	38.6	29.0
5.0	**26.0**	**45.6**	38.4	**29.1**
Max. T change (°C)	6.4	26.5	19.4	10.0

The following images provide examples of what will remain on the coffee filter when students filter the solids from the liquids for each ratio of reactants.

Masses of Al: $CuSO_4$	Image of dried filtrate	Close-up
0.1 g: 5.9 g		 Note: Undissolved blue copper sulfate crystals are present, and no aluminum is visible.
0.5 g: 5.5 g		 Note: Although the filter paper has a bluish tinge, no blue copper sulfate crystals are visible. There is a small amount of aluminum visible.
3.0 g: 3.0 g (from Lesson 3)		

Masses of Al: $CuSO_4$	Image of dried filtrate	Close-up
4.5 g: 1.5g		

The following images provide an example of what 20 mL of the liquid after filtration looks like in a clean, 8 oz. Styrofoam cup (3.0 g is from Lesson 3).



Key for Analyzing Our Data Collection Methods

In this lesson, students work with a partner to complete *Analyzing Our Data Collection Methods*. This is an opportunity to assess their progress toward **4.A** Evaluate and use accurate methods of data collection to define an optimal proportion of reactants that result in the greatest temperature change and greatest conversion to products. *Analyzing Our Data Collection Methods* is used to specifically evaluate the data collection methods provided in *Investigation Procedure for Proportion of Reactants* for accuracy prior to conducting the Proportion of Reactants Investigation. Each row addresses different aspects of data collection, reflected in the parts of the procedure, and asks students to articulate how the methods help answer the lesson question as well as how the methods contribute to accurate data collection. Students will revisit and add to the last column after conducting the investigation. The key below provides sample student responses.

Part of the procedure	Why are these methods important for answering our question?	In what ways do the methods support accurate data collection? What suggestions do you have for improving the accuracy of our data collection?
Measuring reactants	*If we want to figure out what proportion of reactants to use, we have to know how much of each we are using.*	• *Measure really carefully—be sure no material or substance is left hanging off somewhere or dripping.* • *Measure to the nearest 0.1 g.* • *Record exactly how much we used.*
Collecting temperature data	*We are trying to get a reaction that increases in temperature to heat up our food, so we have to measure the temperature to see what works best.*	• *Keep the thermometer in the solution the whole time.* • *Record the starting and ending temperature (not just the max temperature).* • *Keep the thermometer right in the middle of the system being measured.*
Examining the solids and liquids	*What is left over afterwards might tell us about what is happening with the reaction.* *If there is a lot of one of the reactants left over, it might tell us that there isn't enough of the other reactant.*	• *We need a reference point (way to compare) to be able to compare colors of the liquid and what the solids look like between groups.* • *We could line them up next to each other to compare.*

Example Heater Instructions

Instructions to assemble and use our heater are as follows. (This example is a first draft, which has room for improvements.)

Instructions	Drawings
1. Gather the following materials: • 16 oz. container with lid • 48 oz. container with lid that has two holes in it • 49.5 grams of copper sulfate (root killer) granules • 4.5 grams of shredded aluminum foil • 250 mL of saltwater • 250 grams of food you would like to heat up	
2. Place your food to be heated into the 16 oz. container and secure the lid tightly.	
3. Put the food container inside the larger 48 oz. container.	
4. Add the copper sulfate and shredded aluminum foil to the 48 oz. container so that it surrounds the food container but is not caught on top of the lid of the food container.	

5. Pour the saltwater into the 48 oz. container and put the lid on.

   SAFETY: Make sure the two holes in the lid are not blocked so that they can let the hydrogen gas from the reaction vent out.

6. Gently swirl the container, being careful not to spill the liquid out, but helping everything to mix together well.
7. Continue swirling about 10 swirls every 2 minutes.
8. After 15 minutes, remove your food container from the heater and rinse it off with running water before opening it to enjoy your warm food.

Testing Reaction for Maximum Temperature

Directions:

The purpose of this test is to ensure that the reaction does not reach a temperature that is too high and is unsafe. The crystal size of the copper sulfate can influence the maximum temperature and the time it takes to reach the maximum temperature. Be sure to use the same materials, including the copper sulfate, in your test as students will use to test their prototypes on day 3 and at full scale in Lesson 9.

In Lesson 6, students will scale down their designs and use only one-fourth as much of the reactants and the water bead mixture. After students get feedback and revise their designs in Lesson 7, they will test their designs at full scale. You will do your test at the scaled-down, optimal reactant ratios to ensure the maximum temperature of the reaction. Your goal is to adjust the amounts of the reactants if necessary to ensure the reaction does not exceed safe temperatures.

Materials

12.5 g $CuSO_4$

1.1 g shredded aluminum foil

62.5 g room-temperature saltwater

62.5 g of room-temperature water bead and water "soup"

1 12-oz deli container with lid (for reaction)

1 4-oz sample cup with lid (for water bead and water "soup")

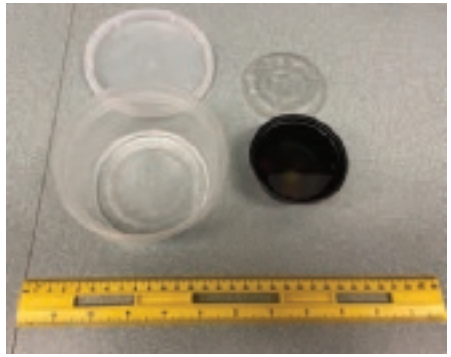
2 thermometers

timer

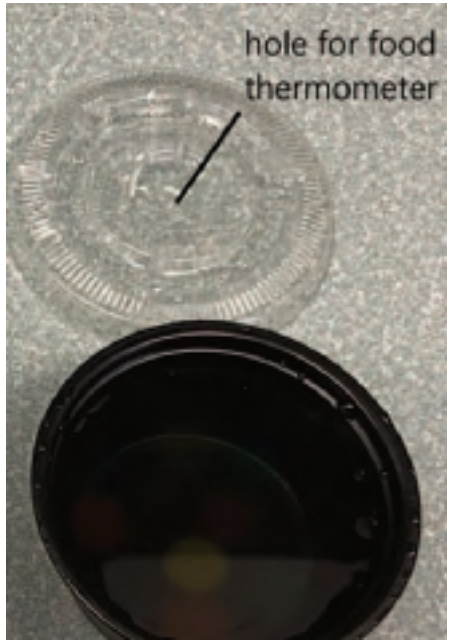
Safety

- Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, test, and clean-up of this activity.
- Immediately wipe up any spilled water and/or granules on the floor—this is a slip and fall hazard.
- Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
- Wash your hands with soap and water immediately after completing this activity.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Use caution when working with heated liquids—this can burn skin!
- In case of accidental exposure to copper sulfate, follow the precautionary statements provided in the teacher reference *Safety Information for Copper Sulfate Pentahydrate*.

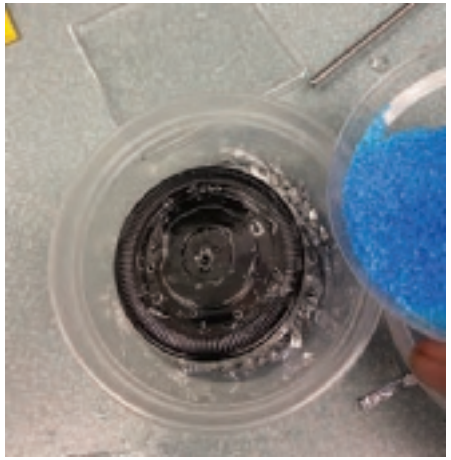
1. Use the same containers from the supplies that your students will be using. Shown here are the containers from the supply kit: a 4-oz sample cup with lid and a 12-oz deli container with lid.



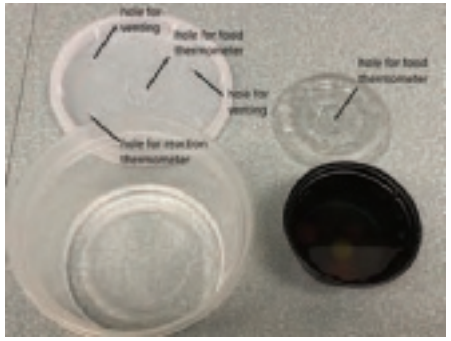
2. Place 62.5 grams of room-temperature water bead and water "soup" in the 4-oz sample cup. Create a hole in the 4-oz sample cup lid so it will be easy to insert the thermometer in upcoming steps. Place the lid on the container.



3. In the reaction container (the 12-oz deli container), add 1.1 g shredded aluminum foil and 62.5 g of saltwater. Carefully rest the smaller container of water beads (with lid) on top of the aluminum foil and saltwater.

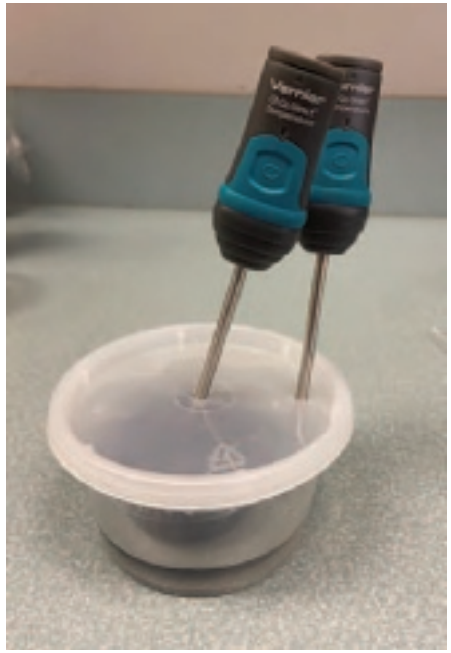


4. Create 4 holes in the lid of the 12-oz deli container. One hole in the center will allow the food thermometer to pass through this lid and then through the 4-oz cup's lid. Another hole will allow the reaction thermometer to be inserted into the reaction solution. The other two holes are created to vent the gas that results from the reaction.



5. Add the 12.5 g $CuSO_4$ to the reaction container so the crystals are immersed in the saltwater, then quickly place the lid on the reaction container. Carefully swirl the setup to mix the reactants.

6. Place the thermometers so one is inserted in the reaction solution and the other is inserted in the water bead soup.
7. Record the temperature of both the reaction and the water bead soup every minute until both temperatures cease to rise. Swirl the reaction carefully to ensure the reactants are mixing around the food container, and to help the mixing of the water bead soup as well.



Troubleshooting temperature concerns

Temperatures Too Hot

The Food and Drug Administration (FDA) recommends reheating foods to 74°C (165°F), which is well above the temperatures to which your students will be heating their simulated food mixtures. However, if your reaction or the food reaches temperatures above 74°C (165°F), reduce the quantities of the reactants used or increase the amount of saltwater to ensure that temperatures do not become dangerously hot. Polyethylene plastic, which is typically used to make resealable storage bags (like those students will be working with in this investigation), starts to soften and lose its integrity at about 90.5°C (195°F) and will melt in boiling water (212°F or 100°C). Following the guidelines in this unit, the temperatures of the reactants and food in this activity will be well below these values and you will not have to worry about melting the containers supplied in the kits.

Temperatures Not Hot Enough

If the crystals of copper sulfate in your supply are large, they will not dissolve quickly and the temperature of the reaction may not rise enough. If this happens, you may want to order a supply of copper sulfate that has a smaller crystal size or purchase root killer at your local hardware store. You can also crush the crystals so that they are smaller before use. Do not crush to a powder. Test the reaction again with these smaller-sized crystals.

Engineering Design Rubric

Team members' names: _____ Date: _____

Use this rubric to self-assess your group's design solution to see how well your group was able to include and apply what we have figured out about the science of flameless heaters and incorporate ideas about what engineers do.

- First, highlight in column 1 ("Secure") just the parts of the statements your group fully met for each of the different categories.
- Next, in column 2 explain in detail, using the questions as guides, specifically how your group included the ideas you highlighted in column 1.
- Last, in column 3 reflect on your group's design solution, using the questions as a guide, to help your group consider ways to include in future design revisions the ideas that were not highlighted in column 1.

Category	Secure (Highlight just the parts of the statement your group fully met for each category.)	Comments (Answer the following questions with details about how your group included the highlighted ideas.)	Comments (Answer the following questions with details about the missing ideas that were not highlighted.)
Developing a design solution	A design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design and assembly instructions are included. The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts.** The transfer of energy is **shown at the particle level** between components of the design solution.	How does your group's design solution capture ideas about energy transfer and explain the reason behind choosing the reactant amounts?	How could your group's design solution make ideas about energy transfer more clear and better explain the reason behind choosing the reactant amounts?
Testing design solutions	There is evidence that the design solution was tested to see if it met **all** criteria and constraints.	Which criteria and constraints were met?	What criteria and constraints were not met in the design?

Category	Secure (Highlight just the parts of the statement your group fully met for each category.)	Comments (Answer the following questions with details about how your group included the highlighted ideas.)	Comments (Answer the following questions with details about the missing ideas that were not highlighted.)
Evaluating design solutions	The design solution was evaluated using a Design Testing Matrix that included **all specific** criteria and constraints. The characteristics of the design that performed the best in each test are identified **based on data recorded in the Design Testing Matrix comparing multiple designs**.	How did your group evaluate whether each criterion and constraint was met? How did your group use data to identify which characteristics of your design performed the best?	How can your group evaluate specific criteria and constraints that need more evidence to see if they are being met?
Combining parts of design solutions	Parts of different design solutions **are combined based on evidence** to create a new and improved design solution.	How did your group incorporate the characteristics of your design that performed the best based on the data collected?	What characteristics of your group's design need more data as evidence to show that they benefit the heater's performance?
Optimizing design solutions	The design solution has been improved based on prior test results, and evidence of those decisions is clearly stated or shown using scientific reasoning. The same tests have been repeated in order to compare designs and continue improving the proposed solution. Relevant stakeholders ***and*** cascading consequences have been considered in order to optimize the design solution.	Explain how characteristics of your group's design were based on evidence from the data and scientific reasoning and are relevant for stakeholders.	What characteristics of your group's design need more data as evidence to show that they benefit the heater's performance?

