4

Chain Reaction: Energy in Motion

NGSS EARLY IMPLEMENTERS

WestEd

A Collaboration of the K–12 Alliance @ WestEd,
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Introduction

The California K–8 NGSS Early Implementation Initiative was developed by the K–12 Alliance at WestEd with close collaborative input on its design and objectives from the California State Board of Education, the California Department of Education, and Achieve. This project was designed to build local education agency (LEA) capacity to fully implement the Next Generation Science Standards (NGSS) as a core subject in the elementary grades (K–5) and as the SBE's preferred integrated model in grades 6–8.

The six-year Initiative provided teachers and administrators with in-depth, content-rich professional development to build leadership capacity and teacher acumen to deliver high-quality 3-dimensional learning for K–8 students. In addition, through collaborations among the K–12 Alliance, Achieve, and others, the LEAs in the Collaborative had opportunities to pilot test new NGSS-aligned tools, processes, assessment item prototypes, and digital and other instructional materials. The LEAs continue to serve as resources for NGSS implementation across California, and in other NGSS-adopting states as well.

This resource presents the conceptual storyline for a unit of instruction at a specific grade level, then focuses on a portion of the storyline called a learning sequence. The learning sequence uses the three dimensions of the NGSS (disciplinary core ideas—DCI; science and engineering practices—SEP; and crosscutting concepts—CCC) to build and deepen student understanding of natural phenomena and design challenges.

Participants in the CA NGSS K–8 Early Implementation Initiative developed and field-tested the lessons in the learning sequence.

Overview

The anchoring phenomenon for this unit is: A Rube Goldberg® machine stalls. In this unit, students recognize that energy transfers and transforms in everyday life as they explore the flow of energy within and between systems. They identify observable changes that occur, where the energy comes from, and where the energy goes. Students investigate energy transfer from place to place and recognize that the faster an object is moving the more energy it possesses. Students investigate energy transformation as the energy source is converted in its actions and apply their understanding by designing a device that transforms energy.

The Performance Expectation(s) addressed in this unit are:

4-PS3-1 Use evidence to construct an explanation relating the speed of an object to the energy of that object.

4-PS3-2 Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-3	Ask questions and predict outcomes about the changes in energy that occur when objects collide.
4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.

Learning Sequence Narrative

The learning sequence narrative briefly describes what students do in each lesson and links the learning between the lessons as a conceptual storyline. At the end of each lesson, students make connections to their understanding of the investigative phenomenon (and to the anchoring phenomenon if appropriate).

The investigative phenomena for the learning sequence are various Rube Goldberg® machines in which objects move. Students figure out these phenomena by:

Science and Engineering Practices (SEPs)

Asking Questions and Defining Problems

- Ask questions about what would happen if a variable is changed.
- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
- Define a simple design problem that can be solved through the development of ~~an object,~~ tool~~, process, or system~~ and includes several criteria for success and constraints on materials, time, or cost.

Developing and Using Models

- Develop a diagram or simple physical prototype to convey a proposed object, tool, ~~or process~~.
- Develop and/or use models to describe and/or predict phenomena.

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.
- Make predictions about what would happen if a variable changes.
- 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~~.

Analyzing and Interpreting Data

- Represent data in tables and/or various graphical displays (bar graphs, pictographs, and/or pie charts) to reveal patterns that indicate relationships.
- Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and or/computation.
- Use data to evaluate and refine design solutions.
- Compare and contrast data collected by different groups to discuss similarities and differences in their findings.

Constructing Explanations and Designing Solutions

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

Engaging in Argument from Evidence

- Compare and refine arguments based on an evaluation of the evidence presented.
- Construct and/or support an argument with evidence, data, ~~and/or a model~~.
- Compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.

Obtaining, Evaluating, and Communicating Information

- Communicate scientific ~~and/or technical~~ information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.

Disciplinary Core Ideas (DCIs)

PS3.A Definitions of Energy

- The faster a given object is moving the more energy it possesses.
- Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.

PS3.B Conservation of Energy and Energy Transfer

- Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects, ~~or through sound, light, or electrical currents.~~ Energy can be converted from one form to another form.
- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion.
- Energy can also be transferred from place to place by electrical currents which can then be used to locally produce motion, sound, heat or light.

PS3.C Relationship Between Energy and Forces

- When objects collide, the contact forces transfer energy so as to change the objects' motion.

PS3.D Energy in Chemical Processes and Everyday Life

- The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use.

ETS1.A Defining and Delimiting Engineering Problems

- Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria).

Crosscutting Concepts (CCCs)

Patterns

- Similarities and differences in patterns can be used to sort, classify, communicate, ~~and analyze simple rates of change~~ for natural phenomena and designed products.

Cause and Effect

- Cause and effect relationships are routinely identified, tested, and used to explain change.

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.

Energy and Matter

- Energy can be transferred in various ways and between objects.

Introduction

The following narrative is based on the conceptual flow found at the end of this section.

Lesson 1: What's Going On?

Investigative Phenomenon: In a Tom and Jerry cartoon, objects in a chain reaction move with one initial contact.

This lesson introduces the students to the investigative phenomenon of chain reactions in a mousetrap in a Tom and Jerry cartoon (similar to a Rube Goldberg® machine) as a common experience for their learning. Students use their prior knowledge from kindergarten through third grade about force and motion to observe and describe chain reactions in terms of action (e.g., movement) and how the action occurred (e.g., forces). They explain their observations in terms of their prior knowledge about energy (DCI), cause and effect (CCC), and in how they ask questions (SEP).

Lesson 2: Oops!

Investigative Phenomenon: A Rube Goldberg® machine stalls when the paper roll doesn't knock over the glass.

In this lesson, students investigate a Rube Goldberg® machine (chain reaction) that stalls. Students compare and contrast the sections of the system that work and those that don't in terms of force, energy (as they understand it), collisions, and speed. They learn about systems (CCC) in terms of their components and interactions by investigating (SEP) their section/part of the Rube Goldberg® machine to begin to explore: what is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred? Where does it come from, what does it do, and where does it go? They look for cause and effect relationships (CCC) and patterns (CCC) in the data.

Lesson 3: Collisions and Speed

Investigative Phenomenon: In a Rube Goldberg® machine, moving objects collide with stationary objects.

In this lesson, students use the knowledge gleaned from their observations of energy transfers to describe energy in terms of speed and collisions by noticing patterns (CCC) and cause and effect relationships (CCC) They plan and conduct an investigation(SEP) about the relationship of speed and energy to collisions of objects. Students also construct an explanation using evidence (SEP) from their investigation to support the claim that faster-moving objects have more energy. Finally, they recall the failed Rube Goldberg® machine from Lesson 2: Oops! and propose a solution.

Lesson 3a: Optional Formative Assessment

Investigative Phenomenon: Bowling pins can fall even if the ball doesn't touch them directly.

Use this **optional assessment** if students need support to understand that observations can produce data as evidence, that within a system, moving objects contain energy, that the faster the object moves, the more energy it has, and that energy can be moved from place to place by moving objects. Students conduct an investigation (SEP) to continue their exploration of how energy moves and formally label this movement as energy transfer. Students continue their exploration of how contact forces transfer energy between components within a system (CCC). Students think about the questions from Lesson 2: Oops! What is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred? Where does it come from, what does it do, and where does it go?

Lesson 4: Energy Transformation

Investigative Phenomenon: Energy transfers can be observed in parts of a Rube Goldberg® machine where energy converts its action to movement, sound, electricity.

In this lesson, students test various devices (SEP) that convert an energy source into a different action (e.g. rubbing hands together to produce heat and sound). Students make observations to produce data that they analyze for trends or patterns that they will use as evidence to construct an explanation. They also learn to refine their arguments based on an evaluation of the evidence. They continue to recognize that energy can be transferred in various ways between objects and continue to ponder the system (CCC). They revisit the questions from Lesson 2: Oops! What is the system of interest? What are the parts of the system? What observable changes are taking place in the system? How is the energy transferred: Where does it come from, what does it do, and where does it go?

Lesson 5: Do-it-yourself Machines

Identified Problem: Use a Rube Goldberg® machine to solve a classroom problem.

In the last lesson of the unit, students apply their understanding of energy and its transfer/transformation in a design solution (SEP) to meet human needs. Students design a Rube Goldberg® machine that humorously solves a classroom problem (CCC) using the principles of engineering (defining a simple design problem that can be solved by the development of a tool using criteria and constraints; making observations to produce data to serve as the basis to test a design solution; applying scientific ideas and evidence to the design of a prototype tool; and comparing and evaluating solutions based on how well they meet the criteria and constraints of the design). At the end of the lesson, students recognize that a Rube Goldberg® machine is a fun but impractical use of energy. Students link different cards to show energy being used for practical purposes.

Learning Sequence 3-Dimensional Progressions

SEP PROGRESSION	
Asking Questions and Defining Problems	
Lesson 1	Accessing prior knowledge from K–2 (ask questions based on observations to find more information about the natural world), students ask questions that can be answered by an investigation.
Lessons 2 and 3	Students ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.
Lesson 4	Students ask questions to plan their investigation. They question what happens when a variable is changed and predict reasonable outcomes based on observed patterns (i.e., cause and effect relationships).

Learning Sequence 3-Dimensional Progressions (continued)

SEP PROGRESSION (continued)	
Asking Questions and Defining Problems (continued)	
Lesson 5	Students define a simple design problem that can be solved through the development of a tool that meets the criteria and constraints for the design.
Developing and Using Models	
Lessons 1 and 2	Students develop and use a model to describe the phenomenon.
Lesson 5	This practice is addressed as a background practice where students develop a simple physical prototype to convey a proposed tool.
Planning and Carrying Out Investigations	
Lesson 3	Students build on their K-2 of conducting an investigation to collaboratively produce data as evidence to support an explanation of a phenomenon. Students continue to build their understanding of the practice including using fair tests in which variables are controlled and the number of trials considered, making predictions about what would happen if a variable changes, and making observations to collect data that can be used as evidence to construct an explanation.
Lesson 4	Students continue to make observations to collect data that can be used as evidence to construct an explanation as to how energy is transferred or transformed.
Lesson 5	Students use their observations to produce data to test a design solution.
Analyzing and Interpreting Data	
Lesson 2	Students represent data pictorially to reveal patterns that indicate relationships.
Lessons 3 and 4	Students analyze and interpret data to make sense of the phenomenon.
Lesson 5	Students use data to evaluate and refine design solutions.
Constructing Explanations and Designing Solutions	
Lesson 3	Students use evidence (observations and patterns) to construct or support their explanations.
Lesson 4	Students use their observations to find trends (patterns) in their data. They use these patterns to construct an explanation about energy transformation.
Lesson 5	Students apply scientific ideas to solve design problems. They use evidence to design a solution to a problem, and they compare solutions based on who well they meet the criteria and constraints of the design solution.

Learning Sequence 3-Dimensional Progressions (continued)

SEP PROGRESSION (continued)	
Engaging in Argument from Evidence	
Lesson 4	This SEP plays a supporting role in constructing an explanation. Students support their argument (claim) with evidence and then compare and refine their argument based on an evaluation of the data presented.
Obtaining, Evaluating, and Communicating Information	
Lesson 4	While this practice is not in the foreground of the learning sequence, it is in the background of most lessons where students are asked to communicate scientific information orally and/or in written format (mostly diagrams and charts). It is specifically addressed in Lesson 4.

DCI PROGRESSION	
Lesson 1	Forces and collisions cause things to move (from K and 3rd grade).
Lesson 2	Energy is present when there are moving objects. Energy has a source and causes an action that we can use. Energy can be moved from place to place by moving objects. Energy transfers in, within, and out of different systems.
Lesson 3	Speed and collisions affect the transfer of energy. The faster an object is moving, the more energy it possesses. When objects collide, the contract forces transfer energy so as to change the object's motion.
Lesson 3a	This optional lesson reinforces the DCIs from Lessons 2 and 3.
Lesson 4	Energy is present whenever there are moving objects, sound, light, or heat. Energy can be transferred (converted) into different actions. Energy can be transformed from place to place by electric currents to produce motion, sound, heat, or light.
Lesson 5	An "energy machine" can be designed to convert stored energy into a desired form for practical use. The expression "produce energy" typically refers to the conversion of stored energy into a desired form for practical use. Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of the solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specific criteria for success or how well each takes the constraints into account.

