10

Developing a Prototype

DESIGN

1–2 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students undertake a design challenge to construct and test a hand warmer device that uses the thermal energy released from an iron exothermic reaction. When testing their designs, students analyze their results and brainstorm ideas for further modification.

NGSS CORRELATIONS

Performance Expectations

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

Working towards 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.

Working towards 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.

Disciplinary Core Ideas

MS-PS1.B Chemical Reactions: Some chemical reactions release energy, others store energy.

MS-ETS1.B Developing Possible Solutions:

A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

MS-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.

MS-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.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze and interpret data to determine similarities and differences in findings.

Constructing Explanations and Designing Solutions: Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

Crosscutting Concepts

Energy and Matter: The transfer of energy can be tracked as energy flows through a designed or natural system.

WHAT STUDENTS DO

Students design a hand warmer and then construct, test, and evaluate a prototype.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

	1	container of absorbent beads
*	1	beaker (1-L or larger)
*		water
		iron filings (5-cc)
		calcium chloride (5-cc)
	1	sealable plastic bag (large 4” x 6”)
	1	Scoring Guide: ENGINEERING DESIGN SOLUTIONS (ENG)

- *For each group of four students*

	1	container of iron filings
	1	container of calcium chloride
	1	container of pre-swelled absorbent beads
	1	sealable plastic bag (large 4” x 6”)
	1	graduated cup (30-mL)
	1	scoop (30-cc)
	3	scoops (5-cc)
*		water
	1	thermometer
		timer or clock
*	1	tray
*		paper towels

- *For each student*

*	1	pair of chemical splash goggles
	1	Student Sheet 10.1, “Hand Warmer Designs”
	1	Scoring Guide: ENGINEERING DESIGN SOLUTIONS (ENG) (optional)

**not included in kit*

Prepare the demonstration hand warmer. Place 5 cc of iron filings and 5 cc of calcium chloride into a sealable plastic bag. When you do the demonstration, you will add 30 cc of water to the bag. Do not add the water until you are ready to show students.

Prepare the pre-swelled absorbent beads at least 24 hours before doing this activity. Place 2 teaspoons of beads (approximately 250) into a 1-L beaker (or larger). Fill the beaker with tap water. Top off the water in the beaker as the beads absorb the water. The beads will absorb the water and completely fill the beaker. This should be enough for eight groups of four students. Any unused beads can be dehydrated by allowing the water to evaporate—just leave the uncovered beaker on the counter top. Note: the beads are made out of sodium polyacrylate. We are calling them absorbent beads and not sodium polyacrylate to prevent confusion between the chemicals used in the reaction.

The water you provide for students should be at room temperature (22–25°C) or a little warmer (up to 30°C). If the water is cold, the reaction will take longer to start.

The sealable bags containing the iron reactions can be disposed of in the garbage. Do not have students pour the reactions down the sink, as the iron will build up in the pipes and produce rust.

The procedure is written for students working in groups of four. Since this is an engineering activity where students are designing their own product, enough materials are provided for each group of students to use the maximum amount of iron filings (15 cc) and calcium chloride (15 cc) as stated in the constraints. Some groups may choose to use less than these amounts. A successful hand warmer can be constructed with 5 cc of each material in combination with 30–60 cc of pre-swelled absorbent beads. This activity can be more engaging if students work in pairs, but you will have to change the constraints (to decrease the maximum amounts of iron and calcium chloride) or supply additional materials.

SAFETY NOTE

No toxic effects are known to result from handling these chemicals, but students should wear their chemical splash goggles and wash their hands thoroughly after finishing the experiment.

A considerable amount of thermal energy is released when calcium chloride dissolves in water. Ensure that students mix the calcium chloride and iron filings together before mixing with water. The amount of calcium chloride that students can use is limited to prevent too high of a temperature. Students must use equal amounts of iron filings and calcium chloride OR less calcium chloride than iron filings to prevent the reaction from becoming extremeley hot. Students should not squish, or otherwise damage, the absorbent beads for the same reason.

TEACHING SUMMARY

GET STARTED

1. Introduce the design challenge.
   a. Introduce the term *engineer*.
   b. Define the problem.
   c. Show the demonstration hand warmer.
   d. Ask students, “Why might this not be the best hand warmer design?”
   e. Introduce the pre-swelled absorbent beads.

DO THE ACTIVITY

2. Introduce the ENGINEERING DESIGN SOLUTIONS (ENG) Scoring Guide.
3. Define the problem in Part A.
4. Have students brainstorm designs in Part B.
   a. Review all of the available materials for their designs.
   b. Distribute Student Sheet 10.1, “Hand Warmer Designs.”

5. Students build and test their prototypes in Part C.
    a. Students choose the designs they want to build.
    b. Students build their hand warmer prototypes.

BUILD UNDERSTANDING

6. Have groups of students work together to evaluate their designs in Part D.
    a. Groups of students share their prototype designs and test results with another group of students in the class.
    b. Students discuss how they could improve their designs.
    c. As a class, discuss the characteristics of everyone's designs.
7. Direct students to the Analysis.
    a. Use Analysis item 3 to foreshadow the next activity.
    b. Use Analysis item 4 to relate the crosscutting concept of energy and matter to this activity.

TEACHING STEPS

GET STARTED

1. Introduce the design challenge.
    a. Introduce the term *engineer*.

        Students will take on the role of engineers in this activity and the next. An *engineer*, as defined in the Student Book, is someone who uses science and tools to build a product that solves a practical problem.

    b. Define the problem.

        The problem is having cold hands and needing a hand warmer. This is introduced in the introduction in the Student Book.

    c. Show the demonstration hand warmer.

        In the "Thermal Energy and Reactions" activity, students found that combining iron, calcium chloride, and water is an exothermic reaction. Tell students using an exothermic reaction is a way to make a hand warmer.

        Introduce a basic hand warmer prototype that simply combines the reactants from the last activity in a bag. Show students the plastic bag you prepared with 5 cc of iron filings and 5 cc of calcium chloride. Add 30 cc of water to the bag, and begin mixing the ingredients by rocking the bag back and forth and squishing the ingredients with your fingers. Use a thermometer to measure the increase in temperature. Demonstrate how to fold the plastic bag around the thermometer so that it is surrounded by the reaction in the bag.