Engineering Design Rubric

Team Name: _____ Team Name: _____ Date: _____

Category	Missing	Developing	Secure
Developing a design solution			Evidence from student artifact includes: • A model or design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design match and are included in the plan. • Evidence from student artifact includes: • how-to instructions. (Compare the designs with student instructions on *How-to Instructions Must-Haves*.) • The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts**. ◦ aluminum ◦ copper sulfate ◦ saltwater • The transfer of energy is **shown using systems interactions or at the particle level** between components of the model or design solution. (Look at student designs.)
Testing design solutions			Student presents evidence to show: • The design solution was tested to see if it met **all** criteria and constraints. (Look at *Design Testing Matrix*.)
Evaluating design solutions			Student presents evidence to show: • The design solution was evaluated using a Design Testing Matrix that included **all specific** criteria and constraints. • The characteristics of the design that performed the best in each test are identified **based on data recorded in the Design Testing Matrix comparing multiple designs**.
Combining parts of design solutions			Student presents evidence to show: • Parts of different design solutions **are combined based on evidence** to create a new and improved design solution.
Optimizing design solutions			Student presents evidence to show: • The design solution has been improved based on prior test results, and evidence of those decisions is clearly stated or shown using scientific reasoning. • The same tests have been repeated in order to compare designs and continue improving the proposed solution. • Relevant stakeholders **and** trade-offs have been considered in order to optimize the design solution.

Exit Ticket Rubric

6.B Apply scientific ideas, and test results, and the interactions identified on system models to modify our designs based on test results in order to improve the flow of energy to food.

SEPs	DCIs	CCCs
Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. Models and the captions should address the changes the student made between the model for the Group's Design Solution and the model for Optimize and Update Design Solution. They may include: • Student response uses evidence to justify the changes they will make to increase the energy flow to the food. • Depending on their design, students may demonstrate understanding by increasing the reactants, decreasing the amount of food, decreasing the amount of saltwater, and/or changing the packaging to allow for more energy transfer between the systems and/or less energy transfer to the surroundings. • Justifications should include mention of the investigation in Lesson 3 where we learned that if you double the reactants and keep the amount of food constant, the temperature of the food will be higher and/or if you double the amount of food and keep the reactants constant, the temperature of the food will not increase as much. • Students may use ideas from investigations they did in *Cup Design Unit* to justify energy transfer at the particle level—especially if discussing materials and insulating the system.	A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. The tasks on the assessment require students to use ideas about energy transfer to explain their thinking using models and the captions for each model. Additionally, this task requires students to use ideas learned in previous lessons to justify the changes they choose to make to their design. Look for justification of the design changes in the model caption. • Students identify whether their design heated food to the target temperature. • Students correctly identify one or more parts of the system to change. • Students explain how the change to their design will result in the "food" reaching the target temperature.	Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. The primary crosscutting concept lens on this assessment is that of Energy and Matter and specifically, how models can be used to track the flow of energy through a designed system. Look for students to make accurate predictions about how the design changes result in changes to energy transfer. • Student model correctly maps the elements of their design to the Energy Transfer Model. • Modifications to the model result in increased energy flow and/or increased "food" temperature. • If more reactants and/or less saltwater were used the energy arrow should increase in size (or student demonstrates they understand energy transfer is increased to the food system another way). • If a student keeps other parts of the system the same but includes less food, their model should show that the temperature will increase but the size of the arrow (or other way to show energy transfer) will not change.

Element of CCC, SEP, and DCI being assessed	Where element is assessed	No evidence that this element is used	Evidence that element is in development	Evidence that element is used effectively
Targeted SEP, CCC, and DCI elements				
CCC 4.2 Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. Students map their specific design elements to the Energy Transfer Model we developed previously. They use this mapped model to identify changes they could make and then create a revised version of the model that incorporates those updates.	In questions 1-3 students are asked to map the elements of their specific design to the Energy Transfer Model. In question 4 students are asked to create an updated version of the Energy Transfer Model with design modification specified and explained.			Student model correctly maps the elements of their design to the Energy Transfer Model. Modifications to the model result in increased energy flow and/or increased "food" temperature. If more reactants and/or less saltwater were used the energy arrow should increase in size (or student demonstrates they understand energy transfer is increased to the food system another way). If a student keeps other parts of the system the same but includes less food, their model should show that the temperature will increase but the size of the arrow (or other way to show energy transfer) will not change.
SEP 6.6 Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process, or system. Students use information from the tests of their prototype and ideas from investigations earlier in the unit to justify the changes they will make to their design.	In question 4 students are asked to create an updated version of the Energy Transfer Model. In question 5 they are asked to explain the design modifications they specified using evidence they collected from previous investigations that helped them understand how the change they suggested will result in the desired effect.			Student response uses evidence to justify the changes they will make to increase the energy flow to the food. Depending on their design, students may demonstrate understanding by increasing the reactants, decreasing the amount of food, decreasing the amount of saltwater, and/or changing the packaging to allow for more energy transfer between the systems and/or less energy transfer to the surroundings. Justifications should include mention of the investigation in Lesson 3 where we learned that if you double the reactants and keep the amount of food constant, the temperature of the food will be higher and/or if you double the amount of food and keep the reactants constant, the temperature of the food will not increase as much. Students may use ideas from investigations they did in *Cup Design Unit* to justify energy transfer at the particle level—especially if discussing materials and insulating the system.

ETS1.B - 1 A solution needs to be tested and then modified on the basis of the test results in order to improve it. Students use information from the tests of their prototype to inform the changes they need to make in order for it to be an optimal design.	In questions 4 and 5 students are asked to make changes to their design solution based on the results of the tests they performed.			Students identify whether their design heated food to the target temperature. Students correctly identify one or more parts of the system to change. Students explain how the change to their design will result in the "food" reaching the target temperature.
Additional Assessment Opportunities				
SEP 2.2 Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. After mapping the specifics of their design solution to the Energy Transfer Model, students are asked to make changes to components of the model in order to reach a desired outcome.	In questions 1-3 students are asked to map the elements of their specific design to the Energy Transfer Model, then in question 4 students are asked to create an updated version of the Energy Transfer Model with design modification specified and show the result of the changes. In question 4 students are asked to create an updated version of the Energy Transfer Model. In question 5 they are asked to explain the design modifications they specified using evidence they collected from previous investigations that helped them understand how the change they suggested will result in the desired effect.			The changes that students make to the components should be represented accurately on the model and the result of those changes should be reasonable. *Examples* If a student changes the amount of reactants, there is also a change in energy flow (using size of the arrow or another way). If the student changes the amount of food without changing the amount of reactants (or saltwater) there should be no change in energy flow, but there should be a change in temperature. Students may use ideas from investigations they did in *Cup Design Unit* to justify energy transfer at the particle level—especially if discussing materials and insulating the system.

Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I used evidence to support my ideas, asked for evidence from others, and/or suggested ways to get additional evidence.			
	I used our time well and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I monitored my own time spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged myself to think in new ways.			
	I may have critiqued the *ideas* we were working with, but I was careful not to critique the *people* I was working with.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

_____

_____

The hardest part about this work was ... (because ...)

_____

_____

Exit Ticket Key

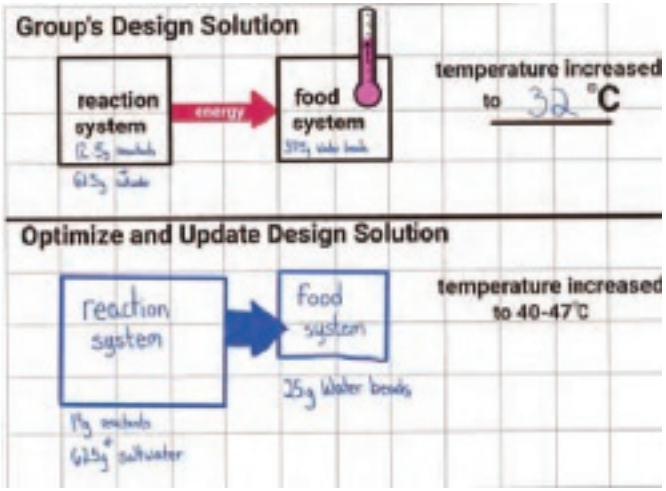
6.B Apply scientific ideas, and test results, and the interactions identified on system models to modify our designs based on test results in order to improve the flow of energy to food.

SEPs	DCIs	CCCs
Apply scientific ideas or principles to design, construct, and/or test a design of an object, tool, process or system. Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed. Models and the captions should address the changes the student made between the model for the Group's Design Solution and the model for Optimize and Update Design Solution. They may include: • Student response uses evidence to justify the changes they will make to increase the energy flow to the food. • Depending on their design, students may demonstrate understanding by increasing the reactants, decreasing the amount of food, decreasing the amount of saltwater, and/or changing the packaging to allow for more energy transfer between the systems and/or less energy transfer to the surroundings. • Justifications should include mention of the investigation in Lesson 3 where we learned that if you double the reactants and keep the amount of food constant, the temperature of the food will be higher and/or if you double the amount of food and keep the reactants constant, the temperature of the food will not increase as much. • Students may use ideas from investigations they did in *Cup Design Unit* to justify energy transfer at the particle level—especially if discussing materials and insulating the system.	A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. The tasks on the assessment require students to use ideas about energy transfer to explain their thinking using models and the captions for each model. Additionally, this task requires students to use ideas learned in previous lessons to justify the changes they choose to make to their design. Look for justification of the design changes in the model caption. • Students identify whether their design heated food to the target temperature. • Students correctly identify one or more parts of the system to change. • Students explain how the change to their design will result in the "food" reaching the target temperature.	Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems. The primary crosscutting concept lens on this assessment is that of Energy and Matter and specifically, how models can be used to track the flow of energy through a designed system. Look for students to make accurate predictions about how the design changes result in changes to energy transfer. • Student model correctly maps the elements of their design to the Energy Transfer Model. • Modifications to the model result in increased energy flow and/or increased "food" temperature. • If more reactants and/or less saltwater were used the energy arrow should increase in size (or student demonstrates they understand energy transfer is increased to the food system another way). • If a student keeps other parts of the system the same but includes less food, their model should show that the temperature will increase but the size of the arrow (or other way to show energy transfer) will not change.

Student Instructions:

Below is an Energy Transfer Model similar to the one we constructed back in Lesson 3. Assume this Energy Transfer Model represents your group's design solution.

First, answer the questions that follow to consider how you will update the model using information from your group's design solution. Then, use the updated model to identify ways to optimize your design so that it raises the temperature of the food from room temperature to 40-47°C. Finally, you will revise the model to highlight and explain the modifications to your design.



Caption

Answers will vary. This example might have a caption like: The first design solution used 12.5 g of reactants and 62.5 g of saltwater. This resulted in energy transfer to the food system which contained 37.5 g of water beads and caused the temperature to increase to 32°C. We increased the mass of the reaction system to 14 g in the same amount of saltwater and decreased the mass of water beads to 25 g. The investigation we did in Lesson 3 showed that a larger mass of reactants results in more energy transfer. Additionally, we saw in the same investigation that decreasing the amount of food can cause a larger temperature increase.

Questions:

1. What temperature did your design solution get to? (write it in the space on the Group's Design Solution model above that says "temperature increased to *37*°C")
2. In your group's design:
   - What was the total mass of reactants used in your protype? answers will vary
   - What was the mass of saltwater used? answers will vary
   - Label the model above to show this information.
3. In your group's design:
   - How much "food" (water beads) did you use to test your specific design? answers will vary
   - Label the model above to show this information.
4. Draw an updated Energy Transfer Model that optimizes your group's design solution. Consider which parts of your model that you think would be productive to change, and then draw an updated model that shows the changes you think your group should implement for the redesign.
   a. Consider how each component could be optimized and updated:
      i. Does your group need to change the amount of reactants? The amount of saltwater? How will you show this on your revised Energy Transfer Model?
      ii. Does your group need to change the amount of "food"? How will you show the new amount of "food" on your design model?
      iii. How do you predict energy flow will change after your changes are made? How will you show the predicted new temperature? Will the size of the energy arrow change or stay the same?

b. Are there other components in your actual design that are not being represented in the Energy Transfer Model that you would consider changing in order to optimize energy flow to the food? List what other parts of your group's design you might consider changing and explain how changing them would improve the function of your heater. Answers will vary but will likely include materials and containers and/or ways to insulate the system.

5. Use the ideas above to create a revised model. Include a caption below the model describing each change you made and why you chose the specific parts of your model to change. Your caption should include:
   a. An explanation for how each of the changes you make will result in your "food" system reaching the target temperature
   b. One or more pieces of evidence you collected from previous investigations that helped you understand that your change will result in the desired effect.

Optional Extension—Cascading Consequences Practice

If students need more support, you may insert this 10-minute activity prior to the whole class beginning to build their team charts together. Some steps in this extension are repeated in the *Teacher Guide*. You may need to modify those steps to avoid redundancy (for example, adding "cascading consequences" to the Word Wall).