Learning Sequence 3-Dimensional Progressions (continued)

CCC PROGRESSION	
Patterns	
Throughout the learning sequence, students use the same questions to debrief their learning from various explorations. The answers to these questions establish patterns in a variety of ways that can be used as evidence for their explanations.	
Cause and Effect	
Lessons 1 and 2	Students identify causal relationships and use these relationships to explain change.
Lesson 3	Students identify causal relationships, speed and energy, and use these relationships to explain the change (increased speed equals increased energy).
Lesson 4	Students use the crosscutting concept of cause and effect relationships to understand a variety of energy transformations.
Lesson 5	Students test causal relationships as they design their Rube Goldberg® machine and use those relationships to explain change.
Energy and Matter	
Throughout the learning sequence, students focus on the fact that energy can be transferred in various ways and between objects.	
Lesson 1	Students begin to recognize that energy transfer occurs in the Tom and Jerry cartoon.
Lesson 2	Students continue to identify energy transfers in the Rube Goldberg® machine.
Lesson 3	Students use the crosscutting concept of energy and matter to explore the relationship between speed and energy in collisions.
Lesson 4	Students continue to recognize that energy can be transformed in various ways and between objects.
Lesson 5	Students design a Rube Goldberg® machine using this crosscutting concept.
Systems and System Models	
Throughout the learning sequence, students have various experiences with the element "a system can be described in terms of its components and their interactions."	
Lesson 2	Students are introduced to a system as a group of related parts that make up a whole, and they describe the system in terms of its components and their interactions. These two ideas are carried into Lessons 3, 4 and 5.
Lesson 3	Students describe the system in terms of speed and collisions.
Lesson 4	Students describe various energy transformations in terms of their components and interactions.
Lesson 5	Students describe the system of their own Rube Goldberg® machine.

References

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

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Grade 4 Chain Reaction: Energy in Motion Conceptual Flow

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Energy is transferred and transformed in everyday activities.

Investigative Phenomena and Identified Problem

Objects in a chain reaction move with one initial contact.	A Rube Goldberg® machine stalls when the paper roll doesn't knock over the glass.	Moving objects collide with stationary objects.	Optional assessment: Bowling pins can fall even if the ball doesn't touch them directly.	Energy in a Rube Goldberg® machine converts its actions to movement, sound, light, electricity.	Use a Rube Goldberg® machine to solve a classroom problem.
PS3.A, PS3.B, PS3.C	PS3.A, PS3.B, PS3.C	PS3.A, PS3.B	PS3.B	PS3.B	PS3.A, PS3.D, ETS1.A
Contact forces can cause chain reactions.	Contact forces cause objects to move; energy is present in moving objects.	When objects collide, energy can be transferred from one object to another.	Energy in moving objects can be transferred through collisions.	Energy is present whenever there are moving objects, sound, light, or heat. Energy can be transformed to produce motion, sound, heat, light, electricity.	"Produce energy" refers to conversion of stored energy into practical use; solutions must consider constraints and criteria.

Asking questions and defining problems

Developing and using models

Planning and carrying out investigations

Analyzing and interpreting data

Constructing explanations and designing solutions

Engaging in argument from evidence

Obtaining, evaluating, and communicating information

Cause and Effect

Energy and Matter

Patterns

Systems and System Models

What's Going On?

4.1


Image via shutterstock.com/Bottle Top Photography

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Lesson Concept

Ask questions about the contact forces and energy used to cause chain reactions.

Investigative Phenomenon

In a Tom and Jerry cartoon, objects in a chain reaction move with one initial contact.

Standards

Refer to Appendix 4.1 for NGSS, CCSS (ELA), and California ELD standards.

Storyline Link

This is the first lesson of this learning sequence and introduces the students to a phenomenon (chain reactions in a cartoon) to which they can initiate their learning. The lesson provides a common experience for students to learn what a Rube Goldberg® machine is. Students use their prior knowledge from kindergarten through grade 3 about force and motion to observe and describe chain reactions in terms of action (movement) and how the action occurred (forces). They explain their observations in terms of their prior knowledge about energy (DCI and CCC), cause and effect (CCC), and by asking questions (SEP).

In the next lessons, students compare and contrast observations from a Rube Goldberg® machine that works but then fails.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

TEACHER NOTE

The concept of energy is difficult for fourth graders to construct intuitively. Most can describe that they need energy to ride their bike or that they eat to get energy to do other things.

The unit is designed for students to describe chain reactions as something that happens because of forces (from grade 3) while starting to make connections to the word *energy*. In Lessons 1–2, it is okay if student thinking about energy is tentative; by Lesson 3: Collisions and Speed students should be using the concept to describe what they are observing.

Try to provide opportunities for students to mention energy. Here is one example of an exchange between student and teacher.

Student: The ball was moving because a contact force made it move.

Teacher: How did the force cause it to move?

Student: Somebody pushed it.

Teacher: How did the person get the motion to push it?

Students discuss possible ways that happen; they might use the word *energy*.

Teacher: (if students didn't mention energy): Describe a time when you didn't feel like moving.

Student: When I was tired; I had no energy

Teacher: Was there energy in the Rube Goldberg machine? How do you know?

Student: Yes, things moved in the Rube Goldberg machine, so there was energy.

Whenever students mention energy, conduct a discussion with probing questions about what they mean by the word, trying to tie it to their everyday life. *Expected Student Responses (ESRs): I need energy to ride my bike; my baby brother runs out of energy and falls on the floor; when our car runs out of gas, we need to get some to make the car go.*

Time

110 minutes

Part I

20 minutes Engage

Part II

45 minutes Engage

Part III

45 minutes Engage

Materials

Whole Class

- *Tom and Jerry* video (https://www.youtube.com/watch?v=GvnEBX9aedY&feature=youtu.be)

Groups (Groups of 4)

- Sentence strips
- Chart paper (or large whiteboards)
- Markers

Individual

- Science notebook

Advance Preparation

1. Gather supplies.
2. Prepare two charts: **Our Questions** and **Our Thinking So Far**. Both charts will be referred to throughout the learning sequence.
2. Test the *Tom and Jerry* video (https://www.youtube.com/watch?v=GvnEBX9aedY&feature=youtu.be) to make sure it works.

Procedure

TEACHER NOTE

This entire lesson is an Engage phase of the 5Es. The lesson is about:

1. uncovering students' prior knowledge and experience,
2. increasing students' awareness of their own relevant ideas and experiences, and
3. expanding and broadening their ideas by hearing others' ideas.

Because there are no right or wrong answers in these initial discussions, it's a good time to encourage every student to add his or her voice.

Accept answers as students provide them. It is okay to ask questions to help students clarify their thinking, but do not at this point try to change student ideas. As students move through the next lessons, there will be opportunities for them to revisit their initial thoughts and build on or modify them.

At the end of the lesson, the class will create the **Our Thinking So Far** chart. This chart will be modified as students go through the learning sequence. In some cases, thinking will be revised, changed completely, or added to.

For more information about Talk Science and the discussion types, visit: https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

Part I

Engage (20 minutes)

Ask questions about patterns and cause and effect observations of a chain reaction.

1. Introduce the lesson with this scenario: "Jenny went to the pantry to get a bag of chips. She noticed a hole in the bottom of the bag and showed it to her mom, who exclaimed, 'We've got mice! We need to get rid of them.' What do you think they might do?" Ask students to think-pair-share some ideas.
2. Ask students to discuss what criteria would make a good mousetrap and chart their ideas.

   Expected Student Responses (ESRs): One that catches the mouse without harming it; doesn't use chemicals; kills the mouse; kills quickly so the animal doesn't suffer, is small enough to fit in the cabinet, etc.)
3. Continue the scenario: "Jenny's family looked online to find some solutions and came across this video. They decided to watch it to see if it meets their criteria."
4. Play the *Tom and Jerry* video and tell students to just observe. Then replay the *Tom and Jerry* video and ask students to think about their criteria and record their observations in their science notebook.

5. ▶ (Pre-assessment of using criteria to solve problems). Ask table groups to share their observations and conduct a discussion as to whether the mousetrap met the criteria.

   Expected Student Responses (ESRs): It wasn't very efficient; in the end the mouse got away; there were no chemicals; it had too many parts, etc.

   Ask students what questions they have and what are they wondering about. Chart their responses.

Part II

Engage (45 minutes)

Ask questions about patterns and cause and effect observations of a chain reaction

6. Ask students to consider what happened and if they could make the trap better. Then replay the *Tom and Jerry* video again, asking students to carefully observe the sequence and write their observations in their science notebook. It may be helpful to pause the video, showing "chunks" to facilitate note taking.

7. Ask students to briefly share their observations with their table group by stating what they observed happening and what caused it. Encourage students to use their notes to help with their sharing.

8. Distribute sentence strips and markers to each group. Ask the groups to record actions that they agreed they observed, using cause and effect words. *ESRs: The fan caused the boat to move across the water; the cuckoo bird sawed the rope, causing it to break and make the safe fall.*

9. After the groups have recorded the actions they observed, replay the *Tom and Jerry* video again and ask if students want to add any additional actions. Provide additional sentence strips if necessary.

10. Replay the *Tom and Jerry* video one more time, and ask table groups to arrange their sentence strips in the order of the actions.

11. Call on several groups to share the order of the actions, so that the class has a sense of how others viewed the actions. It is okay if the groups don't agree.

12. Have several students share how the order of actions represents *cause and effect relationships*. For example identify a cause (fan blows) and the effect (boat moves) as well as the change: the boat was sitting in the water and did not move until the fan created the wind to make it move.

TEACHER NOTE

Reflect on students' prior knowledge about cause and effect relationships (from K–2) and how these relationships are used to explain the change. Later in the learning sequence students will test their ideas about cause and effect relationships.

Part III

Engage (45 minutes)

Ask questions about patterns and cause and effect observations of a chain reaction.

13. ▶ Provide chart paper and markers to each group and ask them to create a model of one section of the mousetrap that involves at least 3 changes. Ask them to describe how the mousetrap works in their section.

> **TEACHER NOTE**
>
> ▶ Look for their models to include a drawing of the mousetrap sections and labels for the parts. Look for some explanation of the cause and effect relationships including forces can change object speed or direction of motion (grade 3).

14. Select several groups to share their models. Ask the class to identify patterns in the models (e.g., there is always a cause and effect; there is always motion, and it changes direction and speed).

15. Ask students to individually think about any questions they have about the mousetrap. Have them share their ideas with a partner. Then ask the class to share aloud, charting their questions.

    Expected Student Responses: What is the fewest number of chain reactions you could use to make a mousetrap? What else besides forces makes a mousetrap work? How fast does a chain reaction have to be to move things? Can a chain reaction be slow? In the video, how did the windshield wipers turn on after the banana hits them? Does the mousetrap always work?

16. Using the **Our Questions** chart made in Advance Preparation, briefly discuss, using testable/non-testable criteria, which of the questions *might lead to an investigation* that would help students to understand their observations.

> **TEACHER NOTE**
>
> Reflect on the student's prior knowledge about how to generate questions based on their observations, a K–2 grade band element of asking questions.
>
> Then assess how students are thinking about questions that might lead to an investigation, a 3–5 grade band element of asking questions. The remainder of this 3–5 grade band element of asking questions (which states that students predict reasonable outcomes based on patterns such as cause and effect relationships) is NOT part of this prior knowledge prompt, but it is a skill that will be developed in this learning sequence.

TEACHER NOTE

It is okay at this point in the learning sequence if this energy discussion is tentative. Students will strengthen their ideas in the next lessons.

If the students don't mention energy, it is okay to skip Steps 17 and 18; energy will begin to be addressed in Lesson 2: Oops!

17. Build on any questions that ask about what else might be involved in the chain reaction or any question that asks about energy. Conduct a class discussion about energy by first having students talk about the word with a partner, then as a table group. Select several table groups to share their ideas about energy and chart them.

18. Ask probing questions about how they think energy might be involved in the mousetrap. Ask them to return to their models and add any ideas about energy.

19. Have students share and add their input to the **Our Thinking So Far** chart. Record how students are describing their observations based on their concepts about energy.

TEACHER NOTE

The **Our Thinking So Far** chart will be modified as students go through the learning sequence. Thinking will be revised, changed completely, or added to.