Teacher's note: Hand warmers containing an iron chemical reaction are actual products used today, but they are single-use products. You and your students may be more familiar with reusable hand warmers, which contain a super-saturated salt solution that releases heat when the salt precipitates. This reaction can be reversed, so the hand warmer can be reused. Since the NGSS's focus is on a chemical process, we are focusing this activity on the iron exothermic reaction.

d. Ask students, "Why might this not be the best hand warmer design?"

Students should observe that the reaction looks messy. If the bag breaks open, there would be a watery, gritty mess. They might also point out that they would have to carry water with them to add when they wanted to start the reaction.

e. Introduce the pre-swelled beads.

Tell students that they can use these pre-swelled beads as an alternative to water. The beads start as very tiny plastic beads. When soaked in water, they absorb water and grow up to 10 times their original size. You might want to show the difference in size of a dried bead and a swelled bead. The water exits the beads very slowly.

Ask students, "Why might we want the water to leave the beads slowly?" Water is one of the reactants. Slowly adding the water controls how fast the reaction goes. The slower the water interacts with the iron and calcium chloride, the longer the reaction will continue.

DO THE ACTIVITY

2. Introduce the ENGINEERING DESIGN SOLUTIONS (ENG) Scoring Guide.

The Procedure in this activity is the first use of the ENGINEERING DESIGN SOLUTIONS (ENG) Scoring Guide. Optionally project or distribute the Scoring Guide. Point out how it has the same levels as other Scoring Guides but different descriptions for each level. Review the levels as needed. For more information, see Teacher Resources III, "Assessment."

In this activity, students will begin the engineering design process, but they will be formally assessed in the "Refining the Design" activity.

3. Define the problem in Part A.

   The problem is cold hands. As engineers, students will design solutions to this problem in the form of a hand warmer.

   Review the criteria and constraints listed in the Student Book. As a class, clarify the criteria and constraints, and add anything missing. Note that in the following activity, “Refining the Design,” students will focus on starting the reaction when they want. That is not part of the criteria yet.

4. Have students brainstorm designs in Part B.

   a. Review all of the available materials for their designs.

      Point out that the hand warmers must be contained in a sealable plastic bag. The pre-swelled beads are available, but students can also choose to use water directly in their hand warmer.

   b. Distribute Student Sheet 10.1, “Hand Warmer Designs.”

      Instruct students to record their design ideas on their Student Sheets. They should make sure to include the materials and amounts. If students are having difficulty starting, you can lead a brainstorming session about variables that they can modify in their designs. These variables include using absorbent beads or water, varying the amount of iron, varying the amount of calcium chloride, and varying the amount of water/beads.

      At this point, you may need to clarify how much of each reactant they can use. Students are not required to use a specific amount of each reactant—which is a variable they can choose to alter in their designs—but they must use no more than 15 cc of iron and 15 cc calcium chloride. Students can choose to add increments of 5 cc of iron or calcium chloride since they are provided with 5-cc scoops. The 30-cc scoop should be reserved for the absorbent beads. The addition of calcium chloride to water also produces an increase in temperature. If too much calcium chloride alone is mixed with water, the temperature can rise above 50°C and possibly melt the sealable plastic bags.

      Design ideas are provided on Sample Student Response to Student Sheet 10.1 at the end of this activity.

5. Students build and test their prototypes in Part C.

   a. Students choose the designs they want to build.

      Instruct groups of students to discuss their prototype ideas. Remind them of the limited materials they are able to use. Have them choose the prototype design they want to build and test, and have them explain why they think they should build that particular one.

b. Students build their hand warmer prototypes.

Have students build their hand warmer prototypes. Remind students to keep their materials on the tray to contain any spills or leaks from their bags. Make sure they are building according to their design specifications on their Student Sheets and recording the temperature change.

BUILD UNDERSTANDING

6. Have groups of students work together to evaluate their designs in Part D.

    a. Groups of students share their prototype designs and test results with another group of students in the class.

    Students should discuss why they made their design choices and whether their designs met all of the criteria and constraints. The groups should also identify the similarities and differences between their two designs.

    b. Students discuss how they could improve their designs.

    Groups of students should discuss ways to further improve their designs by combining characteristics of each other's designs.

    c. As a class, discuss the characteristics of everyone's designs.

    Make a list of characteristics from the students' designs. This list could include the amount of the reactants used and whether they used pre-swelled beads or water.

    Ask students, "Did your design meet all of the criteria and constraints? If so, which characteristic(s) of your design do you think helped it succeed? If not, which characteristic(s) do you think hurt your design?"

7. Direct students to the Analysis.

    a. Use Analysis item 3 to foreshadow the next activity.

    Have students start thinking about how they might redesign their hand warmers so they can control the start of the reaction.

    b. Use Analysis item 4 to relate the crosscutting concept of energy and matter to this activity.

    Remind students that the increase in temperature is due to the release of thermal energy from the chemical reaction inside their hand warmers.

SAMPLE RESPONSES TO ANALYSIS

1. Did your prototype meet the criteria for the hand warmer? If not, what did your design fail to meet?

   Student responses may vary depending on their prototype. One sample response is shown here:

   No, our prototype did not maintain 40°C for 5 min. It only worked for 3 min.

2. How could you improve your design? Is there a feature of another design or a material that you did not use that you would like to include? Why or why not?

   Student responses may vary depending on their prototype. One sample response is shown here:

   I think we needed to add more iron filings and calcium chloride to our design. I don't think we started with enough reactants so not enough energy was released.

3. When you combine the reactants provided in this activity, the reaction begins almost instantly. How do you think you could make the reaction start when you want it to?

   Student responses may vary. One sample response is shown here:

   I could somehow keep one of the reactants separate from the others. When I want the reaction to start, I would mix them all together.

4. (QUICK CHECK) The reaction in your hand warmer releases thermal energy, which increases the temperature of the warmer.

   a. Why does the warmer not stay warm forever?

      The temperature increase is due to the energy release from the chemical reaction. Since there is only a certain amount of reactants, the reaction will stop once they all react.

   b. Where does the released energy from the reaction in the hand warmer go?

      The released energy is thermal energy and can be felt as an increase in temperature. Since we were holding the hand warmer, the thermal energy was being transferred to our hands, which were colder than the hand warmer.

REVISIT THE GUIDING QUESTION

How do engineers design and test a prototype hand warmer?

Students use their understanding about an exothermic reaction to design a product that can contain that reaction and maintain a certain temperature. Variables such as reactant amounts can be varied to determine optimal reaction conditions to meet the criteria. Students may find that their prototypes did not meet the criteria, but features from other designs could be incorporated to improve their designs.