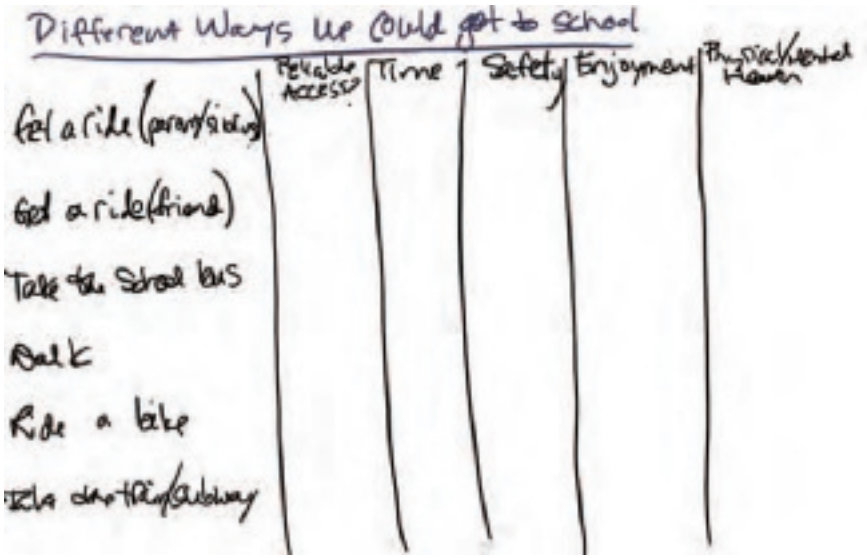
Materials: science notebook, 1-2 pieces of chart paper, chart markers

PRACTICE CREATING A CASCADING CONSEQUENCES CHART

Activity description: Create a Consequences Chart together as a class using an issue that students are familiar with in order to demonstrate how making one decision may affect several other factors that were not initially planned.

Consider possible methods, as well as criteria and constraints, for getting to and from school. Display **slide F1.** Say, *This is a really complicated task, so I prepared an example about something I think many of you need to think about—how to get to and from school. Would you like to construct a Consequences Chart together to help me make a decision about this*?

As students are listing the possible ways to get to and from school, record them on a chart. When they list criteria and constraints, say, *Maybe we should try to set this up so that it looks similar to what we did with our Design Matrix—I'm going to list those across the top.*

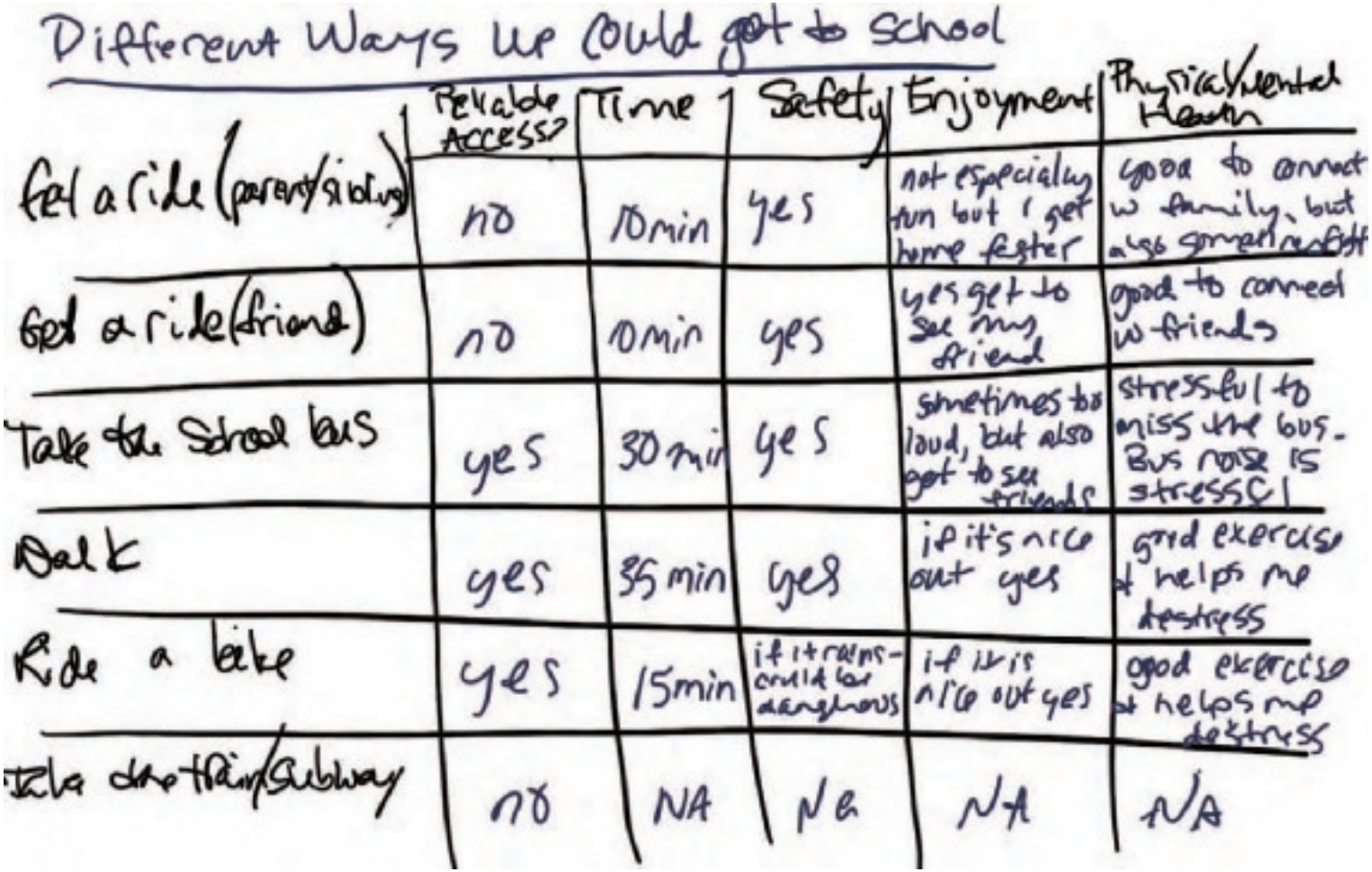


Suggested prompts	Sample student responses
What are some options we might have for getting to and from school?	*School bus.* *Get a ride from parent or sibling.* *Get a ride from a friend.* *Train or subway.* *Walk.* *Bike.*
What are the criteria and constraints we would need to consider when thinking about how we get to and from school?	*Time it takes.* *Availability and access.* *Enjoyment.* *Health and safety.* *Cost.*

Additional Guidance

Depending on where your school is located, students may or may not be very familiar with the surrounding neighborhood, or they may not have many different options for transportation. If this example would be difficult, consider asking the class to come up with another example of a decision, such as choosing what school lunch to buy, choosing what drink to have with their meal, or choosing what elective class to take. There is an optional handout—*Optional Decision Matrix for Class Practice Consequences Chart*—with a blank matrix that students can fill in if you choose this option.

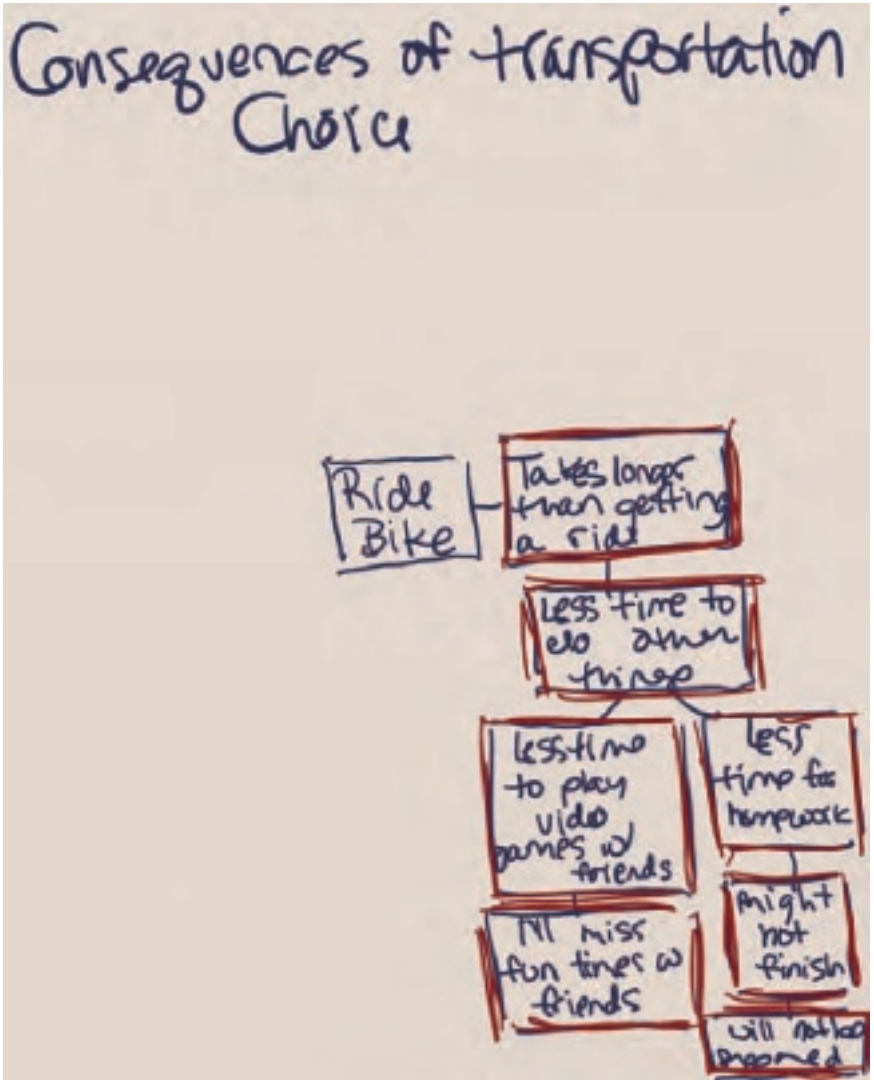
Facilitate the construction of the Consequences Chart. Say, *OK, let's choose one option and put that in the middle. Then we can think about all the consequences of that choice*. Write one of the choices in a box on the center of a piece of chart paper (e.g., "ride a bike"). Then, lead a discussion asking for the possible consequences in terms of our criteria and constraints for this option.

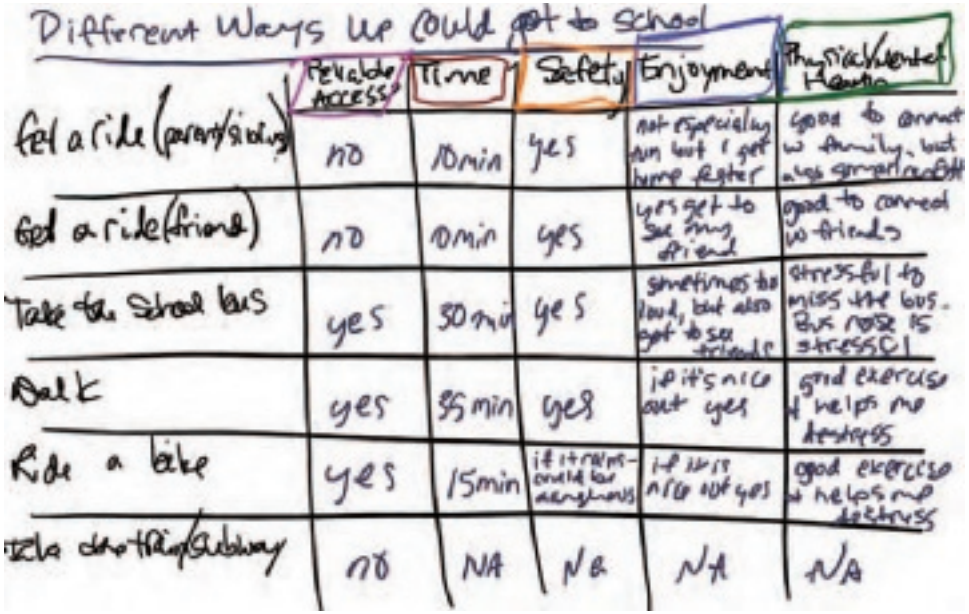


Suggested prompts	Sample student responses
So what is one consequence or effect of riding a bike to school? We can think about our criteria and constraints. For example, what about the time it takes?	*It takes longer than getting a ride.* *It is faster than walking.*
OK, so let's work on the idea that it takes longer than getting a ride. What are the consequences of that?	*I have less time for other things in the morning.* *I might have to get up earlier.*
OK, and what are some effects of having less time?	*I will miss out on playing video games.* *I will be tired all day or have to go to bed earlier.* *My homework won't get done.*

As students are suggesting the effects of a particular change, add them as connected boxes arranged as one "arm" or "branch" off of the center box.

After completing one arm, pause and say, *Wait, this is going to get messy. Maybe if we color-code these we can keep track of them better.* Go back to the chart on which we listed the criteria and constraints we need to consider when choosing how to get to and from school and draw a different-colored box around each of the categories so that we can keep track of them better on our Consequences Chart.