Reflect on the student ideas and take note of IF and HOW the ideas below are shared in the student models. Do not expect this language on the models at this point! Students will build their academic language over the course of the learning sequence. If these ideas are expressed in the student models, or the class chart, consider how to build on them as you facilitate the next lessons.

- Forces can change an objects speed or direction of motion (from grade 3)
- A force started the motion; contact force transfers energy.....(PS3.C)
- Energy can be moved from place to place by moving objects or through sound...... electrical currents (PS3.A)
- Energy is present whenever there are moving objects, sound... (PS3.B)
- When objects collide, energy can be transferred from one object to another (PS3.B)
- Energy can be transferred from place to place by electrical currents which can then be used locally to produce motion.....the currents may have been produced to begin with by transforming the energy of motion into electrical energy (PS3.B)

TEACHER NOTE (continued)

Also, take note of students' prior knowledge about the science and engineering practices and crosscutting concepts. Be sure to reflect on student knowledge and understanding of these elements that will be:

- asking questions that can be investigated
- using patterns to make predictions
- identifying cause and effect relationships to explain change

These will be more fully developed in the learning sequence.

References

Stem Teaching Tools. (n.d.). Talk Science Printable. Retrieved from http://stemteachingtools.org/assets/landscapes/TalkSciencePrintable.pdf

TNTuxedoBlog. (March 10, 2012). *Tom and Jerry—Rube Goldberg Fail*. Retrieved from https://www.youtube.com/watch?v=GvnEBX9aedY&feature=youtu.be

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
4-PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object. *[Assessment Boundary: Assessment does not include quantitative measures of changes in the speed of an object or on any precise or quantitative definition of energy.]*
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. *[Assessment Boundary: Assessment does not include quantitative measurements of energy.]*
4-PS3-3	Ask questions and predict outcomes about the changes in energy that occur when objects collide. [Clarification Statement: Emphasis is on the change in the energy due to the change in speed, not on the forces, as objects interact.] *[Assessment Boundary: Assessment does not include quantitative measurements of energy.]*
4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.* [Clarification Statement: Examples of devices could include electric circuits that convert electrical energy into motion energy of a vehicle, light, or sound; and, a passive solar heater that converts light into heat. Examples of constraints could include the materials, cost, or time to design the device.] *[Assessment Boundary: Devices should be limited to those that convert motion energy to electric energy or use stored energy to cause motion or produce light or sound.]*

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)

Asking Questions and Defining Problems

- K–2: Ask questions based on observations to find more information about the natural ~~and/or designed~~ world(s).
- 3–5: Ask questions that can be investigated ~~and predict reasonable outcomes based on patterns such as cause and effect relationships~~.

Developing and Using Models

- Develop and/or use models to describe and/or predict phenomena.

DISCIPLINARY CORE IDEAS (DCI)

(Note: Energy is not introduced until fourth grade, so this prior knowledge might be expressed from a student's life experiences or if they have already experienced other learning sequences in fourth grade that address energy DCIs.)

PS3.A Definitions of Energy

- Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.

Appendix 4.1

DISCIPLINARY CORE IDEAS (DCI) (continued)
PS3.B Conservation of Energy and Energy Transfer
• Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. • Energy can also be transferred from place to place by electrical currents, which can then be used locally to produce motion, sound, heat, or light.
PS3.C Relationships Between Energy and Forces
• When objects collide, the contact forces transfer energy so as to change the objects' motion.

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Cause and effect relationships are routinely identified, tested, and used to explain change.
Energy and Matter
• Matter is made of particles. • Energy can be transferred in various ways and between objects.
Patterns
• K–2: Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence.

Common Core State Standards (CCSS)

CCSS ELA WRITING
CCSS.ELA-LITERACY.W.4.8
Recall relevant information from experiences or gather relevant information from print and digital sources; take notes, paraphrase, and categorize information.

Appendix 4.1

California English Language Development (ELD) Standards

CA ELD		
Part 1.4.1 Exchanging information and ideas with others through oral collaborative conversations on a range of social and academic topics		
EMERGING	EXPANDING	BRIDGING
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you touch on the following standard as well: **P1.4.9** Expressing information and ideas in formal oral presentations on academic topics		

Oops!

4.2

Image via iStock.com/eternalcreative

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Lesson Concept

Ask questions about the contact forces and energy used to cause chain reaction.

Investigative Phenomenon

A Rube Goldberg® machine stalls when the paper roll doesn't knock over the glass.

Standards

Refer to Appendix 4.2 for NGSS, CCSS (ELA), and California ELD standards.

Storyline Link

In Lesson 1: What's Going On?, students identified cause and effect relationships in a chain reaction and analyzed a tool (mousetrap) against criteria. Students drew models of the cause and effect relationship using forces (and tentatively added energy as they understood it).

In this lesson, students investigate a Rube Goldberg® machine (chain reaction) that stalls. Students compare and contrast the sections of the system that work and those that don't in terms of force, energy (as they understand it), collisions, and speed. They look for cause and effect relationships and patterns in the data.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

Time

135 minutes

Part I

30 minutes	Engage

Part II

45 minutes	Explore

Part III

45 minutes	Explain

Part IV

15 minutes	Elaborate/Evaluate

Materials

Whole Class

- ❑ *Tom and Jerry* video (https://www.youtube.com/watch?v=GvnEBX9aedY&feature=youtu.be)
- ❑ *Audri's Rube Goldberg Monster Trap* video (https://www.waimeaelementary.org/apps/video/watch.jsp?v=111342)
- ❑ 4.2.R1: Rube Goldberg® Cartoon
- ❑ 4.2.C1: Energy Questions

Groups (Groups of 4)

- ❑ Sentence strips
- ❑ Chart paper (or large whiteboards)
- ❑ Markers

Individual

- ❑ Science notebook

Advance Preparation

1. Gather supplies.
2. Make sure the **Our Questions** chart and the **Our Thinking So Far** chart from Lesson 1: What's Going On? are available.
3. Make a chart from **4.2.C1: Energy Questions**. Note: This chart will be used in this lesson and the next lessons.
4. Preview the *Audri's Rube Goldberg Monster Trap* video.

Procedure

Part I

Engage (30 minutes)

Ask questions about the cause and effect relationships in a chain reaction that fails.

1. As a class, review the questions from the **Our Questions** chart from Lesson 1: What's Going On? Look for questions such as: *Do things like this happen in real life? Does it always work?* Explain that today students will have an opportunity to try to answer their questions.
2. Display **4.2.R1: Rube Goldberg® Cartoon** (How to Get Rid of a Mouse). Explain that while the students have just watched a cartoon, people actually do design machines that solve a simple problem in a complex way. These are called Rube Goldberg® machines, named after a man with a good sense of humor! Rube Goldberg (1883–1970) was a Pulitzer-Prize-winning cartoonist best known for his zany invention cartoons. He was born in San Francisco, graduated from the University of California, Berkeley with a degree in engineering, and went on to become a cartoonist who drew more than 50,000 cartoons. Each of his cartoons told a story, and his goal was to get readers to laugh. A Rube Goldberg® machine is "a comically involved, complicated invention, laboriously contrived to perform a simple operation."
3. Point to a question on the **Our Questions** chart that asks if Rube Goldberg® machines work in real life. Have students review their models from Lesson 1: What's Going On? What patterns did they notice? Chart their ideas. *Expected Student Responses (ESRs): Cause and effect forces caused objects to move and change direction, etc.* Discuss how these patterns might play out in a real Rube Goldberg® machine.
4. Say, "Here is a real Rube Goldberg® machine," and then play the *Audri's Rube Goldberg Monster Trap* video from the beginning to 1:38. Ask students to turn to a partner and discuss what they heard about how the Rube Goldberg® machine was going to work. Play *Audri's Rube Goldberg Monster Trap* video again, and ask students to record the sequence they think is supposed to happen in their science notebook, using cause and effect statements.
5. With a partner, ask students to compare their cause and effect statements about this Rube Goldberg® machine and some of the patterns they noticed in the **4.2.R1: Rube Goldberg® Cartoon** (Step 2). Conduct a class discussion about the patterns they expect to observe to make sure all students have a general idea of the planned actions.
6. Play the *Audri's Rube Goldberg Monster Trap* video from 2:18–2:23 (failure #2) and ask students just to observe. Play the section again. In table groups, ask students to discuss why the Rube Goldberg® machine stalled. What questions do they have?
7. Ask table groups to share their questions and wonderings and chart their responses on the **Our Questions** chart. *ESRs: Why didn't the ball push the tube to make the wine glass fall? How much force is needed to make the ball hit the tube to make the wine glass fall? The balls were bouncing around when they hit the paper roll—did that slow them so they didn't have enough strength/force/energy to hit the tube? What happened to the energy when the ball hit the tube? Why did it work from the beginning but didn't work for the paper roll section?*

Part II

Explore (45 minutes)

Compare and contrast observations of the system a successful and failed Rube Goldberg® machine in terms of cause and effect relationships.

8. Look on the chart for questions such as "Why did it work in some places and not in others?" Discuss with students their ideas for comparing and contrasting the patterns of when the monster trap worked and when it did not.

9. To observe when it works, play the *Audri's Rube Goldberg Monster Trap* video (success) from 2:37–3:15) and ask students to just observe. Then replay *Audri's Rube Goldberg Monster Trap* and ask students to record observations in their science notebook.

10. Ask students how they might compare what they observed when the Rube Goldberg® machine worked versus when it stalled. If necessary, suggest that they do what they did in Lesson 1: What's Going On? Have them use sentence strips and models to compare different sections of the Rube Goldberg® machine.

TEACHER NOTE

Steps 11–14 are designed to build interdependence in the classroom. Half the room will create cause and effect statements for the successful Rube Goldberg® machine; the other half of the room will create a cause and effect statement for the failed Rube Goldberg® machine. Then groups will compare their sentence strips. The strips should be very similar to each other up to the point of the paper roll hitting the swivel tube. In the failed Rube Goldberg® machine, the sequence ends here. In the successful Rube Goldberg® machine, the sequence continues to the wine glass, release of the ball, and the cap being lowered onto the monster.

This side-by-side comparison should elicit student conversation about what is missing in the failed Rube Goldberg® machine compared to the successful Rube Goldberg® machine. Students may talk about this as force or strength, and hopefully energy. (See Step 16.)

11. Ask students what they mean by the word section, and then ask whether these sections could be considered systems. In groups, discuss whether they think sections match their understanding of what a system is (based on prior knowledge). Have groups share their ideas and come up with a class definition of what a system is. *ESRs: A group of related parts that make up the whole; the whole does more than the individual parts can do; if there is a change in a part, it can impact the whole.*

TEACHER NOTE

The 3–5 grade band of the K–12 progression for the crosscutting concept of systems and system models states, "Students understand that a system is a group of related parts that make up a whole and can carry out functions its individual parts cannot." Using prior Knowledge related to Systems and System Models from the K–2 grade band, students understand that objects and organisms can be described in terms of their parts and that systems in the natural and designed world have parts that work together.

In fourth grade, Systems and System Models is the focus Crosscutting Concept for Life Science where students learn, "A system can be described in terms of its components and their interactions." If you are teaching this learning sequence prior to a life science sequence, be sure to refer to this learning sequence so students can build on their understanding of system interactions when exploring systems in other science domains. In this way they will see that the crosscutting concepts really do help in making meaning across all science domains. If students have already experienced a life science learning sequence and have explored interactions in systems from a life science context, be sure to make explicit connections to that learning.

12. Ask partners to discuss why looking at a system might help them understand why the Rube Goldberg® machine worked in some parts but not as a whole. *ESRs: It might help us think about what happens in one part and how that affects the next part; it might help us observe what works in one part and why it doesn't work in another part.*

13. Divide the class into two groups: one group will look at the system that allowed the Rube Goldberg® machine to be successful; the other group will look at the system that failed. Distribute sentence strips and markers to groups. Ask students to select or be assigned a part of the system (make sure all parts are covered for both groups).