ACTIVITY RESOURCES

KEY VOCABULARY

engineer

prototype

Name____ Date___________

STUDENT SHEET 10.1

HAND WARMER DESIGNS

1. Draw and label your preliminary designs.
2. Circle the design you and your group choose to build a prototype for and test.
3. Record your observations.

Design 1 Variable changed from the original design: Testing result(s):	Design 2 Variable changed from the original design: Testing result(s):
Design 3 Variable changed from the original design: Testing result(s):	Design 4 Variable changed from the original design: Testing result(s):

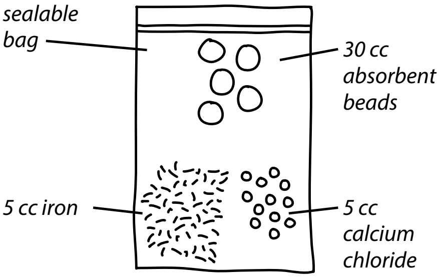
Name *Sample student response* Date

STUDENT SHEET 10.1

HAND WARMER DESIGNS

1. Draw and label your preliminary designs.
2. Circle the design you and your group choose to build a prototype for and test.
3. Record your observations.

Design 1



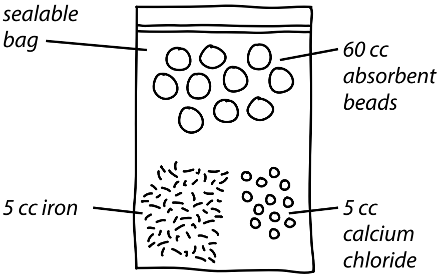
Variable changed from the original design:

Use 30 cc of absorbent beads instead of 30 mL water

Observations while testing:

Did this design meet all the criteria?

[✓ Design 2]



Variable changed from the original design:

Use 60 cc of absorbent beads instead of 30 mL water

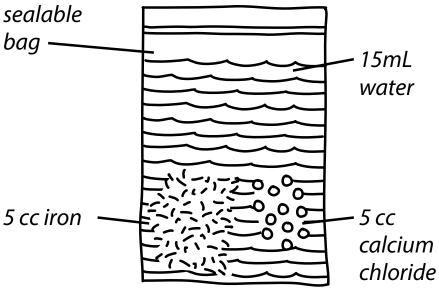
Observations while testing:

Water left the absorbent beads and mixed with the iron and calcium chloride. The temperature increased as we continued to squish everything together. It started close to 22°C and then increased to 40°C after a few minutes. The reaction in the bag only got warm where the water was mixing with the iron and calcium chloride. There was a lot of water in the bag, which could be messy if it opened or leaked.

Did this design meet all the criteria?

Yes—everything, including iron, was in the bag; it warmed up to 40°C and stayed there for 5 min.

Design 3



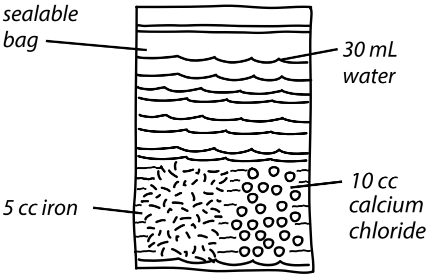
Variable changed from the original design:

Use 15 mL instead of 30 mL of water

Observations while testing:

Did this design meet all the criteria

Design 4



Variable changed from the original design:

Use 10 cc calcium chloride instead of 5 cc

Observations while testing:

Did this design meet all the criteria?

ENGINEERING DESIGN SOLUTIONS (ENG)

When to use this Scoring Guide:

This Scoring Guide is used when students design, evaluate, and refine solutions.

What to look for:

- Response includes a complete design relevant to the problem to be solved.
- Response includes evidence of how well the design meets criteria within the defined constraints.
- Response indicates how scientific disciplinary core ideas and crosscutting concepts relate to the successful design.

Level	Description
Level 4 Complete and correct	The student's design • meets all of the criteria within the defined constraints, AND • has further improved on the design, AND • uses relevant scientific concepts to explain why any revisions were made to optimize the design.
Level 3 Almost there	The student's design • meets all of the criteria within the defined constraints, AND • explains the relevant scientific concepts.
Level 2 On the way	The student's design • meets all of the criteria but exceeds the defined constraints OR • meets some of the criteria within the defined constraints.
Level 1 Getting started	The student's design does not meet any of the criteria.
Level 0	The student proposes no design or an irrelevant design.
x	The student had no opportunity to respond.

11

Refining the Design

DESIGN

2–3 CLASS SESSIONS

ACTIVITY OVERVIEW

NGSS CONNECTIONS

Students use the thermal energy release from combining iron, calcium chloride, and water to design a hand warmer. Students redesign, construct, test, and evaluate their hand warmer designs from the "Developing a Prototype" activity. A new criterion is introduced—students must consider how to control the start of the chemical reaction in their design modifications. This activity provides an assessment opportunity for Performance Expectation MS-PS1-6.

NGSS CORRELATIONS

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.

Working towards 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.

Working towards 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.

Applying 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.

Disciplinary Core Ideas

MS-PS1.B Chemical Reactions:

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.

MS-ETS1.B Developing Possible Solutions:

A solution needs to be tested, and then modified on the basis of the test results, in order to improve it.

There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.

Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.

MS-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.

MS-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.

Science and Engineering Practices

Analyzing and Interpreting Data: Analyze and interpret data to determine similarities and differences in findings.

Constructing Explanations and Designing Solutions: Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints.

Crosscutting Concepts

Energy and Matter: The transfer of energy can be tracked as energy flows through a designed or natural system.

WHAT STUDENTS DO

Students brainstorm new designs that will allow users to start the chemical reaction when they want to use the hand warmer. These designs may be redesigns of those developed in the previous activity or may be totally new. Students discuss designs and choose one to build as a prototype. Pairs of students exchange prototypes, and test and evaluate them. Students then think about how to further modify their designs.