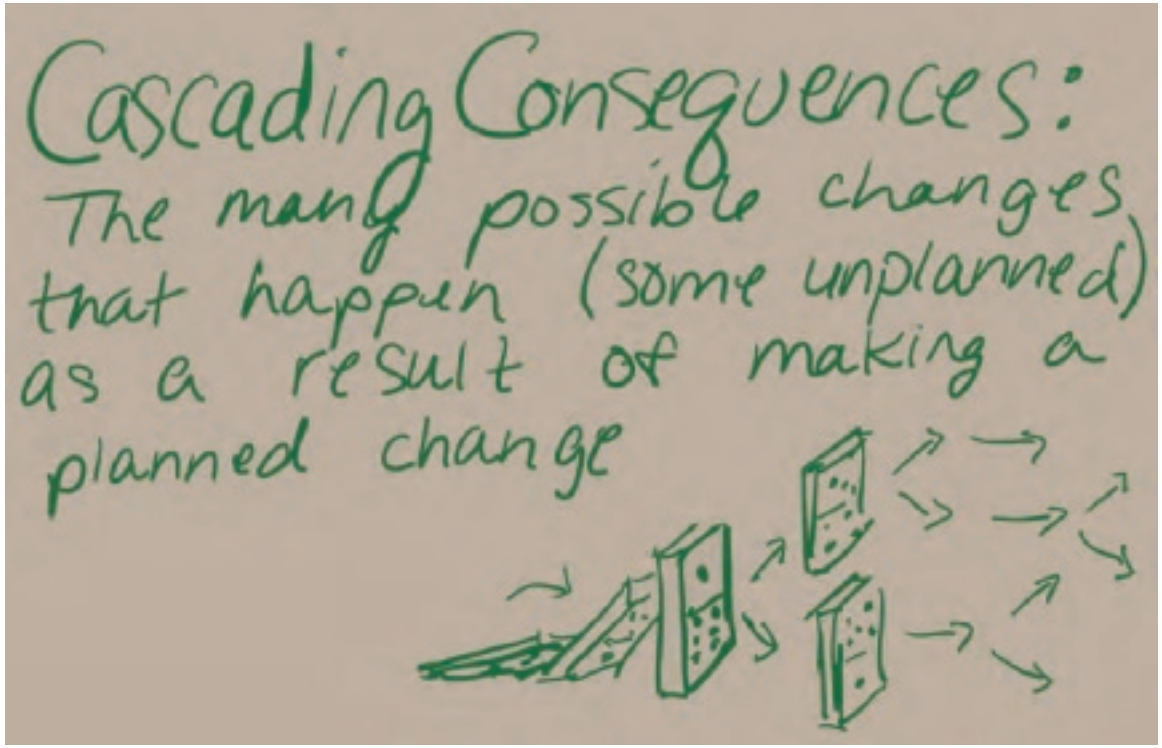


Add the corresponding color to your Cascading Consequences Chart (e.g., put red around the boxes that relate to the amount of time it takes). Then, ask for another consequence of riding a bike to and from school and add another arm to the chart in a different color.

Additional Guidance

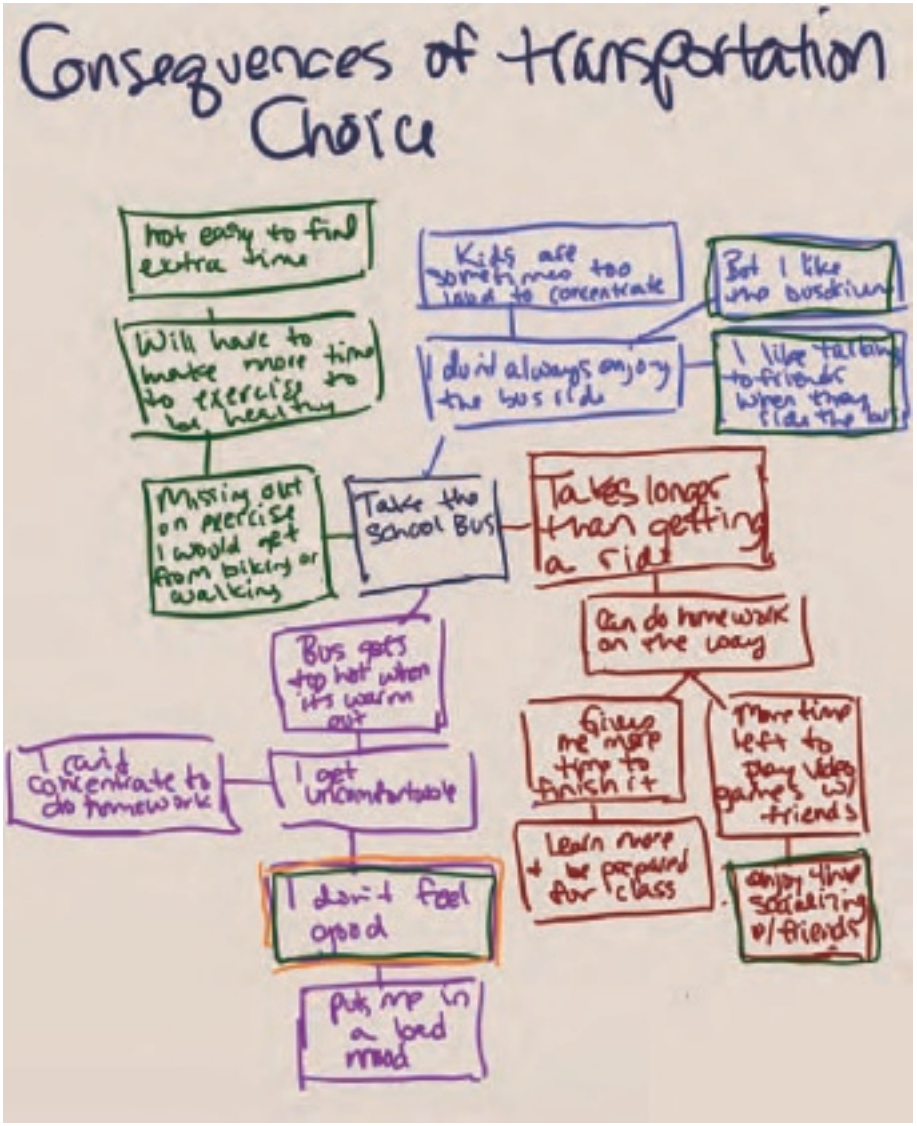
The chart arms should start with ideas present on the matrix, but as the class works, they may realize that there are other cascading consequences resulting from those changes and we will need to add those to the chart as well. There is no right or wrong answer here, as long as the ideas are relevant. If students want to put consequences in more than one category, that is also OK (see parts of the chart that have more than one color highlighted).

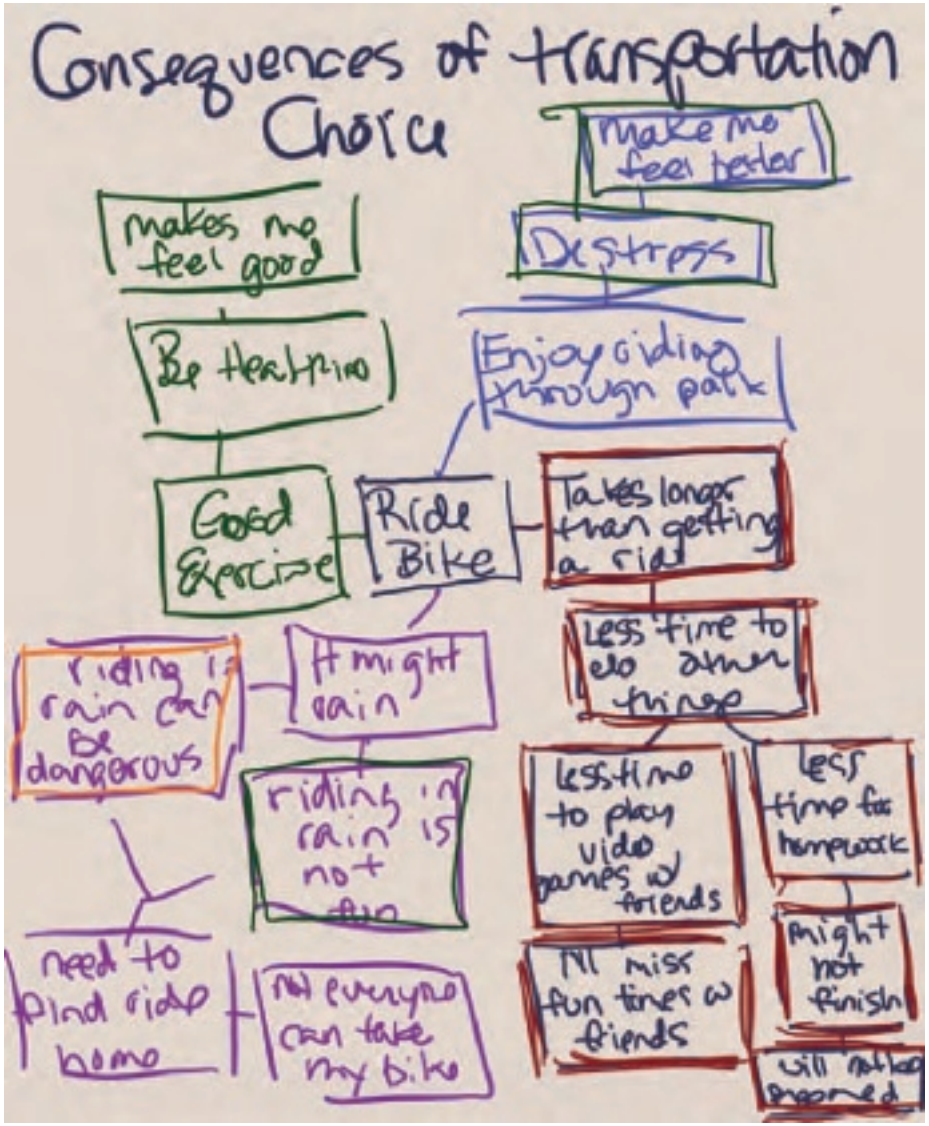
Add "cascading consequences" to our Word Wall. *Say, Wow! There are consequences here that seem unrelated, but they are definitely affected by our changes! Making that one change affected a lot of other things that we might not have even thought about. When we think through consequences like this we call it "cascading consequences"—like how tipping one domino in a row of standing dominos affects a lot of other dominos. This is definitely an idea we should add to our Word Wall.*