14. Ask students to write their cause and effect statements that explain the sequence on the sentence strips.

    - *ESRs for the successful Rube Goldberg® machine: Dominoes collided with each other causing the bowling pin to fall; the falling bowling pin pushes the gyroscope which hits the marker causing it to release the marble; the marble travels down the ramp and hits the switch causing the toaster to turn on. When the toaster is hot enough, it causes the lever to rise, "dumping" the ball that was in the tube; this ball collides with the other two balls to hit the paper roll, causing it to fall down and roll to the swivel tube. The swivel tube moves to knock down the wine glass with the steel ball; when it falls, it pulls on the pulley to lower the "cap," which falls on the monster and traps it.*
    - *ESRs for the failed Rube Goldberg® machine: Dominoes collided with each other causing the bowling pin to fall; the falling bowling pin pushes the gyroscope which hits the marker causing it to release the marble; the marble travels down the ramp and hits the switch causing the toaster to turn on. When the toaster is hot enough, it causes the lever to rise, "dumping" the ball that was in the tube; this ball collides with the other two balls which hit the paper roll, causing it to fall down and roll to the swivel tube and stop.*

15. Conduct a parallel sharing of the sentence strips at the front of the room using a class T-chart. Ask the successful group to share their first strip; then ask the failed group to share their first strip. (They should be similar.) Continue alternating for each step. After the step where the paper roll falls and hits the swivel tube, the failed group should be out of sentence strips, but the successful group continues to the end.

16. Debrief with the class what they noticed about the patterns in both situations. Ask the class to come to some consensus cause and effect statements about what they observed. *ESRs: There was not enough force/energy/speed at the end, but enough all the rest of the times; it needed something to stop the bigger balls from bouncing around; the collisions before helped things move along (dominoes to bowling pin to gyroscope to marker with small marble), but collisions of the big balls didn't hit the paper hard enough to get the force/energy to the tube.*

Part III

Explain (45 minutes)

Construct a model to explain the cause and effect action and the movement of energy in a Rube Goldberg® machine system.

17. Ask students what they might do to better understand how the action unfolded. Hopefully they will suggest drawing a model as they did in Lesson 1: What's Going On? If not, ask what they did to better understand the *Tom and Jerry* video.

18. Before having students create their models, return to the discussions about energy. Point to the sentence strips where the boy pushes the dominoes.

    - Ask questions such as, "What started the movement?" *ESR: The boy pushed it.* "How did the boy get the motion to push it?" *ESR: He moved his arm.* "What caused him to move his arm?" *ESR: He used his muscles.* "What do you need to move your muscles?" *ESR: Energy*
    - Scientists use the word energy whenever there is motion. Ask, "Do you think there was energy in the Rube Goldberg® machine?" *ESR: yes.* "How do you know?" *ESR: There was motion from the boy to the dominoes, and then the dominoes moved, etc.*

> **TEACHER NOTE**
>
> In this lesson, it is still okay for students to be struggling with how energy works in relationship to the contact force.

19. Provide chart paper and markers to the "part groups" to create a model just like they did in Lesson 1: What's Going On? to show how this machine operates. Ask what they might include in their model this time: *ESR: Parts of the model, labels, something that shows the motion, where is the energy.*

20. Allow groups time to work on their model, and then by table group, show the prompt on **4.2.C1: Energy Questions**: Where did the energy come from? What did it do? Where did it go? Have students consider these questions as they develop their model.

21. Select several table groups to share their models. Ask the class to compare these models to theirs. Identify what is similar and what is not similar in the models.

22. Ask students to think about what questions they have about the Rube Goldberg® machine. What are they wondering about? What else do they want to know? Chart questions on the **Our Questions** chart. *ESRs: What do we need to do to make the failed one work? Can I make it go faster? Can I get more energy into the Rube Goldberg® machine?*

Part IV

Elaborate/Evaluate (15 minutes)

Communicate information about how we know energy is present and that it moves from place to place in predictable patterns.

23. Focus on the **Our Thinking So Far** chart from Lesson 1: What's Going On? and add to or refine their thinking.

24. ▶ Tell students they are going to have an opportunity to apply what they learned in this lesson to Lesson 1: What's Going On? They will re-watch a clip of the *Tom and Jerry* video and identify observable changes in the system that provides evidence that energy is present. Provide students with the exit slip prompts: How do we know energy transferred in the system? Where does the energy come from? Where does the energy go? Then replay *Tom and Jerry* video (0:39–0:50).

25. ▶ Ask students to use words and/or pictures to answer the prompts. *ESR: The glove/hand transfers energy to the red pail each time it touches it. We know energy is transferred because we see the pail move. Then the sand falls from the pail and transfers energy to the blue pail. The blue pail is on the balance. When it fills with sand, the balance moves and hits the switch (applies a contact force), which transfers energy to the fan. The fan turns on, and the blades move, which creates wind. The wind transfers energy to the sailboat, and the sailboat and pool stick move across the pool. The pool stick hits the ball, and the contact force transfers energy, causing the ball to roll.)*

26. ▶ Collect exit slips.

TEACHER NOTE

▶ Review the exit slips to determine if students understood the targeted three dimensions of the lesson or if they need additional support or review in Lesson 3: Collisions and Speed.

References

Rube Goldberg. (2012, March 10). How to Get Rid of a Mouse! Retrieved from https://www.rubegoldberg.com/artwork/how-to-get-rid-of-a-mouse-2/.

TNTuxedoBlog. (2012, March 10). *Tom and Jerry - Rube Goldberg Fail*. Retrieved from https://www.youtube.com/watch?v=GvnEBX9aedY&feature=youtu.be.

Waimea Elementary School. (2016, April 25). *Audri's Rube Goldberg Monster Trap*. Retrieved from https://www.waimeaelementary.org/apps/video/watch.jsp?v=111342.

Toolbox Table of Contents

Energy Questions

1. What is the system of interest?

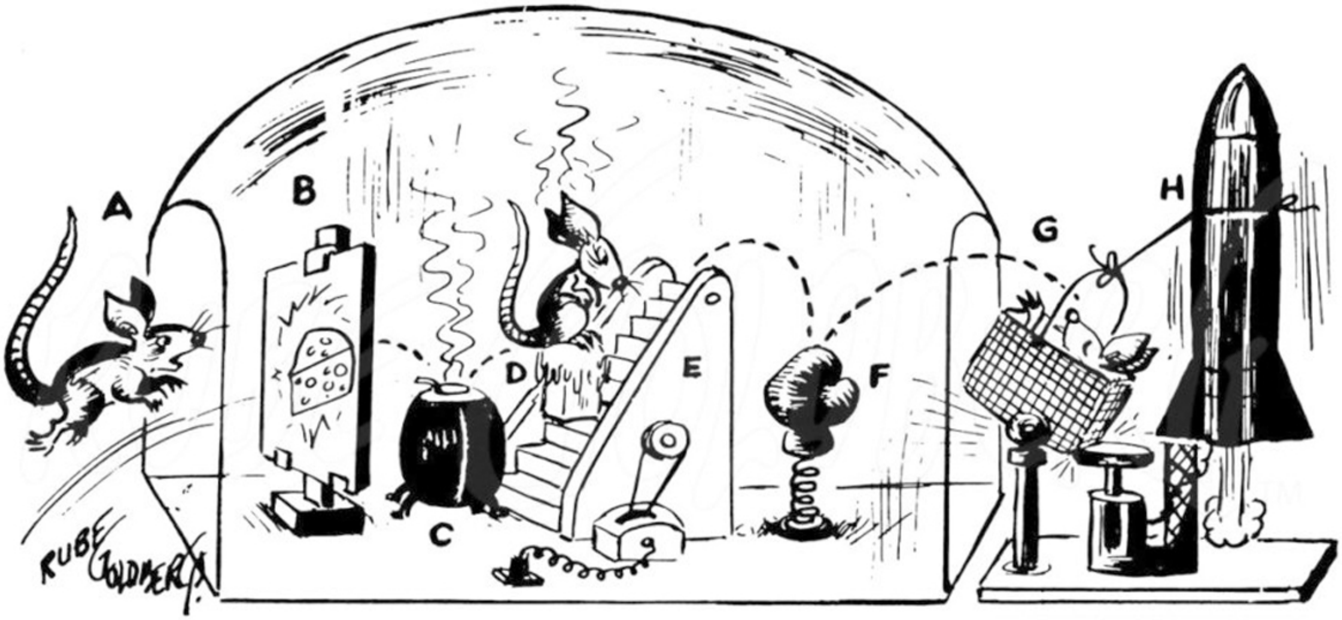
2. What are the parts of the system?

3. What observable changes are taking place in the system?

4. How is the energy transferred:
   - Where does the energy come from?
   - What does the energy do?
   - Where does the energy go?

Rube Goldberg® Cartoon

How to Get Rid of a Mouse



Drawn for Newsweek by Rube Goldberg

The best mousetrap by Rube Goldberg: Mouse (A) dives for painting of cheese (B), goes through canvas and lands on hot stove (C). He jumps on cake of ice (D) to cool off. Moving escalator (E) drops him on boxing glove (F) which knocks him into basket (G) setting off miniature rocket (H) which takes him to the moon.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
4-PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object. *[Assessment Boundary: Assessment does not include quantitative measures of changes in the speed of an object or on any precise or quantitative definition of energy.]*
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. *[Assessment Boundary: Assessment does not include quantitative measurements of energy.]*
4-PS3-3	Ask questions and predict outcomes about the changes in energy that occur when objects collide. [Clarification Statement: Emphasis is on the change in the energy due to the change in speed, not on the forces, as objects interact.] *[Assessment Boundary: Assessment does not include quantitative measurements of energy.]*
4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another. [Clarification Statement: Examples of devices could include electric circuits that convert electrical energy into motion energy of a vehicle, light, or sound; and, a passive solar heater that converts light into heat. Examples of constraints could include the materials, cost, or time to design the device.] *[Assessment Boundary: Devices should be limited to those that convert motion energy to electric energy or use stored energy to cause motion or produce light or sound.]*

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)

Asking Questions and Defining Problems

- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.

Developing and Using Models

- Develop and/or use models to describe and/or predict phenomena.

Analyzing and Interpreting Data

- Represent data in ~~tables and/or~~ various graphical displays ~~(bar graphs, pictographs, and/or pie charts)~~ to reveal patterns that indicate relationships.

Appendix 4.2

DISCIPLINARY CORE IDEAS (DCI)
PS3.A Definitions of Energy
• Energy can be moved from place to place by moving objects ~~or through sound, light, or electrical currents~~.
PS3.B Conservation of Energy and Energy Transfer
• Energy is present whenever there are moving objects, sound, light or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion.
PS3.C Relationships Between Energy and Forces
• When objects collide, the contact forces transfer energy so as to change the objects' motion.

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Cause and effect relationships are routinely identified, tested, and used to explain change.
Patterns
• Similarities and differences in patterns can be used to sort, classify, communicate, and analyze simple rates of change for natural phenomena and designed products.
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 also describe in terms of its components and their interactions.
Energy and Matter
• Energy can be transferred in various ways and between objects.

Common Core State Standards (CCSS)

CCSS ELA WRITING
CCSS.ELA-LITERACY.W.4.2
Write informative/explanatory text to examine a topic and convey ideas and information clearly.

Appendix 4.2

California English Language Development (ELD) Standards

CA ELD		
Part 1.4.1 Exchanging information and ideas with others through oral collaborative conversations on a range of social and academic topics		
EMERGING	EXPANDING	BRIDGING
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you touch on the following standard as well: **P1.4.9** Expressing information and ideas in formal oral presentations on academic topics		

Collisions and Speed

4.3

Image via iStock.com/Photoartbox

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Lesson Concept

Plan and carry out an investigation that shows the cause and effect relationship between the speed of an object and the energy it possesses.

Investigative Phenomenon

In a Rube Goldberg® machine, moving objects collide with stationary objects.

Standards

Refer to Appendix 4.3 for NGSS, CCSS (ELA), and California ELD standards.

Storyline Link

In prior lessons, students observed movement in a Rube Goldberg® machine and transitioned their conversation from contact forces to energy being present whenever there are moving objects. Students looked for cause and effect relationships that explained change within a system by identifying where the energy comes from, what the energy does, and where the energy goes.

In this lesson, students notice patterns and cause and effect relationships by observing what energy does as it transfers to describe energy in terms of speed and collisions. They plan and conduct an investigation about the relationship between speed and energy and the impact of collisions on objects. Students also construct an explanation using evidence from their investigation to support the claim that faster-moving objects have more energy. Finally, they recall the failed Rube Goldberg® machine from Lesson 2: Oops! and propose a solution.