MATERIALS AND ADVANCE PREPARATION

- *For the teacher*

	1	Visual Aid 11.1, “Engineering Design Process”
	1	Scoring Guide: ENGINEERING DESIGN SOLUTIONS (ENG)

- *For each group of four students*

	1	container of iron filings
	1	container of calcium chloride
	1	container of pre-swelled absorbent beads
		sealable plastic bags (small 3” x 3”, medium 3” x 4”, and large 4” x 6”)
	1	graduated cup (30-mL)
	1	scoop (30-cc)
	3	scoops (5-cc)
*		water
	1	thermometer
		timer or clock
*	1	tray
*		paper towels

- *For each student*

*	1	pair of chemical splash goggles
	1	Student Sheet 11.1, “Evaluation of Hand Warmer Design”
	1	Scoring Guide: ENGINEERING DESIGN SOLUTIONS (ENG) (optional)

**not included in kit*

If you do not have enough beads from the last activity, prepare more pre-swelled absorbent beads at least 24 hours before doing this activity. Place 2 teaspoons of beads into a 1-L beaker (or larger). Fill the beaker with tap water. Top off the water in the beaker as the beads absorb the water. The beads will absorb the water and completely fill the beaker. Any unused beads can be dehydrated by allowing the water to evaporate—just leave the uncovered beaker on the counter top.

The water you provide for students should be at room temperature (22–25°C) or a little warmer (up to 30°C). If the water is cold, the reaction will take longer to start.

The sealable bags containing the iron reactions can be disposed of in the garbage. Do not have students pour the reactions down the sink, as the iron will build up in the pipes and cause a lot of rusting.

Similar to the “Developing a Prototype” activity, this procedure is written for students working in groups of four. Since this is an engineering activity where students are designing their own product, enough materials are provided for each group of students to use the maximum amount of iron filings (15 cc) and calcium chloride (15 cc) as stated in the constraints. Some groups may choose to use less than these amounts. A successful hand warmer can be constructed with 5 cc of each material in combination with 30–60 cc of pre-swelled absorbent beads. This activity can be more engaging if students work in pairs, but you will have to change the constraints (to decrease the maximum amounts of iron and calcium chloride) or supply additional materials.

SAFETY NOTE

No toxic effects are known to result from handling these chemicals, but students should wear their chemical splash goggles and wash their hands thoroughly after finishing the experiment.

TEACHING SUMMARY

GET STARTED

1. Introduce the *engineering design* process.

   Use Visual Aid 11.1, “Engineering Design Process,” to introduce the steps of the process.

DO THE ACTIVITY

2. Have students complete Part A.
   a. Review the problem.
   b. Introduce the added criterion that the user needs to be able to control when the hand warmer is activated.
   c. Have students brainstorm possible improvements to their designs.
   d. Demonstrate the use of a bag inside a bag.
3. Have students build, test, and evaluate designs in Part B.
   a. Instruct students to build their designs but not to activate them.

      Groups of students should decide which idea they want to build and then build it.
   b. Have each group share their design with another group in the class.
   c. Student groups exchange and evaluate prototypes using Student Sheet 11.1, “Evaluation of Hand Warmer Design.”

BUILD UNDERSTANDING

4. Have students discuss their test results.
5. Direct students to the Analysis.
   a. Discuss Analysis item 1.
   b. Analysis item 2 focuses on how designing a product is an iterative process.
   c. (ENG ASSESSMENT) Have students individually draw a labeled diagram of their hand warmer for Analysis item 3.
   d. Discuss Analysis item 4.

TEACHING STEPS

GET STARTED

1. Introduce the *engineering design* process.

Use Visual Aid 11.1, "Engineering Design Process," to introduce the steps of the process.

This diagram is also in the introduction in the Student Book. Students have already engaged in this process in several activities in this unit. Specific to this and the last activity, the problem is having cold hands. In "Developing a Prototype," students brainstormed possible solutions, designed prototypes, chose one and built it, tested and evaluated their designs, and shared their solutions. Through discussions, students have brainstormed ideas for redesigns. Since you presented a demonstration hand warmer, students technically redesigned your original prototype design. Point out that some steps seem linear. But this process is not linear; it is iterative and sometimes may cycle back to an earlier step in the process. Oftentimes, steps are repeated several times.

DO THE ACTIVITY

2. Have students complete Part A.
   a. Review the problem.

Remind students that the problem is cold hands, and they have been trying to design a product to solve that problem. Ask students, "In the last activity, you designed a hand warmer prototype. The class built and tested several different designs. Based on what you know about hand warmers, what other features should we include in our designs?"

Students may suggest a variety of things. Accept all student suggestions. If no one mentions it, talk about how the hand warmer turns on.

b. Introduce the added criterion that the user needs to be able to control when the hand warmer is activated.

Students need to design a product to warm cold hands. Review the criteria and constraints listed in the Student Book. Point out that these are the same as those from the last activity but with one additional criterion—students must design a solution that allows the user to start the reaction when they want to.

Ask students why this new criterion would be important in a product such as this. Students should point out that users would want to turn the hand warmer on when they need it. If the reaction starts when the product is built, the reaction will have stopped before the user gets it or needs it.

All of the materials from the last activity are available. In addition, there are three different sizes of sealable plastic bags.

c. Have students brainstorm possible improvements to their designs.

Have student groups brainstorm ideas and record their ideas in their science notebooks. Point out that they already have designs for a hand warmer from the last activity. They should be considering how to modify their designs to meet the new criterion. Students may also wish to start new designs if they feel their old designs cannot be modified to meet the new criterion. If this is the case, they should still rely on the test results of the class's previous designs.

d. Demonstrate the use of a bag inside a bag.

Ask students to share some of their group's design ideas with the class. A common idea may be to use a smaller sealable bag inside of a larger bag. Ask students how they will get the contents out of the smaller bag. Demonstrate how difficult it might be to "pop" open the inner bag. Take a smaller sealable bag, inflate it by blowing into the bag, and seal it. Press on the bag to show how the bag does not easily open the seal when pressed. Have students revisit their design ideas with this new knowledge in mind.

3. Have students build, test, and evaluate designs in Part B.

a. Instruct students to build their designs but not to activate them.

Groups of students should decide which idea they want to build and then build it.

b. Have each group share their design with another group in the class.

Students should show their designs and their built prototypes. They should explain their design choices to the other pair. Groups should identify similarities and differences in their designs.

c. Student groups exchange and evaluate prototypes using Student Sheet 11.1, "Evaluation of Hand Warmer Design."

Have groups of students explain how to activate their hand warmers. Remind students to keep the hand warmers over their trays to catch any spills or leaks from their hand warmers. Groups exchange hand warmers, activate them, and test them to see if they meet the criteria and constraints.

BUILD UNDERSTANDING

4. Have students discuss their test results.

Student groups should exchange Student Sheets with the other group and share whether the other group's design met the criteria and constraints. They should specify which criteria and constraints the designs did and did not meet. As a larger group, they should discuss how they might use parts from each of their designs to further redesign their hand warmers to better meet the criteria and constraints.