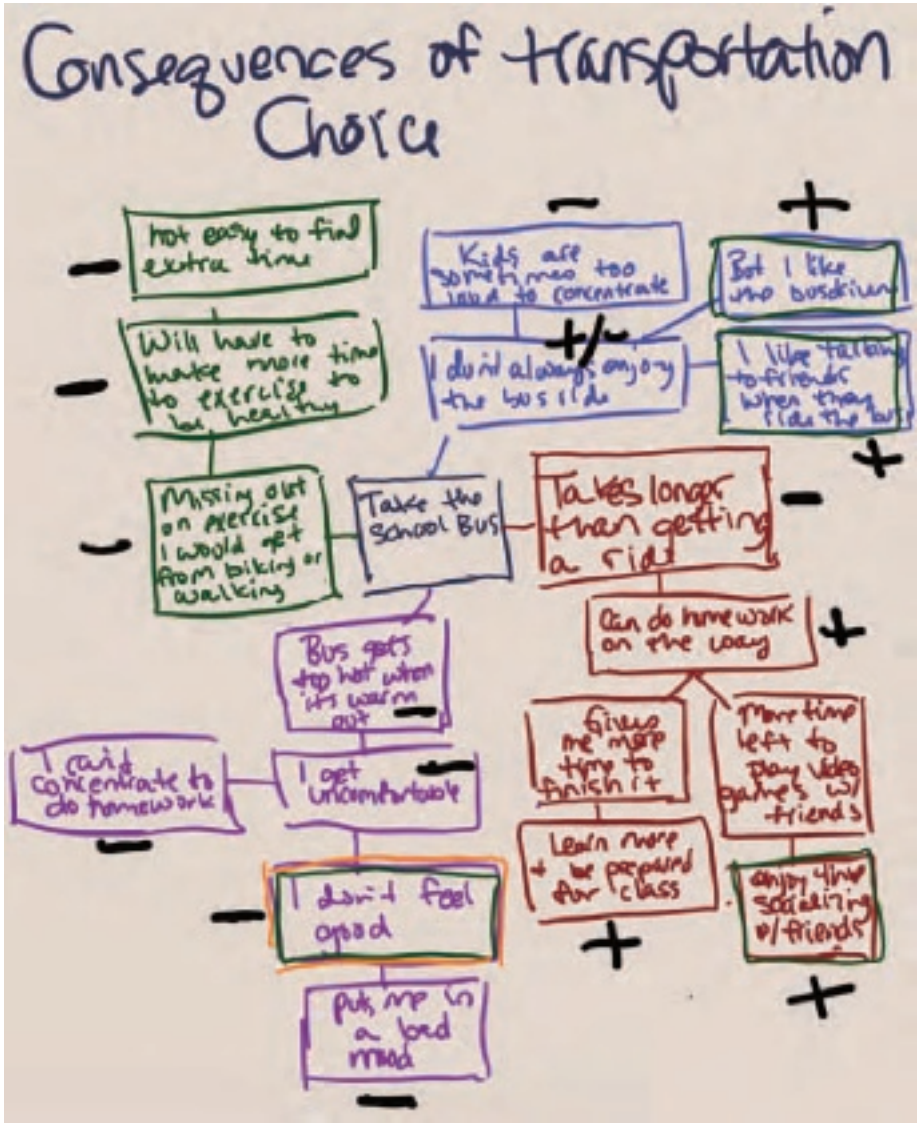
Additional Guidance

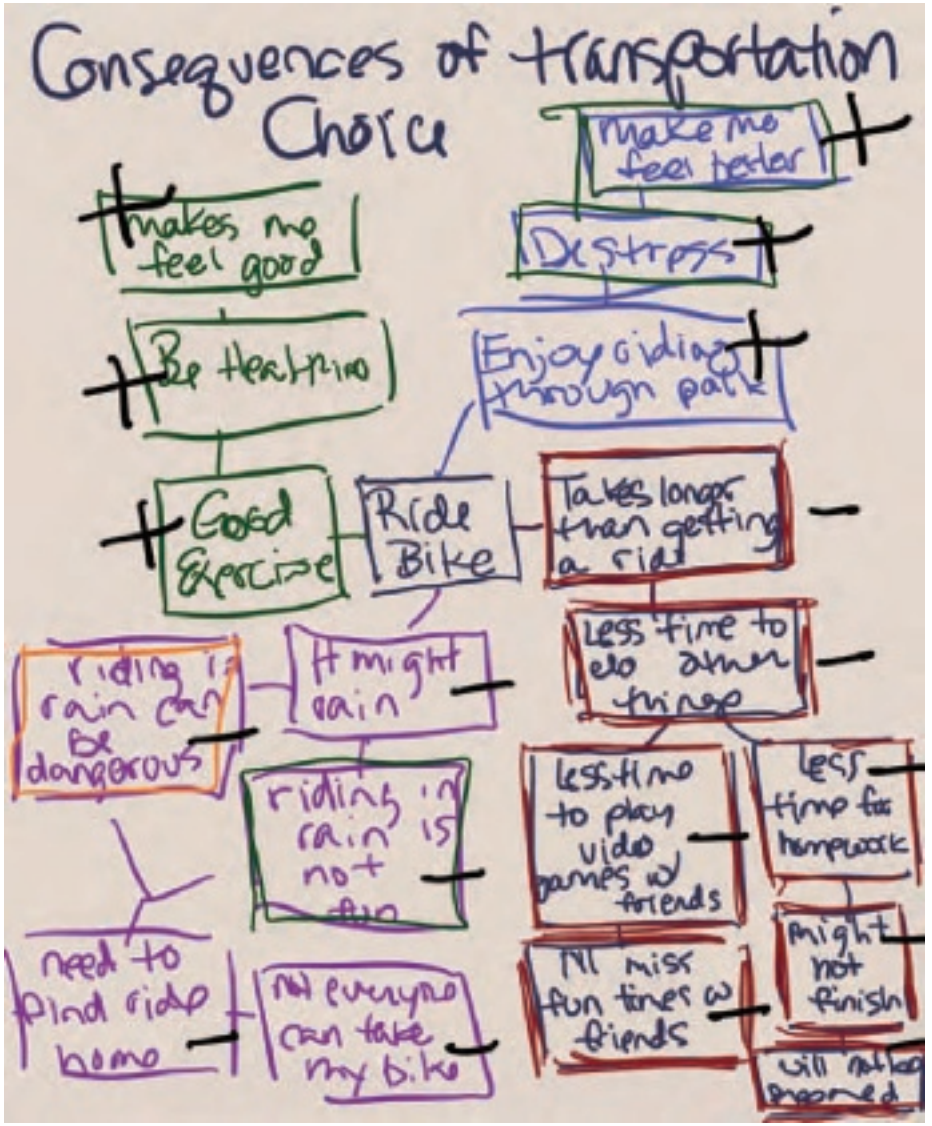
Make sure there are at least three arms to consider on the practice Consequences Chart so that it will be similar to what they will do in teams. Use a different-color chart marker for each arm so that it is easier to keep track of.





Consider that there are many things that changed as a result of what we changed. Ask students to look at each of the effects of their decision. Say, *Are all of these changes equal in their potential impact? Let's look at each box that changed as a result of the changes we made*. Get students to give input as you add "+" and "-" signs to the boxes, depending on whether the consequence would be generally considered a positive or negative impact.





Say, OK, great! So that helped us consider our decision about how to get to and from school, but how do we start to create one of these for our homemade heater design?

Additional Guidance

Pick up the lesson in the *Teacher Guide* at "**Facilitate the construction of the Consequences Chart**," which corresponds to **slide F**. Be mindful that you will need to watch for occasional redundancy between activities placed in both this extension activity and in the *Teacher Guide*.

Optional Extension Opportunity Student Example Responses

Criteria and constraints	Access to method	Cost	Time involved	Enjoyment	Health	Safety
Possible method	We need to have reliable access to this method.	We need to be able to afford it.	The method should not take longer than 30 minutes	We should find the method enjoyable.	This should be beneficial for mental and physical health.	The method must be safe.
Walking	*Yes*	*free*	*Takes a little longer than 30 minutes*	*Sometimes I'm just too tired or the weather is bad, but usually I enjoy it.*	*The exercise is good, and I also get to de-stress.*	*Yes, there is a sidewalk the whole way.*
Taking the school bus	*Yes*	*free*	*Usually takes 30 minutes*	*It's loud and hard to concentrate, but also my friends ride the bus.*	*No exercise involved, and the noise on the bus can be stressful.*	*Yes*
Riding my bike	*Yes*	*free plus cost of bike repairs*	*Takes a little less than 30 minutes*	*Sometimes I'm just too tired or the weather is bad, but usually I enjoy it.*	*Good exercise, but it's stressful worrying if I need to get a ride in case there is unexpected unsafe riding weather.*	*There is a busy road with no bike path for a part of the way.*
Getting a ride	*No*	*fuel cost*	*Takes about 10 minutes*	*I like to listen to music on the ride home, and I get home fast.*	*It's stressful when my ride forgets to pick me up.* *No exercise*	*My sibling is a crazy driver.*

Engineering Design Rubric

Team members' names: _____ Date: _____

Use this rubric to self-assess your group's design solution to see how well your group was able to include and apply what we have figured out about the science of flameless heaters and incorporate ideas about what engineers do.

- First, highlight in column 1 ("Secure") just the parts of the statements your group fully met for each of the different categories.
- Next, in column 2 explain in detail, using the questions as guides, specifically how your group included the ideas you highlighted in column 1.
- Last, in column 3 reflect on your group's design solution, using the questions as a guide, to help your group consider ways to include in future design revisions the ideas that were not highlighted in column 1.

Category	**Secure** (Highlight just the parts of the statement your group fully met for each category.)	**Comments** (Answer the following questions with details about how your group included the highlighted ideas.)	**Comments** (Answer the following questions with details about the missing ideas that were not highlighted.)
Developing a design solution	A design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design and assembly instructions are included. The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts.** The transfer of energy is **shown at the particle level** between components of the design solution.	How does your group's design solution capture ideas about energy transfer and explain the reason behind choosing the reactant amounts?	How could your group's design solution make ideas about energy transfer more clear and better explain the reason behind choosing the reactant amounts?
Testing design solutions	There is evidence that the design solution was tested to see if it met **all** criteria and constraints.	Which criteria and constraints were met?	What criteria and constraints were not met in the design?

Category	Secure (Highlight just the parts of the statement your group fully met for each category.)	Comments (Answer the following questions with details about how your group included the highlighted ideas.)	Comments (Answer the following questions with details about the missing ideas that were not highlighted.)
Evaluating design solutions	The design solution was evaluated using a Design Testing Matrix that included **all specific** criteria and constraints. The characteristics of the design that performed the best in each test are identified **based on data recorded in the Design Testing Matrix comparing multiple designs.**	How did your group evaluate whether each criterion and constraint was met? How did your group use data to identify which characteristics of your design performed the best?	How can your group evaluate specific criteria and constraints that need more evidence to see if they are being met?
Combining parts of design solutions	Parts of different design solutions **are combined based on evidence** to create a new and improved design solution.	How did your group incorporate the characteristics of your design that performed the best based on the data collected?	What characteristics of your group's design need more data as evidence to show that they benefit the heater's performance?
Optimizing design solutions	The design solution has been improved based on prior test results, and evidence of those decisions is clearly stated or shown using scientific reasoning. The same tests have been repeated in order to compare designs and continue improving the proposed solution. Relevant stakeholders ***and*** cascading consequences have been considered in order to optimize the design solution.	Explain how characteristics of your group's design were based on evidence from the data and scientific reasoning and are relevant for stakeholders.	What characteristics of your group's design need more data as evidence to show that they benefit the heater's performance?

Engineering Design Rubric

Team name: _____ Members: _____ Date: _____

Category	Missing	Developing	Secure
Developing a design solution			Evidence from student artifact includes the following: • A model or design solution that releases energy using a chemical reaction is **fully** developed—**all** materials used in the design are included appropriately in the how-to instructions. (Compare the designs with student instructions.) • The substances and amounts used in the chemical reaction are identified, **including reasoning for those amounts.** ◦ aluminum ◦ copper sulfate ◦ saltwater • The transfer of energy is **shown using systems interactions or at the particle level** between components of the model or design solution. (Look at student designs.)
Testing design solutions			Student presents evidence to show the following: • The design solution was tested to see if it met **all** criteria and constraints. (Look at *Design Testing Matrix*.)
Evaluating design solutions			Student presents evidence to show the following: • The design solution was evaluated using a Design Testing Matrix that included **all specific** criteria and constraints. • The characteristics of the design that performed the best in each test are identified **based on data recorded in the Design Testing Matrix comparing multiple designs**.
Combining parts of design solutions			Student presents evidence to show the following: • Parts of different design solutions **are combined based on evidence** to create a new and improved design solution.
Optimizing design solutions			Student presents evidence to show the following: • The design solution has been improved based on prior test results, and evidence of those decisions is clearly stated or shown using scientific reasoning. • The same tests have been repeated in order to compare designs and continue improving the proposed solution. • Relevant stakeholders **and** trade-offs have been considered in order to optimize the design solution.

Name: _____ Date: _____

Teamwork Self-Assessment

While working with my team ...		Not today	Once or twice	Several times
I participated in the work.	I shared my thinking and contributed ideas to our design.			
	I used evidence to support my ideas, asked for evidence from others, and/or suggested ways to get additional evidence.			
	I used our time well and helped us stay on task.			
	I contributed to the work of drawing, writing, and building.			
I made sure that my teammates were included in the work.	I monitored my own time spent talking, drawing, writing, building, and/or leading so that others also had a chance to participate in the work.			
	I asked questions to help us understand everyone's ideas.			
	I encouraged others to share their ideas.			
	I provided support and genuine encouragement.			
I kept an attitude that was helpful to problem solving.	I came prepared to work toward a common goal.			
	I was open to changing my mind and challenged myself to think in new ways.			
	I may have critiqued the *ideas* we were working with, but I was careful not to critique the *people* I was working with.			
	When things did not go how we had planned or hoped, I stuck with it and learned from our failures.			

Something I did that I was really proud of during this work was ... (because ...)

_____

_____

The hardest part about this work was ... (because ...)

_____

_____

Name: _____ Date: _____

Design Testing Matrix for Sea Turtle Assessment

Design	Egg rotation?	Temperature of incubator	Power source needed?	Humidity	Length of time temp is held	Location of heat source
1a. Optimal solution						
Incubator A	Yes	Adjustable temperature	Yes	20-85%	Indefinite	Top
3a. Incubator B						

Rubric for Sea Turtle Assessment

This assessment can be used to evaluate student progress on the LLPEs. The LLPEs are an integration of elements from the three dimensions, so look for these three aspects working together across the students' explanations.

10.A Make a written argument that supports or refutes the advertised performance of a sea turtle incubator based on evidence concerning whether the incubator meets relevant criteria and constraints, such as transferring the right amount of energy to the sea turtle eggs.

10.B Apply the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the system containing the turtle eggs.

SEPs	DCIs	CCCs
Develop and/or use a model to predict and/or describe phenomena. Use data to evaluate and refine design solutions. Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints. Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.	Some chemical reactions release energy; others store energy. 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. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. A solution needs to be tested and then modified on the basis of the test results in order to improve it.	Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. The transfer of energy can be tracked as energy flows through a designed or natural system.

Targeted SEP, CCC, and DCI elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
SEP 2.5 *Develop and/or use a model to predict and/or describe phenomena.*	**Question 2b. Draw a model to explain "How does the heat pack keep the turtle eggs warm?"** Use an Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction.			**Question 2b** Student models include representations of • the types and amounts of reactants before the reaction, • the types and amounts of products after the reaction, • groups of atoms breaking apart and rearranging, and • a way to show energy is transferred from the reaction system (heat pack) to outside of the system (turtle eggs and incubator).
SEP 4.5 *Use data to evaluate and refine design solutions.*	**Question 3a.** Using the information provided about incubator B, complete row "3a. Incubator B" in the *Design Testing Matrix for Sea Turtle Assessments* to organize the data and help you think about how it will perform in tests against the criteria and constraints. **Question 3b.** Which incubator design would work best to incubate the sea turtle eggs in order to meet our target design goal?			**Question 3a** • Student has accurately populated the design matrix with characteristics of incubator B. **Question 3b** • Student explanation accurately includes data about the characteristics of each design that would fit the criteria and constraints best and justification for choosing those data in relation to meeting the goal of the design.

Targeted SEP, CCC, and DCI elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
SEP 7.4 *Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints.*	**Question 1b.** Use the testing matrix to write an argument that states whether incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints in the Design Testing Matrix and the advertised performance of incubator A in your argument. **Question 3c.** For the criterion of temperature, how would you optimize the design using the chemical reaction in incubator B in order to ensure the hatching of male sea turtle? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used. In your response, update the Energy Transfer Model you made for question 2b to explain why your redesign will work. Include a caption that addresses the changes you made and the effect those changes had on the energy transfer between parts of the system. **Question 3d.** Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.			**Question 1b** Student response • uses evidence provided in the prompt to support their claim about whether the incubator meets the advertised performance and • uses reasoning linked to the criteria and constraints. **Questions 3c** Student response • accurately suggests changes to the amounts of reactants (or not), • justifies the choice based on reasoning linked to the criteria and constraints, and • uses reasoning tied to the relative amount of energy that would be transferred as a result. **Question 3d** Student response • indicates additional characteristics from each design that best fit criteria and constraints, • justifies the choices based on reasoning linked to the criteria and constraints, and • includes reasoning tied to the relative amount of energy that would be transferred as a result.