In the next lesson, students will apply their understanding of energy to explore the transformation of energy in sound, light, or heat. They continue using cause and effect to view how energy changes.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

Time

265 minutes

Part I

10 minutes	Engage

Part II

30 minutes	Explore 1

Part III

60 minutes	Explore 2

Part IV

45 minutes	Explore 3

Part V

45 minutes	Explain

Part VI

60 minutes	Elaborate

Part VII

15 minutes	Evaluate

Materials

Whole Class

- ❑ 4.2.C1: Energy Questions (from Lesson 2: Oops!)
- ❑ 4.3.C1: Analyze Data Questions

Groups (Groups of 4)

- ❑ Chart paper or large whiteboard
- ❑ Moving objects (2 of each: marble, toy car, balls, etc.)
- ❑ Ramp (grooved meterstick or yardstick or a toy car ramp)
- ❑ Meterstick for measurement
- ❑ Textbook(s) for height

Group (Groups of 2)

- ❑ 10 marbles
- ❑ 20 dominoes
- ❑ 2 ramps (see above)
- ❑ 4 wooden blocks

Individual

- ❑ Science notebook
- ❑ 4.3.H1: Exit Ticket

Advance Preparation

1. Gather supplies
2. Have available the **Our Questions** chart and the **Our Thinking So Far** chart from Lesson 1: What's Going On? and **4.2.C1: Energy Questions** from Lesson 2: Oops!
3. Make a chart based on **4.3.C1: Analyze Data Questions** to use in Step 16.
4. Print **4.3.H1: Exit Ticket** for each student.

Procedure

Part I

Engage (10 minutes)

Answer questions and identify possible cause and effect relationships (speed of a moving object) in a Rube Goldberg® machine.

1. Refer to the **Our Questions** chart and point out questions such as *What do we need to do to make the failed one work? If I make it go faster, could it work? How can I give it more energy so it will not stall?*
2. With a partner, ask students to discuss their ideas to answer these questions. Conduct a classroom discussion and chart their ideas.

Part II

Explore 1 (30 minutes)

Carry out investigations that explore patterns of how energy can move from place to place in moving objects.

3. Offer each set of partners the materials (10 marbles, 20 dominoes, 2 ramps (rulers), 4 wooden blocks), and ask them to investigate patterns of movement using these materials. Ask students to record their setups and their observations in their science notebook.

> TEACHER NOTE
>
> This is "constructive playtime" for students to explore the ways in which these objects interact. Don't tell them what to do with the materials. Instead, look for students setting up and knocking down dominoes, using the marbles to knock down dominoes, and using the rulers and blocks as ramps for marbles to knock down the dominoes or collide with other marbles.

4. After about 15 minutes, conduct a class discussion and chart their ideas. Have partners share what they did and what they observed. What patterns did they notice? *ESRs: We had to push the marble harder to knock down more dominoes. We had to stack the dominoes closer together to knock more down. We didn't knock down as many dominoes when the marble moved slowly, etc.*

5. Ask students to relate their observations to their list of ideas from Step 2 about how to make the failed Rube Goldberg® machine work. What do these observations mean? Have them share with a partner and then discuss as a class. *ESRs: If we make it go faster, it should work. If we make it go faster, it will have more energy to make it work.*

6. What is a statement the students can make about what they think is the relationship between speed and energy? *ESR: A fast-moving object has more energy than a slow-moving one.* Write the statement on the board.

Part III

Explore 2 (60 minutes)

Collaboratively plan an investigation to explore the cause and effect relationship of the speed of an object to the energy it possesses.

7. Point to the statement the students made in Step 6 and ask how they could investigate the relationship between the speed of an object and the energy it possesses. Have students share ideas.

> **TEACHER NOTE**
>
> If students have planned an investigation before, they should be adept at identifying the phenomenon, the data that can serve as evidence, and understanding the idea of controls and variables. When scientists conduct an experiment, they test one thing at a time. The thing they change is called a *variable*. They want to see what happens when that one thing is changed. Everything else is controlled to be the same so that it does not influence their results.
>
> If this is the students' first attempt at planning an investigation, take the time to help students understand these components of planning an investigation.

8. Show the materials students have available to use for their investigation (textbooks, ramps, metersticks, marbles, toy cars, and balls). Ask them to work in partners to think about what they learned in the first Explore and how they can apply that to use these materials to test their ideas. *ESRs: When the marbles went faster, they knocked down more stuff; marbles, cars, and balls moved at different speeds. More or less speed has an impact on energy and its transfer. Things that move faster go farther and knockdown things more easily.*

9. Have several partners share their ideas with the class. If necessary, ask probing questions such as:

   a. Why are we conducting this investigation? *ESR: Trying to understand how we can make the failed Rube Goldberg® machine work; trying to see if more speed would keep the Rube Goldberg® machine from stalling.*

   b. Ask, "What would count as evidence that more speed means more energy? Does less speed mean less energy? What data would make you think this wasn't true?"

   c. Ask, "What would happen if you change the speed of the objects?" If necessary, guide them to think about how they can change the speed of marbles, toy cars or balls using ramps and textbooks. Ask students to think about what would happen if they pushed their object on a flat surface compared to it going down a ramp. Think about what would happen to their object if the ramp that was even higher/steeper.

10. Ask the following questions, provide time for students to discuss, and record their ideas on the board:

    a. Discuss the variable they think they want to change (for example, the height of the ramp).

    b. "What will they observe/measure when they change the height of the ramp?" *ESR: How far the object traveled.* "How can they measure that distance?" *ESR: With a meterstick.* "What unit should they use?" *ESR: Centimeters*

    c. "What do they need to control (keep the same)?" *ESR: The object, the ramp, the type of textbook, etc.*

11. Explain that the class is going to use the ideas on the board to collaboratively decide on a procedure to use for the experiment. Work with the class to determine a step-by-step plan that the class agrees will help make the results similar (standardized). Ask students why this type of procedure is important (so that others can replicate the experiment).

    TEACHER NOTE

    The following plan is provided as an example. Your students may construct a different way to do this investigation.

    The following items are part of the plan:

    a. Help students come up with a plan that uses the textbooks to provide height to a ramp that an object will go down. Ask: "What will this help us see?" *ESR: If speed and energy are related.*

    b. Have students predict if they think height will make a difference in how far their object travels when it goes down a ramp. Allow them time to discuss. Ask students if they think this is something they can test. If so, how? *ESR: Stack textbooks on top of one another to increase the height of the ramp.*

    c. Have students consider how the books should be stacked on top of one another. Inform them that everyone needs to come to an agreement about how the books are stacked so that they are the same. Ask them why all students need to stack the books the same way. If students struggle with this, ask: "Would it be helpful to compare our results if we did not conduct the investigation in the same way?"

    d. Ask students how many times they think they need the car to go down a ramp. They may say one time. Encourage students to think about the validity of their results with one trial and how multiple trials would provide more data. Work towards an agreement of 3 to 5 trials for each ramp height.

    e. Ask students how they should collect their data. *ESR: Organized in a table, a list, a model, etc.*

Part IV

Explore 3 (45 minutes)

Collaboratively conduct an investigation to explore the cause and effect relationship of the speed of an object to the energy it possesses.

12. Review the plan previously developed with students. Ask if there are any questions about the process or anything that may need to be changed.

13. Have students work in groups of 3 or 4 to conduct the experiment according to the plan. Monitor students to ensure they follow the plan. Make sure data is being collected and recorded.

14. After they conduct the investigation, allow students time to discuss their observations within their groups, focusing on speed and energy.

Part V

Explain (45 minutes)

Analyze data to construct an explanation of the observed cause and effect relationship between the speed of an object and its energy.

15. Create a class data chart with data from the individual groups. Ask groups to record their data on the chart.

16. As a class, discuss the questions on **4.2.C1: Energy Questions** from Lesson 2: Oops!; Where did the energy come from? What did it do? Where did it go? Then answer questions 1–3 on **4.3.C1: Analyze Data Questions**. What is the pattern they noticed? *ESR: Objects that moved faster had more energy and went farther.* What might this pattern imply?

17. Refer to the statement they made as a class in Step 6—The faster something moves the more energy it has. "What question are we trying to answer?" *ESR: Does speed increase the energy of an object?*

18. Ask the class, "What data do you have that might support this claim?" *ESR: Patterns of the data on the class chart.* "Do you have evidence from other patterns you have observed so far?" If necessary, refer them to the patterns and models they developed in Lesson 1: What's Going On? and Lesson 2: Oops!

19. Ask, "How do these patterns support the claim?" Have table groups to share their ideas. Help students to notice that they now have two sources of data (ramps and patterns in the Rube Goldberg® machine) and in both cases, the patterns in the data indicate that things that move faster have more energy. These patterns are evidence to support a claim.

20. Distribute chart paper to each table group and ask them to write a claim and the evidence that supports it using their discussion from Steps 17–19. Ask students to also record their claim and evidence statements in their science notebook.

21. Select several groups to share their claim and evidence statements.

22. Conduct a class discussion. “Is the evidence that was used appropriate to support the claim? Why or why not? Was the evidence sufficient? Why or Why not? What other evidence could be cited to make the claim stronger?”

TEACHER NOTE

The purpose of the claim and evidence at this point is to help students understand:

a. raw data is not evidence; it has to be analyzed;

b. evidence has to be appropriate to support the claim; and

c. evidence from multiple sources is more conclusive than evidence from one source.

The evidence from the experiments/investigations/videos is appropriate to the claim. The evidence could be stronger by repeating the experiments with different materials.

Part VI

Elaborate (60 minutes)

Predict outcomes about patterns in the changes in energy when objects collide.

TEACHER NOTE

For Steps 25 and 29 have groups film their tests with a tablet if possible. In that way they can watch their recordings several times during partner discussions and the class discussion.

23. Place a stationary object at the bottom of a ramp. Ask students to work with a partner to predict what would happen if they released a moving object. Tell them to use their previous claim to generate testable questions about this system of objects.

24. Provide each table group with 2 cars and a ramp. Ask students to decide how to test their questions based on their previous investigation.

25. Ask them to conduct the experiment, individually record their observations in a drawing, and label where the energy is changing—what did they observe? Remind students that we observe using our five senses. Then ask them to think about what they can observe using their hearing.

26. Have students partner with another student and discuss the collision in terms of energy changes. *Possible student discussion: The car coming down the ramp had energy. It hit the car at the bottom transferring some energy to it to make it move. The original car stopped, so it must have lost some energy.*

27. Distribute whiteboard and markers. Ask partners to divide the board in half and make a pictorial representation of their discussion on one half of the board.

28. Have groups change the height of the ramp. "What do they predict will happen? What is their evidence for this prediction?"

29. Ask them to conduct the experiment and record their observations.

30. Have partners discuss the collision and make a pictorial representation of their discussion on the other half of the board.

31. Select several partners to share their pictorial representations of the two experiments. "What was similar about the two experiments? What patterns did they notice?" *ESR: Energy was in the moving objects; when it was transferred more went into the moving object--less was in the object that stopped.* "What was different?" *ESR: The higher ramp made the car move faster, and its collision was stronger so that the car moved farther.* "Is this another pattern?"

32. Based on their data, ask students to think about what would happen if the cause (cars) were switched for balls or marbles. "Can they predict the effect? Why? How does the cause and effect relationship help them explain their prediction?"

33. ▶ Ask students to use their experiment's results to describe in their science notebook what they now think about the relationship of the moving object to how much energy it possesses and how energy can be moved from place to place by moving objects.

34. Have groups add any evidence to their chart paper and provide time for students to copy their whiteboard drawings into their science notebook.

35. Focus on the **Our Thinking So Far** chart from Lesson 1: What's Going On? and add to or refine their thinking.

Part VII

Evaluate (15 minutes)

Use evidence based on patterns to solve a problem relating the speed of an object to the energy of that object.

36. ▶ Provide students with **4.3.H1: Exit Ticket** and have students individually complete it.