5. Direct students to the Analysis.

a. Discuss Analysis item 1.

This item asks students about their rationale for making their design choices. Point out that engineers do not always design through a trial-and-error method. They intentionally make design choices based on evidence they have collected and logical reasoning about what is likely to improve their design so their design will meet the given criteria and constraints.

b. Analysis item 2 focuses on how designing a product is an iterative process.

Students should recognize that you can always improve a design, and these improvements should be based on data from evaluating designs.

c. (ENG ASSESSMENT) Have students individually draw a labeled diagram of their hand warmer for Analysis item 3.

Analysis item 3 provides an opportunity to check students' understanding of how a product can be designed that uses a chemical reaction that releases thermal energy. This item corresponds to Performance Expectation MS-PS1-6, and can be assessed using the ENG Scoring Guide.

A sample Level-4 response is provided in Sample Responses to Analysis. For more information, see Teacher Resources III, "Assessment."

d. Discuss Analysis item 4.

MS-PS1-6 indicates that students design a product that uses a chemical reaction that releases or absorbs thermal energy. In this unit, students focus on exothermic reactions. This question has them consider what products might use an *endothermic* reaction.

SAMPLE RESPONSES TO ANALYSIS

1. How did you modify your hand warmer design to allow you to control when the reaction started? Why did you make this design choice?

   Student responses may vary based on their prototype design. One sample response is shown here:

   We decided to put the beads into a separate bag that could be opened when we wanted to start the reaction. We chose to keep the beads separate because they were the liquid part of the reaction. That way all the dry reactants were kept dry and separate from the beads.

2. Based on the testing of your hand warmer and seeing your classmates' designs, how might you further modify your design?

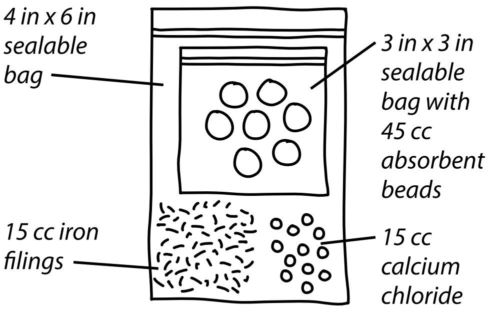
   Student responses may vary based on their prototype design. One sample response is shown here:

   I might try putting water in a separate bag inside the main bag. Water might be easier than the beads to get out of the smaller bag. Water also mixes faster with the dry reactants.

3. (ENG ASSESSMENT, MS-PS1-6) Draw a labeled diagram of your final hand warmer design. Be sure to label all of the materials, the quantities of each, and their sizes. Use your diagram to explain

   - the design criteria and constraints.
   - the chemical process used to solve the problem.
   - the movement of thermal energy when your hand warmer is activated.
   - how and why your design changed throughout the engineering design process.
   - how your design choices helped you meet the criteria and constraints.

SAMPLE LEVEL-4 RESPONSE



All reactants are in a large sealable bag. When the reactants mix, the chemical reaction is exothermic. The extra thermal energy is released and increases the temperature to around 40°C for at least 5 min. The reaction starts when the user releases the absorbent beads from the smaller sealable bag so they can mix with the iron and calcium chloride. All the materials in our design were provided, and we did not exceed the limits for the iron or calcium chloride. The main change to our design throughout the engineering design process was figuring out how to keep the reactants separated until the user wanted to start the reaction. We also tried different amounts of the reactants but decided to use these amounts based on the success of classmates' designs.

4. **Reflection:** For what purpose might you design a product that uses an endothermic reaction?

   An endothermic reaction would be useful in a cold pack to treat an injury or in a container to keep a drink cold.

REVISIT THE GUIDING QUESTION

How can the hand warmer design prototypes be redesigned and improved?

Following the engineering design process, an engineer often has to design, test, evaluate, redesign, etc. Based on results from the testing and evaluation, new designs can be made with improvements that will better meet the criteria and constraints.

This is a good place to reintroduce the third and fourth driving question for this sequence of learning. Revisit and add to or revise students' ideas as needed.

ACTIVITY RESOURCES

KEY VOCABULARY

criteria

constraints

engineering design process

exothermic

prototype

Name____ Date___________

STUDENT SHEET 11.1

EVALUATION OF HAND WARMER DESIGN

Hand warmer engineers: ____

Criteria and constraints	Does the design meet the criterion or constraint?	Evidence for or against
Is contained within a sealable bag		
Uses an exothermic reaction containing iron		
Reaches and maintains a temperature of 35–45°C for at least 5 min		
Allows the user to activate the warmer		
Uses only the materials provided		
Uses no more than 15 cc iron filings and 15 cc calcium chloride		