Targeted SEP, CCC, and DCI elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
CCC4.2 *Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy, matter, and information flows within systems.*	**Question 2b.** Draw a model to describe "How does the heat pack keep the turtle eggs warm?" Use the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction. **Question 3c** For the criterion of temperature, how would you optimize the design using the chemical reaction in incubator B in order to ensure the hatching of male sea turtles? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used. In your response, update the Energy Transfer Model you made for question 2b to explain why your redesign will work. Include a caption that addresses the changes you made and the effect those changes had on the energy transfer between parts of the system. **Question 3d.** Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.			**Question 2b** Student model includes • energy transferred between parts of the system (i.e., the reaction system [heat pack] and the egg-incubating system). *Student models may include* • energy transferred from the reaction system (heat pack) to the materials the incubator is made of, to the outside environment, or to the thermometer. **Questions 3c** Student model • accurately represents changes to the amounts of reactants (or not) and • is linked to an appropriate change in energy transfer. **Question 3d** Student model • accurately represents the chosen characteristics from each existing incubator and • accurately represents appropriate relative change in energy transfer related to the chosen characteristics.

Targeted SEP, CCC, and DCI elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
CCC 5.4 *The transfer of energy can be tracked as energy flows through a designed or natural system.* Students track the energy flow from the heat packs used in incubator B to the turtle eggs using the Energy Transfer Model.	**Question 1b**. Use the testing matrix to write an argument that states whether incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints in the Design Testing Matrix and the advertised performance of incubator A in your argument. **Question 2b.** Draw a model to explain "How does the heat pack keep the turtle eggs warm?" Use an Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction.			**Question 1b** Student argument • supports claim with explanation tied to how the characteristic of incubator A is related to energy flow. **Question 2b** Student model includes • representation of energy transferring between different parts of the incubator system. *Student models may include* • energy transferred from the reaction system (heat pack) to the materials the incubator is made of, to the outside environment, or to the thermometer.
PS1.B-M3 *Some chemical reactions release energy; others store energy.*	**Question 2a.** Is this an *endothermic or exothermic* reaction? Explain your choice. **Question 2b.** Draw a model to describe "How does the heat pack keep the turtle eggs warm?" Update the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction.			**Question 2a** • Student correctly identifies the reaction as exothermic because energy is being transferred out of the heat pack system, which makes it feel warm. ****If a student answered "endothermic" but has a correct "why" statement here and/or their model is correct, consider having a discussion with the student about their response to this question—they could have just mixed up the terms* endothermic *and* exothermic *and should not be penalized if their understanding is solid.*** **Question 2b** Student model correctly shows • energy is transferred from the chemical reaction system (the heat pack) to other parts of the system (the eggs and incubator system and/or the outside environment, thermometer, other surroundings, and so forth).

Targeted SEP, CCC, and DCI elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
ETS1.B-M2 *There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.*	**Question 1b.** Use the testing matrix to write an argument that states whether incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints in the Design Testing Matrix and the advertised performance of incubator A in your argument. **Question 3a.** Using the information provided about incubator B, complete **row "3a. Incubator B"** in the *Design Testing Matrix for Sea Turtle Assessment* to organize the data and help you think about how it will perform in tests against the criteria and constraints. **Question 3d.** Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.			**Question 1b** Student completes the Design Testing Matrix to organize the information used to fill out the table that justifies the pieces of each solution they would use. Student support for the argument refers to the criteria and constraints, including the following: • Incubator A moves the eggs around; however, sea turtle eggs cannot rotate or change orientation when they are moved from one location to another. This is a criterion. • Incubator A requires a power source, and one constraint we have is that there is not a power source available during transport. **Question 3a** • Student has accurately populated the design matrix with characteristics of incubator B. **Question 3d** • Student responds to each criterion and constraint to inform the final design solution.
ETS1.B-M3 *Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.*	**Question 3b.** Which incubator design would work best to incubate the sea turtle eggs in order to meet our target design goal? **Question 3d.** Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.			**Question 3b** • "Combined design features of A and B" is the ideal response from students. • (*If students select "Incubator A" or "Incubator B" coordinate this response with their response in question 3d to decide how well they understand the idea that some design solutions are optimal when they combine features from across design solutions.*) **Question 3d** • Student chose a combination of design characteristics when completing the table.

Opportunities to show growth in these elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
SEP 2.2 *Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.*	**Question 2b.** Draw a model to describe "How does the heat pack keep the turtle eggs warm?" **Update the Energy Transfer Model** to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction.			**Question 2b** The Energy Transfer Model is updated to accurately include • the reactants and products named in the prompt, • labels indicating the area where eggs would be incubating, and • energy transferring from the chemical reaction system to the egg-incubating system.
PS1.B-M1 *Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.*	**Question 2b.** Draw a model to describe "How does the heat pack keep the turtle eggs warm?" Update the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of **what is happening to the substances that are undergoing the chemical reaction**.			**Question 2b** Student models include accurate representations of • the kinds and numbers of atoms in the reactants are the same as the kinds and number of atoms in the products and • molecules of reactants breaking apart and rearranging. *In addition, models **may** include the following:* • reactants that are made of 1 calcium atom connected to 2 chlorine and 1 oxygen atom connected to two hydrogen atoms (the specific arrangement of atoms within each reactant is not assessed) • products that are made of 1 calcium atom connected to 1 oxygen atom and 1 hydrogen atom and 1 chlorine atom connected to 1 hydrogen atom (the specific arrangement of atoms within each reactant is not assessed) • reactants and products in the correct ratio (i.e., for every 1 calcium chloride there are 2 water and for every 1 calcium hydroxide there are 2 hydrochloric acid)

Opportunities to show growth in these elements				
Element of CCC, SEP, and DCI being assessed	**Where element is assessed**	**No evidence that this element is used**	**Evidence that element is in development**	**Evidence that element is used effectively**
ETS1.B-M1 *A solution needs to be tested and then modified on the basis of the test results in order to improve it.*	**Questions 3c**. For the criterion of temperature, how would you optimize the design using the chemical reaction in **incubator B** in order to ensure the hatching of male sea turtles? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used. In your response, update the Energy Transfer Model you made for question 2b to explain why your redesign will work. Include a caption that addresses the changes you made and the effect those changes had on the energy transfer between parts of the system.			**Question 3c** Student response • uses information about incubator B as well as the criteria and constraints to make decisions about revising the incubator design.

Name: _____ Date: _____

Form A: Sea Turtle Assessment

Sea Turtle Population in Danger?

In 2018, there were a lot of news stories with headlines like this: "The sea turtle population in Australia is mostly females" and "Most of the new sea turtles born are female."

The problem: In 2018, scientists in Australia conducted a study to understand the proportion of male to female sea turtles near the Great Barrier Reef. They expected to find slightly more females because of the rising temperatures on this warm beach. They were surprised to find that, of a population of 200,000 sea turtles, 99.1% of the youngest ones were female, 99.8% of the teenage turtles were female, and 86.8% of the whole population was female. Sea turtles' sex is determined by the temperature of the egg while it is developing in the sand. This table shows the temperatures at which sea turtles hatch into males or females.

Temperature	Sea turtles that hatch
28°C (82°F) or below	Mostly males
Between 28°C (82°F) and 31°C (88°F)	Half male and half female
31°C (88°F) or above	Mostly females

With more and more female sea turtles, the populations of sea turtles around the world are in danger because both male and female sea turtles are needed to survive and reproduce.

A solution? Sea turtle conservation efforts are trying many different approaches to protect the sea turtle population. One idea is to move the eggs to an environment in which they can be kept at a controlled temperature. However, the eggs still need to be moved safely. In order to move sea turtle eggs safely, consider the following:

Criteria

- Sea turtle eggs must not rotate or change orientation from how they were first laid in the ground.
- In a natural environment, sea turtle eggs are heated from above as the Sun warms the sand on top of the eggs.
- Sea turtle eggs need humidity to grow, ideally between 80% and 90% relative humidity.
- A temperature of 28°C (82°F) or slightly lower is needed to help produce more male turtles.
- It takes about 10 minutes to move the eggs, so a heater must maintain the desired temperature for 10 minutes.

Constraints

- There is no access to a power source during transportation.

Your task: Evaluate and select the best possible design for a sea turtle egg incubator (a device that keeps objects warm) that can be used when the sea turtle eggs are moved to a more-permanent location.

Part 1. Evaluate an Existing Incubator: Incubator A

This is an existing egg incubator available for purchase online. Will it work to move the sea turtle eggs? Review the advertised characteristics of this incubator below:

- Incubation temperature is adjustable.
- Heating element is above the eggs.
- Eggs are rotated on rotating disks.
- Humidity can be set for up to 85% relative humidity.
- Power supply is from a cord to an outlet.
- It holds up to 7 eggs.
- The cost is $200.

Brinsea Mini II Advance Automatic Incubator

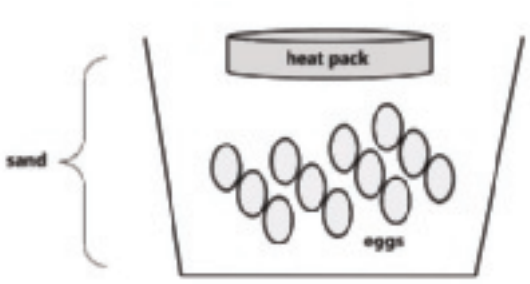
1a. Complete the "1a. Optimal solution" row in the *Design Testing Matrix for Sea Turtle Assessment* to show the ideal incubator characteristics using the information shown in the list provided above of criteria and constraints for moving sea turtle eggs safely.

1b. Incubator A was tested against the criteria and constraints, and the results of those tests are shown in the Design Testing Matrix.

Use the Design Testing Matrix to write an argument below that states whether incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints presented in the Design Testing Matrix and the advertised performance of incubator A in your argument.

Part 2: Alternative Design: Incubator B

In a Google search, we found a homemade turtle egg incubator. Below is a picture and a side-view diagram of the incubator.



This incubator claims that it has the following characteristics that will work to incubate turtle eggs:

- A chemical heat pack placed in the top of the incubator, when started, keeps the eggs warm for 20 minutes.
  - Calcium chloride is on one side, and water is on the other. To start, squeeze the pouch to combine the two substances. The reaction produces calcium hydroxide and hydrochloric acid.
  - Here is the chemical equation: $CaCl_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HCl$
- When the heat pack is in place, the incubator keeps the eggs at about 35°C.
- Eggs sit still in sand.
- There is no guaranteed humidity control.
- Incubator holds up to 20 eggs.
- The cost is $50.

2a. Is this an ***endothermic*** or ***exothermic*** chemical reaction? _____ Explain your choice.

_____

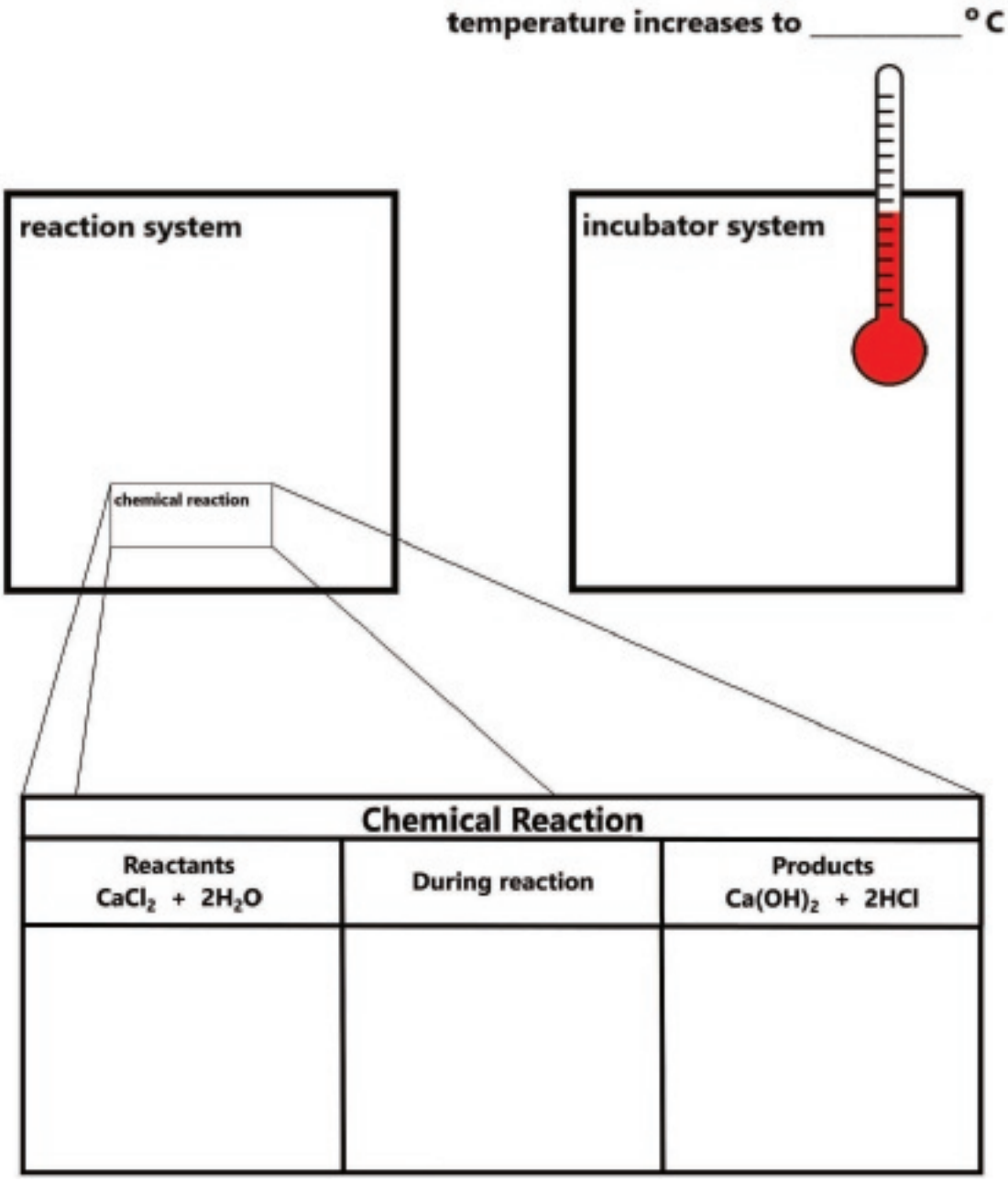
_____

_____

_____

2b. Draw a model to explain "How does the heat pack keep the turtle eggs warm?"