37. Collect **4.3.H1: Exit Ticket** to determine if students understand the three-dimensional learning for the lesson or if they need additional support/review in the next lesson. *ESR: We learned that the faster an object is moving, the more energy it possesses. When objects collide, the energy can be transferred to another object, changing its motion. In our experiment, the higher ramp made the marbles go faster and the cars go farther. We think that if the paper roll in the Rube Goldberg® machine was positioned higher, it would roll faster with more energy to hit the lever, which would knock down the wine glass and lower the trap.*

References

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rubegoldberg.com

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Exit Ticket

Name ______________________________________

Ivan and Alyssa want to fix the stalled Rube Goldberg® machine that traps the monster. How can they use what they learned today to make the Rube Goldberg® machine successful? Cite evidence from your explorations to support your solution.

Analyze Data Questions

1. What patterns do you notice in your data?

2. Did some objects travel farther than others? Why?

3. Describe the relationship between the height of the ramp and the distance the object traveled.

4. Does your evidence support or refute your claim?

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
PS3-1	Use evidence to construct an explanation relating the speed of an object to the energy of that object. [*Assessment Boundary: Assessment does not include quantitative measures of changes in the speed of an object or on any precise or quantitative definition of energy.*]
PS3-3	Ask questions and predict outcomes about the changes in energy that occur when objects collide. [Clarification Statement: Emphasis is on the changes in energy due to changes in speed, not on the forces as objects interact.] [*Assessment Boundary: Assessment does not include quantitative measures of energy.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)

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.
- Make predictions about what would happen if a variable changes.
- 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~~.

Asking Questions and Defining Problems

- Ask questions about what would happen if a variable is changed.
- Ask questions that can be investigated and predict reasonable outcomes based on patterns such as cause and effect relationships.

Constructing Explanations and Designing Solutions

- Use evidence (e.g., ~~measurements,~~ observations, patterns) to construct or support an explanation or design a solution to a problem.

Analyzing and Interpreting Data

- Analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and or/computation.

Appendix 4.3

DISCIPLINARY CORE IDEAS (DCI)
PS3.A: Definitions of Energy
• The faster a given object is moving, the more energy it possesses.
PS3.B: Conservation of Energy and Energy Transfer
• Energy is present whenever there are moving objects, ~~sound, light, or heat~~. When objects collide, energy can be transferred from one object to another, thereby changing their motion. ~~In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.~~

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Cause and effect relationships are routinely identified, tested, and used to explain change.
Systems and System Models
• A system can be described in terms of its components and their interactions.
Energy and Matter
• Energy can be transferred in various ways and between objects.

Common Core State Standards (CCSS)

CCSS ELA SPEAKING AND LISTENING
CCSS.ELA-LITERACY.SL.1 Engage effectively in a range of collaborations.
CCSS.ELA-LITERACY.SL.4 Report on a topic or text.
CCSS.ELA-LITERACY.SL.6 Differentiate between contexts that call for formal English and situations where informal discourse is appropriate.
CCSS ELA WRITING
CCSS.ELA-LITERACY.W.8 Recall relevant information from experiences.

Appendix 4.3

California English Language Development (ELD) Standards

CA ELD		
Part 1.4.1 Exchanging information and ideas with others through oral collaborative conversations on a range of social and academic topics		
EMERGING	EXPANDING	BRIDGING
Contribute to conversations and express ideas by asking and answering *yes-no* and *wh-* questions and responding using short phrases.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, and adding relevant information.	Contribute to class, group, and partner discussions, including sustained dialogue, by following turn-taking rules, asking relevant questions, affirming others, adding relevant information, building on responses, and providing useful feedback.
In addition to the standard above, you may find that you touch on the following standard as well: **P1.4.9** Expressing information and ideas in formal oral presentations on academic topics		

Optional Formative Assessment 4.3a

Image via iStock.com/Jag_cz

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Assessment Concept

Carry out an investigation that explores how energy can move from place to place and be transferred in various ways.

Investigative Phenomenon

Bowling pins can fall even if the ball doesn't touch them directly.

Standards

Refer to Appendix 4.3a for NGSS standards.

4.3a Optional Formative Assessment

TEACHER NOTE

Use this **optional assessment** if students need support to understand that observations can produce data as evidence, that within a system, moving objects contain energy, that the faster the object moves, the more energy it has, and that energy can be moved from place to place by moving objects. **Use student work from Steps 15 and 16 to see if students better understand the learning goals.**

Time

90 minutes

Part I

20 minutes

Part II

30 minutes

Part III

20 minutes

Part IV

20 minutes

Materials

Whole Class

- ❑ 4.2.C1: Energy Questions (from Lesson 2: Oops!)
- ❑ 4.3a.R1: Bowling Alley Picture
- ❑ *2 Kids, One Dream* video (https://www.youtube.com/watch?v=5Eb_NVjFah0)

Groups (Groups of 2)

(Note: These supplies are also used in Lesson 3: Collisions and Speed).

- ❑ 10 Marbles
- ❑ 20 Dominoes
- ❑ 2 Rulers with a center groove
- ❑ 4 Wooden blocks

Individual

- ❑ *Key Concepts: Energy Basics* by Glen Phelan

Advance Preparation

1. Gather materials from Lesson 3: Collisions and Speed.
2. Have available the **4.2.C1: Energy Questions** from Lesson 2: Oops!
3. Test the *2 Kids, One Dream* video to make sure it works.
4. Determine the number of copies of the book, *Key Concepts: Energy Basics* by Glen Phelan, that you will need.

Procedure

Part I

(20 minutes)

1. Play the *2 Kids, One Dream* video. Ask students to work in partners to generate questions about their observations. Chart their questions.
2. Conduct a brief discussion as to whether the bowling video is similar to the *Tom and Jerry* and *Audri's Rube Goldberg Machine*. If so, in what ways? Chart their ideas.
3. Display **4.3a.R1: Bowling Alley Picture**. Ask students to respond to the following prompt in their science notebook: "What are the components of the system?" *ESRs: The lane, the ball, the pins.* "How do these components interact with each other?" *ESRs: The ball rolls down the lane. The ball hits the pins. When the ball hits one pin, that pin hits others.*
4. Remind students of the questions on **4.2.C1: Energy Questions**. Ask them to think about these as you replay the *2 Kids, One Dream* video.
5. Ask students to discuss in partners, then do a class share:
   a. "What was the system of interest?" *ESR: The bowling alley*
   b. "What are the parts of the system?" *ESRs: The lane, the ball, and the pins*
   c. "What observable changes are taking place in the system?" *ESR: The contact force of the ball rolling down the lane moves to the first pin it hits. When the ball hits one pin, that pin hits other pins and applies a contact force.*
   d. "How is the energy transferred?" *ESR: Each time a contact force is applied, energy transfers from one object to another*.
      - "Where did the energy come from?" *ESR: A person had to transfer energy to the system by picking up the bowling ball and rolling it down the lane.*
      - "What did the energy do?" *ESR: When the ball hits the pin, energy transferred from the ball to the pin, and the energy transfers from that pin to the next pin.*
      - "Where did the energy go?" *ESR: The last pin moves further than the others because all of its energy moves to the air instead of some energy moving to another pin.*

Part II

(30 minutes)

6. Have students recall what they learned in Lesson 3: Collisions and Speed when they explored using marbles, dominoes. and blocks.
7. Explain that students will continue to explore the transfer of energy by creating their own mini-bowling alley chain reaction system using the materials from Lesson 3: Collisions and Speed (marbles, dominoes, and rulers).

TEACHER NOTE

The chain reaction must contain two contact forces. A simple example is a marble hits a domino that hits another domino. A marble hits (energy transfer) a marble and then hits a domino. Encourage students to be as complex as they want!

8. Provide students with the following prompt: "Design a chain reaction mini-bowling alley system using these materials: marbles, dominoes, and rulers. Your system must include at least two contact forces (energy transfers)."
9. Ask students to draw a picture of their system (setup). "What components are in the chain reaction system? How many marbles, how many dominoes, and what other components are in the system?"
10. Ask students to answer these questions on their drawing: "How do the components interact? How does the chain reaction start? What is the observable evidence that energy transfers? Where does the energy go at the end of the reaction?"

TEACHER NOTE

Use students' answers to Steps 9 and 10 to look for gaps in understanding. Ask probing questions during Part III to help students refine their thinking.

Part III

(20 minutes)

11. At the end of about 20 minutes, ask students to conduct a data discussion. (See Teacher Note for more details.) Use **4.2.C1: Energy Questions** to help students share their ideas. Ask several students to share their observations. During the discussion, have students state how similar or different their answers were for how energy transferred into the chain reaction systems they created.

TEACHER NOTE

Data discussions are held after students have an opportunity to collect data. These discussions connect the investigation question with data. In this lesson, most of the student data will be qualitative. In data discussions, students grapple with discrepant or anomalous data, identify data that can serve as evidence to support a claim, and link data to a representation. During this discussion, students compare and contrast data collected by different groups in order to discuss similarities and differences in their findings.

For more information about Talk Science and the discussion types, visit
https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf
https://inquiryproject.terc.edu/shared/pd/cc/DiscussionTypes.pdf

12. At the end of the discussion, ask students what was the same about all of the chain reaction systems. *ESR: The components used; the energy transferred in all of them when objects touched/ contacted another object.* Then ask, “What was different about the chain reaction systems?”

13. Allow time for students to record any new ideas that they would like to apply to their chain reactions and anything they are still wondering about.

> **TEACHER NOTE**
>
> At this point in the lesson, content reading should be embedded. If you do not have access to the recommended book, a different book or article that contains pictures with examples of energy transfer (moving from one place to another or moving from one object to another) can be used instead.

14. Have students read Chapter 1 of *Key Concepts: Energy Basics* by Glen Phelan. Let students know that after reading, they will discuss the images using the following prompt with an elbow partner:

    a. Go back through Chapter 1 and look at each picture. “What changes are happening in each drawing or photo? What contact forces do you see being applied? How is energy being transferred?” *ESRs: Page 6: The dog has jumped in the air and stopped the motion of the Frisbee™. Page 7: The train is moving, shaking the tracks, and making noise. Page 9: The girl is diving and making a splash and noise as she enters the water.*

    b. What do you think causes that change? *ESR: Energy causes all of these changes.*

Part IV

(20 minutes)

15. ▶ Have students respond to the following prompt in their science notebook. “Using evidence from your science notebook and the reading, explain how we know that energy is transferred between the components within a system and between systems. What observable evidence do we have?” *ESRs: When things in a system move, we know that energy transferred. When the bowling ball was rolled down the lane, the person transferred energy to the ball to make it move. The ball hit the pin and energy transferred from the ball to the pin. When things are moving, it is evidence that energy transfers. In the* Tom and Jerry *video, energy transfers each time a new thing moves. When we set up our mini-bowling alley, energy transferred from the moving marble to the first domino, and then from the first domino the next domino.*

> **TEACHER NOTE**
>
> ▶ Use student answers to assess understanding.

16. ▶ Have students respond to the following prompt in their science notebook. Students can use data from their science notebook to respond. “Describe a series of actions you did in our lessons or saw happen in your life that involved energy transferring at least three times. Describe how you know energy transferred in the system. What was your observable evidence?”

    ESRs:
    Energy transfers between objects. I can observe changes in the system as evidence that energy was transferred.

    This morning when I walked to school, I opened the door and closed the door. When I got to the corner, I pressed the button for the walk light, and the walk light changed to green.

    In the video we watched (Audri’s Rube Goldberg Monster Trap), *the boy pushed the dominoes, which made the bowling pin fall, pushing the gyroscope to make the marker top push the marble down the spiral tube, into the straight tube. When the marble hit the toaster switch the energy was moved by electrical current to heat which pushed the lever up.*

References

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Bowling Alley Picture

Image by Skitterphoto via pexels.com

Appendix 4.3a

Optional Formative Assessment

Next Generation Science Standards (NGSS)

This lesson is building toward:

SCIENCE AND ENGINEERING PRACTICES (SEP)
Planning and Carrying Out Investigations
• 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~~.

DISCIPLINARY CORE IDEAS (DCI)
PS3.B Conservation of Energy and Energy Transfer
• Moving objects contain energy. The faster the object moves, the more energy it has. Energy can be moved from place to place by moving objects~~, or through sound, light, or electrical currents. Energy can be converted from one form to another form~~.

CROSSCUTTING CONCEPTS (CCC)
Systems and System Models
• A system can be described in terms of its components and their interactions.