Name *Sample student response* Date

STUDENT SHEET 11.1

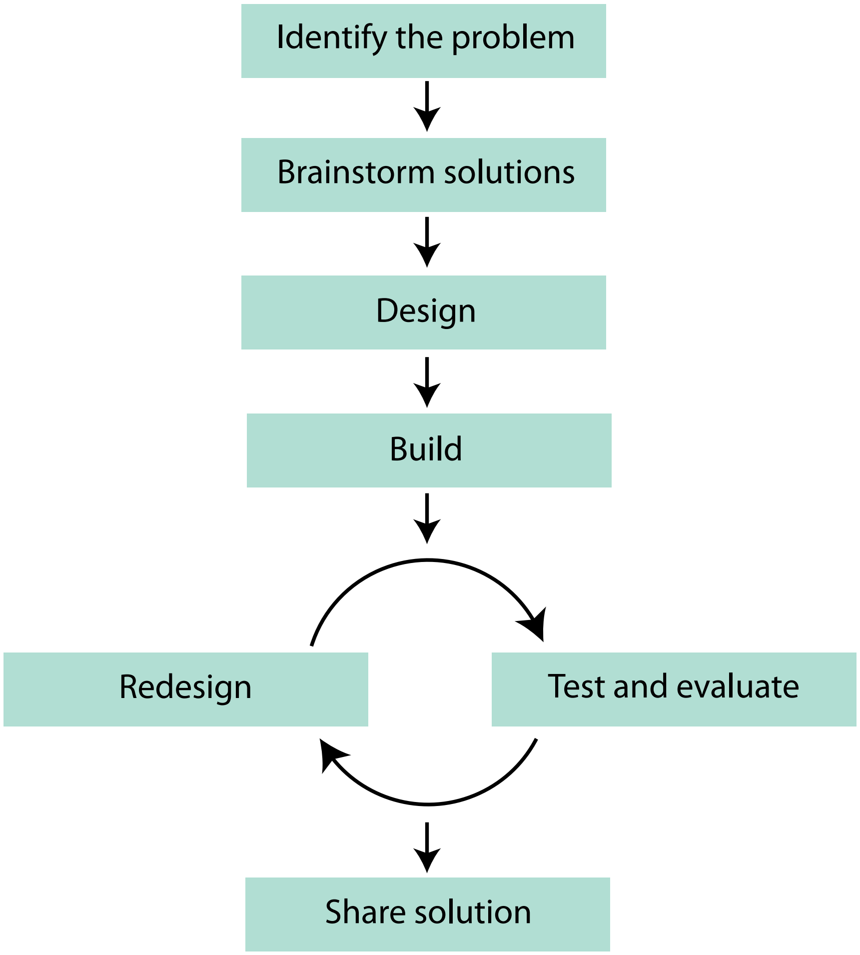
EVALUATION OF HAND WARMER DESIGN

Hand warmer engineers: *Maia and Tim*

Criteria and constraints	Does the design meet the criterion or constraint?	Evidence for or against
Is contained within a sealable bag	*Yes*	*Everything was in one bag; the beads were in a smaller bag inside.*
Uses an exothermic reaction containing iron	*Yes*	*Iron + calcium chloride + beads (water).*
Reaches and maintains a temperature of 35–45°C for at least 5 min	*No*	*Hand warmer reached 40°C but started getting colder after 2 min.*
Allows the user to activate the warmer	*Yes*	*The beads were separated, and the reaction only started when we squished the beads out so they could mix with the iron and calcium chloride.*
Uses only the materials provided	*Yes*	*All the materials were the same that everyone else used.*
Uses no more than 15 cc iron filings and 15 cc calcium chloride	*Yes*	*The design had 15 cc of iron and 10 cc of calcium chloride.*

VISUAL AID 11.1

ENGINEERING DESIGN PROCESS



ENGINEERING DESIGN SOLUTIONS (ENG)

When to use this Scoring Guide:

This Scoring Guide is used when students design, evaluate, and refine solutions.

What to look for:

- Response includes a complete design relevant to the problem to be solved.
- Response includes evidence of how well the design meets criteria within the defined constraints.
- Response indicates how scientific disciplinary core ideas and crosscutting concepts relate to the successful design.

Level	Description
Level 4 Complete and correct	The student's design • meets all of the criteria within the defined constraints, AND • has further improved on the design, AND • uses relevant scientific concepts to explain why any revisions were made to optimize the design.
Level 3 Almost there	The student's design • meets all of the criteria within the defined constraints, AND • explains the relevant scientific concepts.
Level 2 On the way	The student's design • meets all of the criteria but exceeds the defined constraints OR • meets some of the criteria within the defined constraints.
Level 1 Getting started	The student's design does not meet any of the criteria.
Level 0	The student proposes no design or an irrelevant design.
x	The student had no opportunity to respond.

NGSS UNIT OVERVIEW

CHEMICAL REACTIONS

Performance Expectation 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.

Performance Expectation MS-PS1-5: Develop and use a model to describe how the total number of atoms does not change in a chemical reaction and thus mass is conserved.

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

Performance Expectation 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.

Performance Expectation 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.

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
1. **Investigation: Producing Circuit Boards** Students analyze and interpret data to compare the initial and final substances when a copper-coated circuit board is etched. This begins a series of activities that reveal patterns of changes indicating that chemical reactions have taken place.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 RST.6-8.9
2. **Laboratory: Evidence of Chemical Change** Students carry out an investigation and analyze the results to identify evidence that may indicate that a chemical change has taken place. In later activities, the patterns they observe at the macroscopic level will be explained in terms of changes at the atomic/molecular level.	MS-PS1.A MS-PS1.B	Planning and Carrying Out Investigations Analyzing and Interpreting Data Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.3
3. **Reading: Physical Changes and Chemical Reactions** Students read about observable (macroscopic) and atomic/molecular-level patterns of changes in physical and chemical properties and how they can be signs of chemical reactions. They also read about how to use logical reasoning to avoid mistaking physical changes for chemical changes. They integrate ideas in the reading with their observations of chemical changes in the previous investigation, and analyze and interpret several examples to determine whether a change is physical or chemical.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Obtaining, Evaluating, and Communicating Information Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 RST.6-8.4 RST.6-8.7 WH.6-8.9

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
4. **Modeling: Chemical Reactions at the Molecular Scale** Students use molecular models to explore the kinds and numbers of each kind of atom, as well as the arrangements of atoms, in the reactants and products of several chemical reactions. The patterns they observe demonstrate the concept of conservation of atoms in chemical reactions, as well as the relationship between changes at the atomic/molecular scale and changes in the observable properties of substances.	MS-PS1.B	Developing and Using Models Connections to Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Scale, Proportion, and Quantity Structure and Function	ELA/Literacy: RST.6-8.3
5. **Talking it Over: Physical or Chemical Change?** Students analyze and interpret information on the observable properties of substances before and after a change to determine whether the change is a physical change or a chemical reaction. This activity provides an assessment opportunity for Performance Expectation MS-PS1-2.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Systems and System Models Connections to Nature of Science: Scientific Knowledge Is Based on Empirical Evidence	Patterns	ELA/Literacy: RST.6-8.1 SL.8.1
6. **Laboratory: Comparing the Masses of Reactants and Products** Students investigate conservation of mass on a macroscopic scale. Students analyze and interpret data from two reactions to determine how the total mass of the products of a chemical reaction compares to the total mass of the reactants.	MS-PS1.B	Analyzing and Interpreting Data Connections to Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Systems and System Models Scale, Proportion, and Quantity	ELA/Literacy: RST.6-8.3
7. **Modeling: Explaining Conservation of Mass** Students use a combination of molecular modeling and mathematical computation to describe the atomic/molecular basis for mass conservation in chemical reactions. They are introduced to the law of conservation of mass and the relevance of this law to various natural phenomena. This activity provides an assessment opportunity for Performance Expectation MS-PS1-5.	MS-PS1.B	Developing and Using Models Systems and System Models Connections to the Nature of Science: Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Energy and Matter Systems and System Models Scale, Proportion, and Quantity	