Update the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction. Use the table below the Energy Transfer Model to explain what is happening at the scale we cannot see. Use the space in the table to draw a representation of what is happening to the substances that are undergoing the chemical reaction.



Chemical Reaction		
Reactants $CaCl_2 + 2H_2O$	During reaction	Products $Ca(OH)_2 + 2HCl$

Part 3. Remember, our goal is to select an incubator that will support the relocation of eggs while keeping them at a temperature that will result in more males hatching.

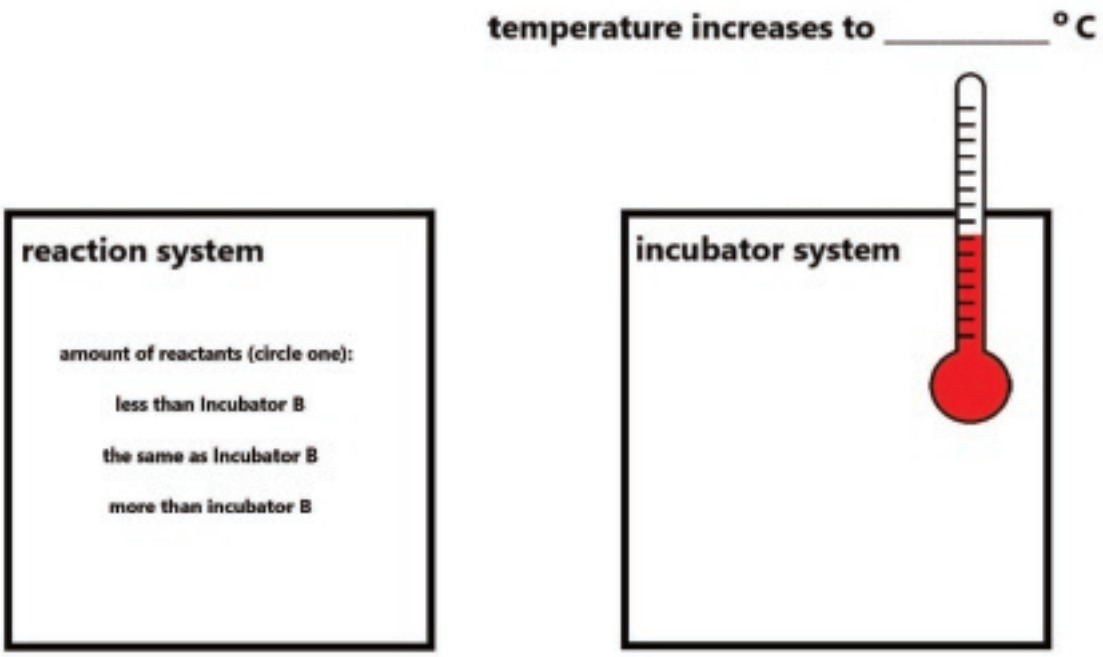
3a. Using the information provided about incubator B, complete row "3a. Incubator B" in the *Design Testing Matrix for Sea Turtle Assessment* to organize the data and help you think about how it will perform in tests against the criteria and constraints.

3b. Which incubator design would work best to incubate the sea turtle eggs in order to meet our target design goal? (Circle one.)

- Incubator **A**
- Incubator **B**
- Combined design features of **A and B**

3c. For the criterion of temperature, how would you optimize the design using the chemical reaction in **incubator B** in order to ensure the hatching of **male** sea turtles? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used.

In your response, update the Energy Transfer Model you made for question 2b to explain why your redesign will work. Include a caption that addresses the changes you made and the effect those changes had on the energy transfer between parts of the system.



3d. Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.

Criteria and constraints	Which design characteristic (incubator A's or B's) would you choose, and why?
Egg rotation	
Power source	
Humidity	
Length of time temperature is held	
Location of heat source	

LESSON 10: ANSWER KEY 1

Key for Sea Turtle Assessment

This assessment can be used to evaluate student progress on the LLPEs. The LLPEs are an integration of elements from the three dimensions, so look for these three aspects working together across the students' explanations.

10.A Make a written argument that supports or refutes the advertised performance of a sea turtle incubator based on evidence concerning whether the incubator meets relevant criteria and constraints, such as transferring the right amount of energy to the sea turtle eggs.

10.B Apply the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the system containing the turtle eggs.

SEPs	DCIs	CCCs
Develop and/or use a model to predict and/or describe phenomena. Use data to evaluate and refine design solutions. Make an oral or written argument that supports or refutes the advertised performance of a device, process, or system based on empirical evidence concerning whether or not the technology meets relevant criteria and constraints. Develop or modify a model—based on evidence—to match what happens if a variable or component of a system is changed.	Some chemical reactions release energy; others store energy. 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. Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. A solution needs to be tested and then modified on the basis of the test results in order to improve it.	Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter, and information flows within systems. The transfer of energy can be tracked as energy flows through a designed or natural system.

Sea Turtle Population in Danger?

In 2018, there were a lot of news stories with headlines like this: "The sea turtle population in Australia is mostly females" and "Most of the new sea turtles born are female."

The problem: In 2018, scientists in Australia conducted a study to understand the proportion of male to female sea turtles near the Great Barrier Reef. They expected to find slightly more females because of the rising temperatures on this warm beach. They were surprised to find that, of a population of 200,000 sea turtles, 99.1% of the youngest ones were female, 99.8% of the teenage turtles were female, and 86.8% of the whole population was female. Sea turtles' sex is determined by the temperature of the egg while it is developing in the sand. This table shows the temperatures at which sea turtles hatch into males or females.

Temperature	Sea turtles that hatch
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31°C (88°F) or above	Mostly females

With more and more female sea turtles, the populations of sea turtles around the world are in danger because both male and female sea turtles are needed to survive and reproduce.

A solution? Sea turtle conservation efforts are trying many different approaches to protect the sea turtle population. One idea is to move the eggs to an environment in which they can be kept at a controlled temperature. However, the eggs still need to be moved safely. In order to move sea turtle eggs safely, consider the following:

Criteria

- Sea turtle eggs must not rotate or change orientation from how they were first laid in the ground.
- In a natural environment, sea turtle eggs are heated from above as the Sun warms the sand on top of the eggs.
- Sea turtle eggs need humidity to grow, ideally between 80% and 90% relative humidity.
- A temperature of 28°C (82°F) or slightly lower is needed to help produce more male turtles.
- It takes about 10 minutes to move the eggs, so a heater must maintain the desired temperature for 10 minutes.

Constraints

- There is no access to a power source during transportation.

Your Task: Evaluate and select the best possible characteristics to include in a revised design for a sea turtle egg incubator (a device that keeps objects warm) that can move the sea turtle eggs to a more permanent location.

Part 1. Evaluate an Existing Incubator: Incubator A

This is an existing egg incubator available for purchase online. Will it work to move the sea turtle eggs? Review the advertised characteristics of this incubator below:

- Adjustable incubation temperature
- Heating element is above the eggs
- Eggs are rotated on rotating disks
- Humidity can be set for up to 85% relative humidity
- Power supply from a cord to an outlet
- Holds up to 7 eggs
- Costs $200

Brinsea Mini II Advance Automatic Incubator

Incubator A was tested against the criteria and constraints, and the results of those tests are shown in the testing matrix.

1a. Complete the "optimal solution" row in the **testing matrix** to show the ideal incubator characteristics using the information provided above.

Check the testing matrix on the separate page found on Design Testing Matrix for Sea Turtle Assessment in the row for 1a.

See testing matrix at the end of this document for expected student responses.

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1b. Incubator A was tested against the criteria and constraints and the results of those tests are shown in the Design Testing Matrix.

Use the testing matrix to write an argument that states whether or not Incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints in the Design Testing Matrix and the advertised performance of Incubator A in your argument.

+ Argument claims that Incubator A will not be sufficient for relocating sea turtle eggs.

Student support for the argument should refer to the criteria and constraints, including the following:

+ Incubator A moves the eggs around; however, sea turtle eggs cannot rotate or change orientation when they are moved from one location to another. This is a criterion.

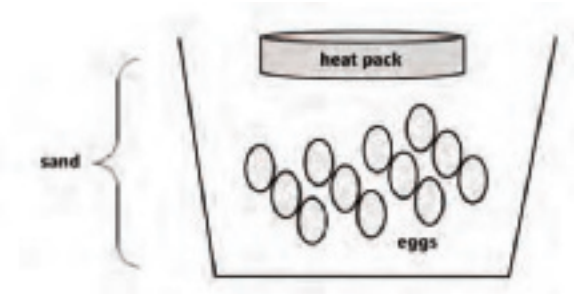
+ Incubator A requires a power source, and one constraint we have is that there is not a power source available during transport.

Part 2: Alternative Design: Incubator B

In a Google search, we found a homemade turtle egg incubator. Below is a picture and a side-view diagram of the incubator.

This incubator claims that it has the following characteristics that will work to incubate turtle eggs:

- Chemical heat packs placed in the top of the incubator, when started, keep the eggs warm for 20 minutes
  - Calcium chloride is on one side, and water is on the other. To start, squeeze the pouch to combine the two substances. The reaction produces calcium hydroxide and hydrochloric add.
  - Here is the chemical equation: $CaCl_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HCl$
- When the heat pack is in place, the incubator keeps the eggs at about 35°C
- Eggs sit still in sand
- No guaranteed humidity control
- Holds up to 20 eggs
- Costs $50



2a. Is this an endothermic or exothermic chemical reaction? _____ Explain your choice.

+ It's an exothermic reaction (or a description that reflects that energy is transferred from the system of atoms rearranging during the chemical reaction).

+ This is because energy is being transferred out of the heat-pack system and into the egg system, which makes it feel warm.

If a student answered "endothermic" but has a correct "why" statement here and/or their model is correct below, consider having a discussion with the student about their response to this question—they could have just mixed up the terms *endothermic* and *exothermic* and should not be penalized if their understanding is solid.

2b. Draw a model to explain "How does the hot pack heat up the turtle eggs?" Update the Energy Transfer model to show how the energy is transferred between the reaction occuring in the hot pack and the incubator system containing the turtle eggs. Include in your description a representation of what is happening to the substances that are undergoing the chemical reaction.

Use the table below the Energy Transfer Model to explain what is happening at the scale we cannot see. Use the space in the table to draw a representation of what is happening to the substances that are undergoing the chemical reaction.

Student models should include the following:

+reactants and products of the reaction

+particles breaking apart from one another and rearranging

+energy transferring from reaction system to the system of eggs that need to be warmed

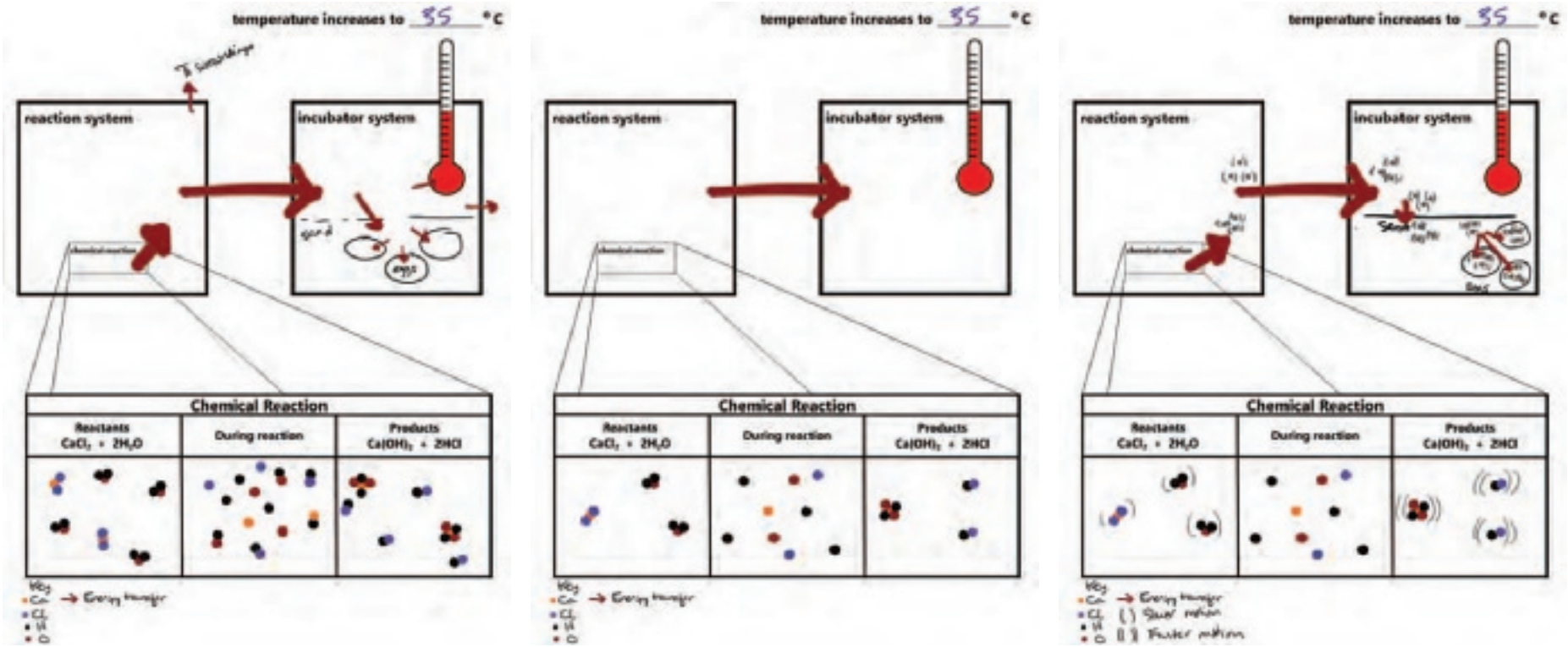
+a key that explains what the symbols used represent

Students' models may also show:

+energy transferring out of the reaction system to other places than the eggs (i.e., surroundings, air, sand, water, and so forth).