Energy Transformation

4.4

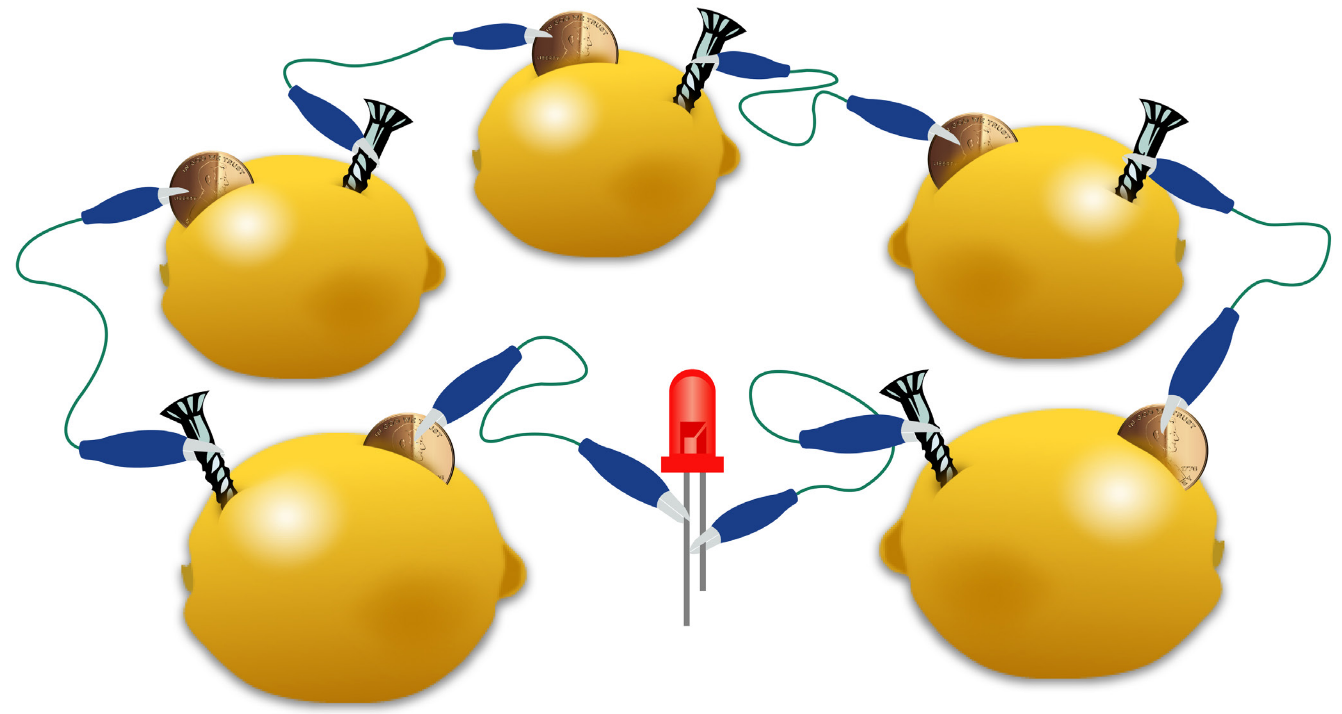


Image via WestEd

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Lesson Concept

Carry out an investigation to explore how energy moves and can be transformed between objects.

Investigative Phenomenon

Energy transfers can be observed in parts of a Rube Goldberg® machine where energy converts its action to movement, sound, electricity.

Standards

Refer to Appendix 4.4 for NGSS, CCSS (ELA), and California ELD standards.

Storyline Link

In the prior lesson, students planned and conducted investigations to explore the speed of objects during collisions in relation to the amount of energy the object possesses.

In this lesson, students test various devices that transform energy, i.e., convert its actions. They make observations to produce data that they analyze for trends or patterns that they use as evidence to construct an explanation. They also learn to refine their arguments based on an evaluation of the evidence. They continue to recognize that energy can be transferred in various ways and between objects. They also continue to define the system to describe its components and interactions.

In the next lesson, students apply what they learned in this learning sequence to design a Rube Goldberg® machine that includes energy transfers and transformations.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

Time

330 minutes (5 hours 30 minutes)

Part I	75 minutes	
	30 minutes	Engage
	45 minutes	Explore 1
Part II		
	60 minutes	Explore 2
Part III		
	90 minutes	Explain
Part IV		
	45 minutes	Elaborate
Part V		
	60 minutes	Evaluate

Materials

Whole Class

- ❑ Chart paper
- ❑ Markers
- ❑ 4.2.C1: Energy Questions (from Lesson 2: Oops!)
- ❑ 4.4.C1: Sentence Frames for Analyzing Our Data: Station 1
- ❑ *3M Rube Goldberg Machine* video (https://www.youtube.com/watch?v=GEzcO3nfjZk)
- ❑ *Audri's Rube Goldberg Monster Trap* video (https://www.waimeaelementary.org/apps/video/watch.jsp?v=111342)

Per Station (For Part II: Explore 2)

> **TEACHER NOTE**
> There are 4 possible stations for students to explore. It is recommended that they do at least 2 or 3 of the stations to experience a variety of transformations (sound, movement, and light). Decide which stations to use and obtain materials for those.

Station 1: Bean/rice with speaker

- ❑ Speaker, (see sample: https://www.amazon.com/Sylvania-SP328-Black-Portable-Bluetooth-Speaker/dp/B00YO2T6ZA/ref=sr_1_22?s=electronics&ie=UTF8&qid=1496357318&sr=1-22&keywords=speaker)
- ❑ Handful of dried beans or rice
- ❑ 4.4.R1: Station Directions: Station 1 Rice/Beans with Speaker

Station 2: Circuit With Motor and Battery

- ❑ Motor with flag or marker to see when turned on (see sample: https://shop.miniscience.com/navigation/detail.asp)
- ❑ AA Battery
- ❑ Wires (2 in each station)
- ❑ 4.4.R1: Station Directions: Circuit with Motor and Battery

Station 3: Circuit with Buzzer and Solar Panel

- ❑ Buzzer (see sample: https://shop.miniscience.com/navigation/detail.asp?id=SSS64104)
- ❑ Solar panel (see sample: http://store.sundancesolar.com/small-solar-panels/)
- ❑ Wires (2 in each station)
- ❑ 4.4.R1: Station Directions: Station 3 Circuit with Buzzer and Solar Panel

Station 4: Circuit with Light Bulb and Hand Generator

- ❑ Light bulb
- ❑ Light bulb holder
- ❑ Hand generator (See sample: https://www.amazon.com/American-Educational-7-1853-Generator-Length/dp/B00657NH7K)
- ❑ Wires (2 in each station)
- ❑ 4.4.R1: Station Directions: Station 4 Circuit with Light Bulb and Hand Generator

Per Station for Elaborate (For Part IV: Elaborate)

TEACHER NOTE

The four stations listed above can be used by changing the source of energy. In addition, the Lemon Light Bulb Circuit could be used. Select the Elaborate stations and obtain materials for those.

Lemon Light Bulb Circuit

- ❑ 5 Lemons
- ❑ 6 Short electrical wires with alligator clips
- ❑ 5 Pennies
- ❑ Sharp knife
- ❑ 5 Galvanized screws
- ❑ LEDs (at least one color)
- ❑ 4.4.R2: Station 5 How to Make a Lemon Battery

Individual

- ❑ Science notebook
- ❑ Pencils
- ❑ 4.4.H1: Energy Transformation Data Sheet

Advance Preparation

1. Decide which stations to use for the Explore (Part II) and the Elaborate phase (Part IV) and adjust time frames based on those selections.
2. Based on the selected stations, obtain the appropriate materials. Set up stations with appropriate materials and test them. Make sure to charge solar panels in the sun. Duplicate the station instructions for the 4 stations **4.4.R1: Station Directions** and put a direction sheet by each station. If you are going to use the lemon battery as a station, obtain the appropriate materials and duplicate **4.4.R2: Station 5 How to Make a Lemon Battery** for this station.
3. Make a chart titled **Questions about Rube Goldberg® Machines**.
4. Decide how to duplicate **4.4.H1: Energy Transformation Data Sheet**. EITHER provide each student with data sheets for the different stations OR place one handout at each station and have students answer the questions in their science notebook.
5. Preview the *3M Rube Goldberg Machine* video.

Procedure

TEACHER NOTE

Energy is a complex topic. Be aware of possible student misconceptions identified in the NRC Framework. "The idea that there are different forms of energy, such as thermal energy, mechanical energy, and chemical energy, is misleading, as it implies that the nature of the energy in each of these manifestations is distinct when in fact they all are ultimately, at the atomic scale, some mixture of kinetic energy, stored energy, and radiation. It is likewise misleading to call sound or light a form of energy; they are phenomena that, among their other properties, transfer energy from place to place and between objects."[1]

In fourth grade, students are expected to know that energy can be moved from place to place by moving objects or through sound, light, or electric currents. In this lesson, they focus on visible evidence to identify energy transformations: e.g., battery and wires light a light bulb; a collision of moving objects creates sound.

1. A Framework for K—12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (pages 120—122).

Part I

Engage (30 minutes)

Communicate information about patterns of energy transfers.

1. Write these words on chart paper: dominoes and marbles colliding; Audri's Rube Goldberg Machine. Ask students with a partner to review their science notebook and discuss what is similar in all the things they have learned.
2. Conduct a discussion about the students' ideas. *ESRs: All involve objects moving. All involve objects hitting something else. All involve energy being transferred from object to object. All involve faster-moving objects having more energy.*
3. Ask the class to collaboratively write a claim about how energy is transferred based on what they know so far. *ESR: Energy is present in moving objects. When they collide, energy can be transferred from one object to another, changing their motion.*

TEACHER NOTE

In the previous lessons, the students focused on energy transfer, where they observed things moving. The energy source was mechanical, and it produced movement of some kind. In this lesson, students explore other ways (e.g., sound, electrical, heat, and light) in which energy is transformed as it moves from object to object.

4. Introduce the *3M Rube Goldberg Machine* video and ask students to observe the actions. Have partners discuss their observations and then conduct a brief class discussion of what they observed.

TEACHER NOTE

Use think-pair-share strategy to get students talking and sharing ideas about their observations.

Use sentence frames to help students engage in partner conversations and a whole group share. Sentence frames can include but are not limited to:

I know that energy _____.

I noticed that _____.

I observed _____.

I agree with _____ because _____.

I want to add that _____.

Focus on energy transformations shown in the video. Prompt students, if needed, to identify where the energy comes from, what the energy does and where it goes to see energy transformation as it moves through the different objects.

5. Ask students if their claims from Step 3 explain everything they observed in the *3M Rube Goldberg Machine* video. If not, what do they still need to figure out? What questions do they have? Chart their questions on the **Questions about Rube Goldberg® Machines** chart.

Explore 1 (45 minutes)

Make observations of patterns to provide evidence that energy can be transformed as it moves from object to object.

6. Write the word transform on the board. Use the student conversation from Step 5 to clarify that **when energy is transformed, its action is converted**. Provide this example: A moving object hits something, and sound is produced.

7. Ask student partner to review their models from Lesson 2: Oops! to find the part of the system where the ball hits the switch. Ask students to discuss what their model shows. Replay the 2:46–3:04 part of the *Audri's Rube Goldberg Monster Trap* video. Ask how students could add to their model in terms of the energy being transformed. *ESR: We could add the word transform to our model. We could say the ball hit the switch, which turned on the electricity to heat up the toaster. When it was hot enough, the lever pushed up.*

8. Tell students to think more about the energy transformations that they observed. Have table groups generate other examples of where energy is transformed in daily live. *ESRs: At night, I turn on the light switch, and the lights go on. My mom turns on the gas to heat the water to make a hard-boiled egg. I flew my kite on a day when the wind made it move; etc.*

9. Facilitate a discussion about how students can get evidence that there is actually energy being transformed in these everyday situations. Ask students to brainstorm ideas, and facilitate a discussion leading to the conclusion that some of these everyday situations could be tested just as they did with the cars and ramps. They could look for patterns where energy is being transferred and transformed.

10. Explain that students have several stations they will go to try to answer their questions about energy transformations.

11. Review **4.4.H1: Energy Transformation Data Sheet**, and explain how students should record their data.

12. Divide students into groups of 3 or 4 and assign them to their station. Explain that they will do one station today and three tomorrow.