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
8. **Investigation: Chemical Batteries** Students investigate how chemical energy can be transformed via a chemical process into electrical energy. After building a prototype wet cell, students brainstorm improvements and build, test, and evaluate new prototypes to meet a set of predetermined criteria within specified constraints.	MS-PS1.B MS-ETS1.B MS-ETS1.C	Constructing Explanations and Designing Solutions	Energy and Matter	ELA/Literacy: RST.6-8.3
9. **Laboratory: Thermal Energy and Reactions** Students explore chemical reactions that absorb or release thermal energy. Through classroom discussion, students are introduced to the crosscutting concept that energy and matter are conserved but can transfer within a system between reactants, products, and the environment. They are also introduced to the idea that the absorption or release of energy is caused by the rearrangement of atoms during a reaction. Some rearrangements require energy; others release it.	MS-PS1.B MS-PS3.A	Analyzing and Interpreting Data	Energy and Matter	ELA/Literacy: RST.6-8.3
10. **Design: Developing a Prototype** Students undertake a design challenge to construct and test a hand warmer device that uses the thermal energy released from an iron exothermic reaction. When testing their designs, students analyze their results and brainstorm ideas for further modification.	MS-PS1.B MS-ETS1.B MS-ETS1.C MS-PS3.A	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions	Energy and Matter	
11. **Design: Refining the Design** Students use the thermal energy release from combining iron, calcium chloride, and water to design a hand warmer. Students redesign, construct, test, and evaluate their hand warmer designs from the "Developing a Prototype" activity. A new criterion is introduced— students must consider how to control the start of the chemical reaction in their design modifications. This activity provides an assessment opportunity for Performance Expectation MS-PS1-6.	MS-PS1.B MS-ETS1.B MS-ETS1.C MS-PS3.A	Analyzing and Interpreting Data Constructing Explanations and Designing Solutions	Energy and Matter	

CHEMICAL REACTIONS (continued)

Activity Description	Disciplinary Core Ideas	Science and Engineering Practices	Crosscutting Concepts	Common Core State Standards
12. **Laboratory: Recovering Copper** Students investigate the use of reactions with three metals for reducing copper waste and reclaiming copper from the used copper etching solution produced in the first activity of the unit. Students use data from their investigation and text sources to develop an evidence- based argument for which metal is the best choice for recovering copper from the waste solution.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Planning and Carrying Out Investigations Engaging in Argument from Evidence	Patterns Energy and Matter	ELA/Literacy: WHST.6-8.1
13. **Laboratory: Another Approach to Recovering Copper** Students close the unit by applying what they have learned in previous activities to conduct a final investigation to figure out which precipitation reaction works best to remove copper from wastewater. Students analyze and interpret their data from this activity and previous activities to develop their evidence-based argument for the best choice of reactions.	MS-PS1.A MS-PS1.B	Analyzing and Interpreting Data Planning and Carrying Out Investigations Engaging in Argument from Evidence	Patterns Energy and Matter	ELA/Literacy: WHST.6-8.1

PHENOMENA, DRIVING QUESTIONS AND STORYLINE

CHEMICAL REACTIONS

This unit explores the anchoring phenomenon: Chemical reactions can be used to solve problems but can also create problems. Examples explored include combining certain substances releases a gas, combining certain substances releases energy (such thermal energy, light, electricity), and combining certain liquids results in a color change or formation of a solid. Students generate and answer questions such as: What happens when new materials are formed? How do particles combine into new substances? How can chemical reactions solve and create problems?

Phenomenon	Driving Questions	Guiding Questions	Activities	PE	Storyline/Flow (How an activity leads to subsequent activities)
Sometimes when we make a product, we get side products that we don’t want.	What are the desired products and wastes from a chemical reaction?	How are chemical processes used to produce circuit boards? (Activity 1)	1 (12, 13)	MS-PS1-2 MS-PS1-5	Chemical reactions are used to produce desirable products (circuit boards), but they also lead to production of wastes (by-products) from chemical processes. (Substances can be identified by their properties and can’t be made to just “go away.”)
When you mix some substances, they do things like fizz, change color, or change temperature.	What is happening when something fizzes, changes color, or changes temperature when you mix substances?	How can you tell if a chemical change has occurred? (Activity 2)	2, 3, 5	MS-PS1-2 MS-PS1-5 MS-PS1-6	Four common signs frequently indicate that chemical reactions have taken place.
		What is the difference between a physical and a chemical change? (Activity 3)			Careful observation of properties is needed to distinguish physical and chemical changes.
		Is the change observed a physical change or a chemical change (reaction)? (Activity 5)			In this activity, students apply what they have learned about physical and chemical changes to several scenarios.

PHENOMENA, DRIVING QUESTIONS AND STORYLINE

CHEMICAL REACTIONS (continued)

Phenomenon	Driving Questions	Guiding Questions	Activities	PE	Storyline/Flow (How an activity leads to subsequent activities)
In chemical reactions, the total amount of matter after the reaction is the same as the total amount of matter before the reaction.	How is mass conserved during a chemical reaction?	What happens to atoms and molecules during a chemical reaction? (Activity 4)	4, 6, 7	MS-PS1-2 MS-PS1-5	Atoms are reorganized and conserved in chemical reactions. Changes in the organization of particles at the atomic/ molecular scale helps to explain physical and chemical changes and to distinguish one from the other.
		What happens to the mass of the reactants during a chemical reaction? (Activity 6)			The total mass of the products of a reaction equals the total mass of the reactants.
		Why is mass always conserved in chemical reactions? (Activity 7)			The conservation of atoms during reactions explains the conservation of mass.
When you mix some chemicals, they get hot or cold or give off electricity or light.	How can chemical reactions be used to provide energy?	How can we improve the design of a chemical battery? (Activity 8)	8, 9, 10, 11	MS-PS1-2 MS-PS1-6 MS-ETS1-3 MS-ETS1-4	Changing certain variables can affect how much energy is produced from a reaction.
		What does thermal energy have to do with chemical reactions? (Activity 9)			Chemical reactions can be used to release or absorb thermal energy.
		How do engineers design and test a prototype hand warmer? (Activity 10)			Variables can be modified as a device, such as a cold pack, is designed and refined through testing.
		How can the hand warmer design prototypes be redesigned and improved? (Activity 11)			

PHENOMENA, DRIVING QUESTIONS AND STORYLINE

CHEMICAL REACTIONS (continued)

Phenomenon	Driving Questions	Guiding Questions	Activities	PE	Storyline/Flow (How an activity leads to subsequent activities)
Sometimes when we make a product, we get side products that we don't want— but we can do something about it.	How can chemical reactions be used to clean up waste?	Which metal is best at reclaiming copper from the used copper chloride solution? (Activity 12)	12, 13	MS-PS1-2 MS-PS1-5	Several chemical reactions can be used to reclaim copper, and the best reaction to use can be evaluated based on several criteria.
		What is the best option for reclaiming copper metal from the used copper chloride solution? (Activity 13)			

UNIT OVERVIEW

CHEMICAL REACTIONS

This unit explores issues related to the use and disposal of chemicals. Listed below is a summary of the activities in this unit. Note that the total teaching time is listed as 19–25 periods of approximately 45–50 minutes (approximately 4–5 weeks).