+differences in speed of particles before and after energy is transferred

The three examples below demonstrate different ways a student might show evidence of understanding.



Part 3. Remember, our goal is to select an incubator that will support the relocation of eggs while keeping them at a temperature that will result in more males hatching.

3a. Using the information provided about Incubator B, complete the testing matrix row to organize the data and help you think about how it will perform in tests against the criteria and constraints.

See design testing matrix at the end of this document for expected student responses.

3b. Which incubator design would work best to incubate the sea turtle eggs in order to meet our target design goal? (Circle one.)

- Incubator **A**
- Incubator **B**
- Combined design features of **A and B**

"Combined design features of A and B" is the ideal response from students. If students select "Incubator A" or "Incubator B" coordinate this response with their response in 3d to decide how well they understand the idea that some design solutions are optimal when they combine features from across design solutions.

3c. For the criteria of temperature, how would you optimize the design using the chemical reaction in **Incubator B** in order to ensure the hatching of male sea turtles? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used.

In your response, update the Energy Transfer Model you made in part 2b to show the changes you would make and how they would affect energy transfer to explain why your redesign would work.

Student responses should include the following:

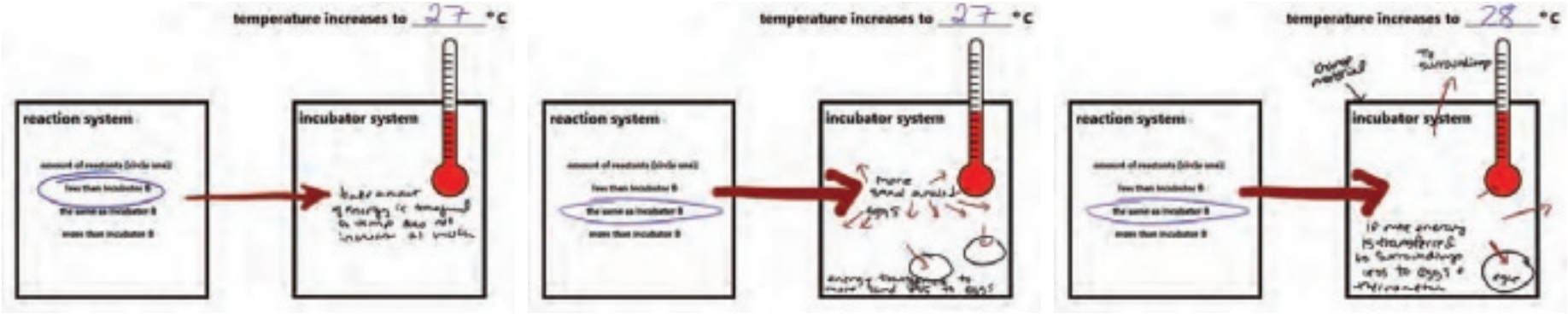
+ I would optimize the design by decreasing the amount of reactants used in the chemical reaction heat pack.

+ That should work because with less reactants, the energy that is released to the eggs will be lower. See the Energy Transfer Model below.

+Energy Transfer Model should communicate that there would be less reactants and therefore less energy transferred to the incubator system. This can be represented graphically by smaller energy transfer arrows (with labels) or in words describing the lower energy transfer to the incubator system because of less reactants.

+If a student chooses to keep amount of reactants the same, the energy transfer arrow from the reaction system to the incubator system should be the same and other design changes should result in an overall lower egg temperature (for example, the addition of more sand or a container with less insulation will have energy transferring more to other systems so less energy will be transferred to the eggs).

The three examples below demonstrate different ways a student might show evidence of understanding.



3d. Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criteria and constraint and state your reasons (including discussion of how energy is transferred) for which design (Incubator A or B) you would choose for that characteristic.

The expected student response includes a claim and support from evidence concerning how the technology meets relevant criteria and constraints. The example student response below is considered complete.

Criteria and Constraint	Which design characteristic (Incubator A's or B's) would you choose and why?
Egg rotation	+ I would use the design from Incubator B for egg rotation because turtle eggs should not be rotated.
Power source	+ I would use the design from Incubator B for power source because there is not a power source available when transporting the eggs and Incubator B does not require a power source.
Humidity	+ I would use Incubator A's design for humidity because the turtles need between 80% and 90% humidity and Incubator A can get to 85%, which is inside that range.
Length of time temperature is held	+Students could choose either design for the length of time needed because both Incubator A's and Incubator B's designs meet the criterion for holding the eggs for 10 minutes. For example, "I would choose Incubator A's design for the length of time the temperature is held because it can be held indefinitely and the optimal turtle design only needs 10 minutes of time held, which is less than forever."
Location of heat source	+ Students could use either design for the location of the heat source because turtle eggs need heat coming from the top and both Incubator A's and Incubator B's designs meet this criterion. For example, "I would choose Incubator B's design because its heat source comes from the top, and sea turtle eggs are used to being warmed at the top by the Sun."

Design Testing Matrix

Design	Egg rotation?	Temperature of incubator	Power source needed?	Humidity	Length of time temp is held	Location of heat source
Question Ia. Optimal Solution	No	Temperature below 28°C	No	80-90%	10 minutes	Top
Incubator A	Yes	Adjustable temperature	Yes	20-85%	Indefinite	Top
Question 3a. Incubator B	No	Temperature keeps eggs at 35°C	No	We don't know	20 minutes	Top

Name: _____ Date: _____

Form B: Sea Turtle Assessment

Sea Turtle Population in Danger?

In 2018, there were a lot of news stories with headlines like this: "The sea turtle population in Australia is mostly females" and "Most of the new sea turtles born are female."

The problem: In 2018, scientists in Australia conducted a study to understand the proportion of male to female sea turtles near the Great Barrier Reef. They expected to find slightly more females because of the rising temperatures on this warm beach. They were surprised to find that, of a population of 200,000 sea turtles, 99.1% of the youngest ones were female, 99.8% of the teenage turtles were female, and 86.8% of the whole population was female. Sea turtles' sex is determined by the temperature of the egg while it is developing in the sand. This table shows the temperatures at which sea turtles hatch into males or females.

Temperature	Sea turtles that hatch
28°C (82°F) or below	Mostly males
Between 28°C (82°F) and 31°C (88°F)	Half male and half female
31°C (88°F) or above	Mostly females

With more and more female sea turtles, the populations of sea turtles around the world are in danger because both male and female sea turtles are needed to survive and reproduce.

A solution? Sea turtle conservation efforts are trying many different approaches to protect the sea turtle population. One idea is to move the eggs to an environment in which they can be kept at a controlled temperature. However, the eggs still need to be moved safely. In order to move sea turtle eggs safely, consider the following:

Criteria

- Sea turtle eggs must not rotate or change orientation from how they were first laid in the ground.
- In a natural environment, sea turtle eggs are heated from above as the Sun warms the sand on top of the eggs.
- Sea turtle eggs need humidity to grow, ideally between 80% and 90% relative humidity.
- A temperature of 28°C (82°F) or slightly lower is needed to help produce more male turtles.
- It takes about 10 minutes to move the eggs, so a heater must maintain the desired temperature for 10 minutes.

Constraints

- There is no access to a power source during transportation.

Your task: Evaluate and select the best possible design for a sea turtle egg incubator (a device that keeps objects warm) that can be used when the sea turtle eggs are moved to a more-permanent location.

Part 1. Evaluate an Existing Incubator: Incubator A

This is an existing egg incubator available for purchase online. Will it work to move the sea turtle eggs? Review the advertised characteristics of this incubator below:

- Incubation temperature is adjustable.
- Heating element is above the eggs.
- Eggs are rotated on rotating disks.
- Humidity can be set for up to 85% relative humidity.
- Power supply is from a cord to an outlet.
- It holds up to 7 eggs.
- The cost is $200.

Brinsea Mini II Advance Automatic Incubator

Brinsea Mini II Advance Automatic Incubator

1a. Complete the "1a. Optimal solution" row in the *Design Testing Matrix for Sea Turtle Assessment to* show the ideal incubator characteristics using the information shown in the list provided above of criteria and constraints for moving sea turtle eggs safely.

1b. Incubator A was tested against the criteria and constraints, and the results of those tests are shown in the Design Testing Matrix.

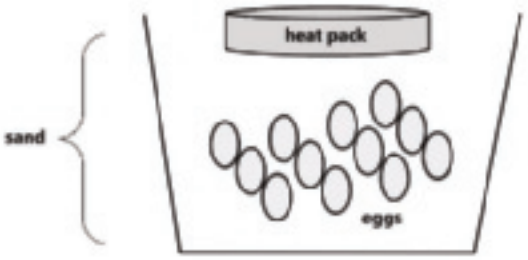
Use the Design Testing Matrix to write an argument below that states whether incubator A will be sufficient to incubate sea turtle eggs effectively during relocation. Consider the criteria and constraints presented in the Design Testing Matrix and the advertised performance of incubator A in your argument.

Part 2: Alternative Design: Incubator B

In a Google search, we found a homemade turtle egg incubator. Below is a picture and a side-view diagram of the incubator.

This incubator claims that it has the following characteristics that will work to incubate turtle eggs:

- A chemical heat pack placed in the top of the incubator, when started, keeps the eggs warm for 20 minutes.
- Calcium chloride is on one side, and water is on the other. To start, squeeze the pouch to combine the two substances. The reaction produces calcium hydroxide and hydrochloric acid.



- Here is the chemical equation: $CaCl_2 + 2H_2O \rightarrow Ca(OH)_2 + 2HCl$
- When the heat pack is in place, the incubator keeps the eggs at about 35°C.
- Eggs sit still in sand.
- There is no guaranteed humidity control.
- Incubator holds up to 20 eggs.
- The cost is $50.

2a. Is this an ***endothermic*** or ***exothermic*** chemical reaction? _____ Explain your choice.

_____

_____

_____

_____

2b. Draw a model to explain "How does the heat pack keep the turtle eggs warm?"

Update the Energy Transfer Model to show how the energy is transferred between the reaction occuring in the heat pack and the incubator system containing the turtle eggs. Include a representation of what is happening to the substances that are undergoing the chemical reaction. Use the table below the Energy Transfer Model to explain what is happening at the scale we cannot see. Use the space in the table to draw a representation of what is happening to the substances that are undergoing the chemical reaction.

Part 3. Remember, our goal is to select an incubator that will support the relocation of eggs while keeping them at a temperature that will result in more males hatching.

3a. Using the information provided about incubator B, complete row "3a. Incubator B" in the *Design Testing Matrix for Sea Turtle Assessment* to organize the data and help you think about how it will perform in tests against the criteria and constraints.

3b. Which incubator design would work best to incubate the sea turtle eggs in order to meet our target design goal?

(Circle one.)

- Incubator **A**
- Incubator **B**
- Combined design features of **A and B**

3c. For the criterion of temperature, how would you optimize the design using the chemical reaction in **incubator B** in order to ensure the hatching of **male** sea turtles? You may choose to increase, decrease, or keep the same amount of reactants in your redesign. It is not necessary to include the exact amounts of reactants used.

In your response, update the Energy Transfer Model you made for question 2b to explain why your redesign will work. Include a caption that addresses the changes you made and the effect those changes had on the energy transfer between parts of the system.

3d. Beyond temperature, which additional characteristics from each design would you use in your optimal design? To do this, go through each criterion and constraint and state your reasons (including discussion of how energy is transferred) for which design (incubator A or B) you would choose for that characteristic.

Criteria and constraints	Which design characteristic (incubator A's or B's) would you choose, and why?
Egg rotation	
Power source	
Humidity	
Length of time temperature is held	
Location of heat source	

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School of Plant and Environmental Sciences

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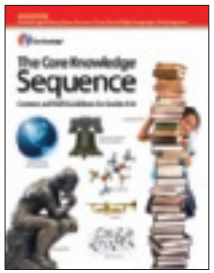

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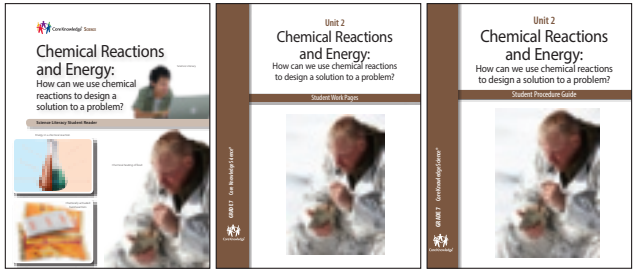

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