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
1. **Investigation: Producing Circuit Boards** After a brief introduction to the function of a circuit board in a computer and other electronic devices, students mask a circuit board and etch it with an acidic copper-etching solution. They then read about the etching process and consider the copper-containing waste it produces.	Properties of substances, circuit boards, evidence, trade-offs LITERACY	Obtain circuit board sample (optional); fill a beaker with water; prepare Student Sheet.		2–3
2. **Laboratory: Evidence of Chemical Change** The class reviews the safety guidelines for working with chemicals in the science classroom. They investigate five chemical changes. For each one, they identify the signs of chemical change and the elements present before and after the reactions. Students discover that in a chemical change, new substances form that have different properties from the starting substances. They are introduced to the idea that the elements in the substances at the beginning and end of the reaction are the same, but they have rearranged into new chemical combinations.	Properties of substances, chemical change, chemical reactions, evidence of reactions LITERACY	Prepare materials for the demonstrations; prepare Student Sheets.	AID A3	2
3. **Reading: Physical Changes and Chemical Reactions** Students read about both physical and chemical changes. They learn how to distinguish these two phenomena at the observable level and begin to describe how they are different at the atomic/molecular scale.	Physical vs. chemical changes at macroscopic and atomic/molecular levels, evidence of reactions, dissolving, precipitate formation LITERACY	Prepare Student Sheet.	AID A4	2
4. **Modeling: Chemical Reactions at the Molecular Scale** Students use molecular models to investigate the reactants and products of chemical reactions. They apply their experiences with the models to develop the idea that kinds of atoms and the number of each kind of atom in the reactants and products are identical.	Chemical equations, conservation of atoms, reactants, products	Prepare modeling sets.	MOD QUICK CHECK A1	1–2

CHEMICAL REACTIONS (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
5. **Talking it Over: Physical or Chemical Change?** Student groups consider six scenarios that describe changes in matter. They apply evidence and logical reasoning to develop arguments about whether each scenario describes a a physical change or a chemical reaction.	Properties of substances, chemical and physical changes, chemical reactions	Prepare Student Sheets.	AID A3 (Assessment of PE MS-PS1-2)	1–2
6. **Laboratory: Comparing the Masses of Reactants and Products** Students explore the law of conservation of mass. They conduct a precipitation reaction and measure the total mass before and after the reaction. Future activities will build on this concept as students are asked to think about the implications of conservation of atoms and mass in their investigations of chemical methods of waste treatment.	Chemical reactions, mass, reactants, products	Set up electronic balances.	QUICK CHECK A2	1
7. **Modeling: Explaining Conservation of Mass** Students are given evidence about the masses of atoms. They use this to model mass conservation as an outcome of conservation of atoms. This is tied to the concept that the copper from the "Producing Circuit Boards" activity has not gone away; it is just in a different form.	Conservation of atoms, conservation of mass	Prepare modeling sets.	MOD A1 (Assessment of PE MS-PS1-5)	1
8. **Investigation: Chemical Batteries** Students build a chemical battery that transforms chemical energy into electrical energy, which in turn powers a motor. After building an initial prototype battery, students are given a set of criteria and constraints and asked to design a chemical battery that spins faster than the initial prototype for at least 5 min. Students brainstorm, build, test, and evaluate their prototypes.	Energy transformation, batteries, design criteria and constraints	Prepare Student Sheet.		1–2
9. **Laboratory: Thermal Energy and Reactions** Students set up two chemical reactions, measuring the temperature of the reactants and products. They use their measurements to identify which reaction releases and which absorbs energy.	Thermal energy, energy change as evidence of reactions, endothermic and exothermic reactions		AID A1	1–2

CHEMICAL REACTIONS (continued)

Activity Description	Topics	Advance Preparation	Assessment	Teaching Periods
10. **Design: Developing a Prototype** Students design a hand warmer and then construct, test, and evaluate a prototype.	Engineering design, criteria, constraints, prototypes, thermal energy, energy transfer, exothermic reactions	Prepare the demonstration hand warmer; prepare the pre-swelled beads 24 hours in advance; prepare Student Sheet.	QUICK CHECK A4	1–2
11. **Design: Refining the Design** Students brainstorm new designs that will allow users to start the chemical reaction when they want to use the hand warmer. These designs may be redesigns of those developed in the previous activity or may be totally new. Students discuss designs and choose one to build as a prototype. Pairs of students exchange prototypes, and test and evaluate them. Students then think about how to further modify their designs.	Engineering design, criteria, constraints, prototypes, thermal energy, energy transfer, exothermic reactions	Prepare the demonstration hand warmer; prepare more pre-swelled beads 24 hours in advance, if needed; prepare Student Sheet.	ENG A3 (Assessment of PE MS-PS1-6)	2–3
12. **Laboratory: Recovering Copper** Students compare the effectiveness of three different metals in extracting copper from the used copper chloride solution from the activity "Producing Circuit Boards." After determining which of the metals removes copper ions from the solution, they examine cost- and health- related information to inform their decisions of which metal to use.	Metal replacement, chemical waste, reclaiming metal waste	Fill empty labeled dropper bottles with used etching solution; set up the copper dilutions series; prepare Student Sheet.	E&T A3	2
13. **Laboratory: Another Approach to Recovering Copper** Students compare two double-replacement reactions for recovering the copper waste. They apply what they have learned in this activity and the previous activity to decide which reaction works best to reclaim the copper.	Metal replacement, chemical waste, reclaiming metal waste LITERACY	Refill dropper bottles with used etching solution; set up the control filtration; prepare Student Sheet.	E&T A2	1