TEACHER NOTE

Modify the directions and the timing based on the number of stations you have selected for the students to explore. **These directions are based on having students explore 4 stations, spending 20 minutes at each station. Each stations should have a resources sheet at the station, which provides directions to the students.**

In Part I, preview the stations and explain the materials (about 10–15 minutes); leaving time for 1 station. In Part II, students complete the other 3 stations using a rotation system. There are instructions and guiding questions at each station.

Station 1: Rice/Beans with Speaker
Students place a handful of rice or dried beans on top of the speaker (where the sound is produced). Students observe the rice/beans moving due to the sound produced by the speaker. Energy source: speakers. Energy receiver: rice/beans. Transformation: Observable phenomenon: sound from speaker (electrical) to observable phenomenon motion of rice/beans (mechanical).

Station 2: Circuit with Motor and Battery
Students connect wires from the motor to each side of the battery to create a circuit. Students observe the motor spinning when the circuit is connected. Energy source: battery. Energy receiver: motor. Transformation: observation battery with + and - sides indicating chemical inside (chemical) to observation of wires (electrical current) to observable phenomenon motion of motor. Note: Students may not recognize chemical energy, and that is OK. **If students have never worked with complete circuits, allow extra time for them to figure out how the connections are made.**

Station 3: Circuit with Buzzer and Solar Panel
Students connect a solar panel to wires from the buzzer to create a complete circuit. Students observe the buzzer making a noise when the circuit is connected. Energy source: solar panel. Energy receiver: buzzer. Transformation: solar to electrical to sound. Note: Students may not recognize the solar energy; so ask probing questions as to how the panel was 'powered'.

TEACHER NOTE (continued)

Station 4: Circuit with Light Bulb and Hand Generator
Students place a light bulb in the light bulb holder making sure that the bottom of light bulb is touching the metal plates. Students connect the light bulb with wires and the hand generator to create a complete circuit. Students observe the light bulb turning on when the hand generator is cranked. Energy source: hand generator. Energy receiver: light bulb. Transformation: motion (mechanical) to electrical to light. Note: Students many not recognize that their hand motion (mechanical) transfers the energy to electricity, and that is OK.

13. Have students engage in the exploration at each station by the following directions on **4.4.R1: Station Directions**. Provide about 20 minutes for students to complete their station and record their observations on the **4.4.H1: Energy Transformation Data Sheet** or in their science notebook. Note that stations that involve setting up circuits might take students a little longer to do.
14. Ask students to return to their desks and clean up or revise any of their observation notes.

Part II

Explore 2 (60 minutes)

Make observations of patterns to provide evidence that energy can be transformed as it moves from object to object.

15. Explain that students will continue their station rotations from yesterday. Re-orient students to the expectations and their beginning station for today.
16. Start the investigations. At the end of 20 minutes, ask students to rotate to their next station.
17. At the end of 20 minutes, ask students to rotate to their last station.
18. At the end of 20 minutes, ask students to return to their desk and clean up or add to any of their observation notes in their science notebook. Students should have completed **4.4.H1: Energy Transformation Data Sheet** at the end of the station rotation.

Part III

Explain (90 minutes)

Analyze and use trends in data (patterns) to provide evidence that energy can be transformed between objects as sound, light, or motion.

TEACHER NOTE

Students will share their data in their groups and look for trends (patterns) that can be used as evidence that energy can be transformed.

Discussion of results from Station 1 will be conducted in a "fishbowl." A fishbowl is a way to have a group process their ideas in front of a larger group who listens to the fishbowl group's conversations. The fishbowl can be used as a way to model the kinds of discussion the other groups should be having when given the opportunity to discuss.

Then groups will conduct their discussions, and finally the class will be brought together to summarize what their results indicate. This is a good time to discuss how what they noticed in one station was similar to what they noticed in another, establishing patterns, and that these patterns can be used as evidence to support an explanation.

Depending on student discussion, this part may take 60–90 minutes and can be broken into two sections by having students discuss data from two stations during one period and then the other two stations in another period.

19. Have students form new groups of 4 students who did not do the rotations together.

20. Remind students that they are going to look at their data to see what can be used as evidence that energy can be transformed. Conduct a brief conversation about the difference between data and evidence.

TEACHER NOTE

If your students are familiar with data and evidence, this conversation should just be a review. If this is new to them, spend more time helping them see that raw data has little meaning. It has to be organized and analyzed (e.g., finding trends, deciding if it is appropriate to the claim, and if it is sufficient to make the claim) to become evidence to support or refute a claim.

21. Tell students that they are going to share their data from each station.

    a. Explain that they will use their ideas that they recorded on **4.4.H1: Energy Transformation Data Sheet** and the questions on the chart made from **4.2.C1: Energy Questions** to guide their discussions.

    b. Select a group and conduct a "fishbowl" to model how the discussions might go for Station 1.

c. Display **4.4:C1: Sentence Frames for Analyzing Our Data: Station 1**. Ask students in the group to take turns sharing their data using the prompts.

d. Encourage students to identify the patterns in the cause and effect relationship of what they observed.

e. Continue the "fishbowl" until students have made their claim.

f. Ask the class to discuss briefly in their groups if they agree with the fishbowl group's evidence and claim. Have the groups share and discuss.

22. Ask the groups to use the process they observed in the fishbowl with their own data from Stations 2, 3 and 4.

23. For each station select a group to share its claim. Help students recognize that their data from one station might be similar to that from another station. This sets up patterns that can be used as evidence to support an explanation.

24. Ask students if they think their claim would be supported by another investigation. How would they find out?

Part IV

Elaborate (45 minutes)

Make observations of a new system to provide evidence that energy can be transformed.

TEACHER NOTE

There are two options for Part IV. Choose to do one or both.

Option 1 uses materials from Stations 1–4 to have students engage in additional exploration of energy transformation by switching sources and receivers.

Option 2 extends students' learning with a different type of transformation: chemical to electrical. Use **4.4.R2: Station 5 How to Make a Lemon Battery** One setup is suggested for each group of 4 or 5 students.

25. Tell students they now have an opportunity to continue to extend their data with another exploration in which they can answer their questions about energy transformation.

a. Option 1: Have students, in small groups, continue to explore energy transformation by switching different energy sources (e.g., battery, hand generator, speaker, and solar panel) with different energy receivers (e.g., light bulb, buzzer, oobleck, and motor). Provide students with materials and have students try different pairings of energy sources and energy receivers (e.g., battery with buzzer, solar panel with light bulb, etc.).

b. Option 2: Have students explore the **4.4.R2: Station 5 How to Make a Lemon Battery** in small groups. Provide the group with the appropriate materials and instructions.

26. Whichever option is selected, have students write their observations in their science notebook and use the questions on **4.2.C1: Energy Questions** to analyze their data.

27. Have several groups share evidence that energy can be transformed.

28. Focus on the **Our Thinking So Far** chart from Lesson 1: What's Going On? and add to or refine their thinking

Part V

Evaluate (60 minutes)

Make a claim supported with evidence from several investigations that energy can be converted or transformed into sound, light, or motion.

29. Collect exit slips. Ask students to work in groups of 4 to respond to this prompt: Based on your observations at the four Explore stations and the Elaborate stations, what claim can you make about energy transformations? What evidence did you gather that supports your claim? How can you use the evidence to support your argument?

TEACHER NOTE

If necessary, use sentence frames to help students guide their conversation. For example:

Energy is ____ because ____.

Energy can_____ because____.

Energy can ____. My evidence is ____.

I observed ____, ____, ____ and ____. Therefore, I think ____.

30. Distribute poster paper and markers. Ask groups to write their claim and list their evidence to support their claim. "What patterns or trends did they notice in the different explorations? How can these patterns be used as evidence to support their claim?"

31. Select a few of the posters and have groups share. Ask other student groups to evaluate the evidence: "How strong do they think the reporting group's evidence is to support the claim? What could be done to make it stronger?"

32. ▶ Play the *3M Rube Goldberg Machine* video from 0:56-1:22. Have students discuss how their claim and evidence statements can help them to explain the flow of energy in the Rube Goldberg® machine.

TEACHER NOTE

- An example of a claim with supporting evidence might be:

Energy can be transferred from place to place. Sometimes when that happens the energy can be used locally to produce motion, sound, heat or light. In each station we explored, the energy that came into the system produced a different action. This pattern occurred in each station. For example, the energy in the battery made the motor turn. In another case, the energy in the solar panel made a buzzer make a sound, and in another case, the energy in cranking the hand generator made the light bulb go on. The energy in the speakers made the rice/beans move.

In a Rube Goldberg® machine, the energy of movement produced sound which then produced movement.

References

3M. (2015, August 3) *3M Brand Rube Goldberg Machine.* https://www.youtube.com/watch?v=GEzcO3nfjZk

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. DOI: https://doi.org/10.17226/13165. 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.

Waimea Elementary School. (2016, April 25). *Audri's Rube Goldberg Monster Trap*. Retrieved from https://www.waimeaelementary.org/apps/video/watch.jsp?v=111342.

Toolbox Table of Contents

Energy Transformation Data Sheet

Name: ____

Station 1: Rice/Beans with Speaker

1. What is happening? Draw a picture of your system and label the parts of the system.

2. Where does the energy come from? How do you know?

3. What observable changes are taking place?

4. Was there an energy transformation? How do you know?

Energy Transformation Data Sheet

Name: ____

Station 2: Circuit with Motor and Battery

1. What is happening? Draw a picture of your system and label the parts of the system.

2. Where does the energy come from? How do you know?

3. What observable changes are taking place?

4. Was there an energy transformation? How do you know?

Energy Transformation Data Sheet

Name: ______________________________________

Station 3: Circuit with Buzzer and Solar Panel

1. What is happening? Draw a picture of your system and label the parts of the system.

2. Where does the energy come from? How do you know?

3. What observable changes are taking place?

4. Was there an energy transformation? How do you know?

Energy Transformation Data Sheet

Name: ____

Station 4: Circuit with Light Bulb and Hand Generator

1. What is happening? Draw a picture of your system and label the parts of the system.

2. Where does the energy come from? How do you know?

3. What observable changes are taking place?

4. Was there an energy transformation? How do you know?

Station Directions

Station 1: Rice/Beans with Speaker

Instructions:

1. Turn on the speaker.
2. Observe what happens to the rice/beans.
3. Review and discuss with a partner the prompts on the Energy Transformation Data Sheet for Station 1.
4. Write your answers in your science notebook or on the data sheet.

Station Directions

Station 2: Circuit with Motor and Battery

Instructions:

1. Connect the battery with the wires and motor. Hold the wires from the motor onto both ends of the battery.
2. Observe what happens to the motor.
3. Review and discuss with a partner the prompts on the Energy Transformation Data Sheet for Station 2.
4. Write your answers in your science notebook or on the data sheet.

Station Directions

Station 3: Circuit with Buzzer and Solar Panel

Instructions:

1. Connect the solar panel with the wires and buzzer.
2. Observe what happens to the buzzer.
3. Review and discuss with a partner the prompts on the Energy Transformation Data Sheet for Station 3.
4. Write your answers in your science notebook or on the data sheet.

Station Directions

Station 4: Circuit with Light Bulb and Hand Generator

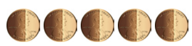
Instructions:

1. Connect the hand generator with wire and light bulb.
2. Turn the generator.
3. Observe what happens to the light bulb.
4. Review and discuss with a partner the prompts on the Energy Transformation Data Sheet for Station 4.
5. Write your answers in your science notebook or on the data sheet.

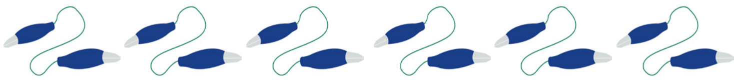
Station 5: How to Make a Lemon Battery

Things you need

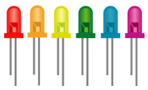
5 lemons 

5 copper pennies 

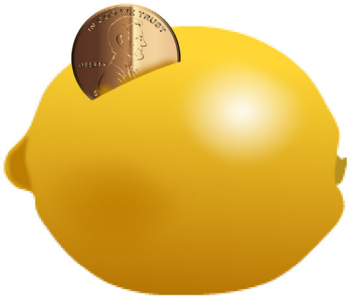
5 galvanized screws 

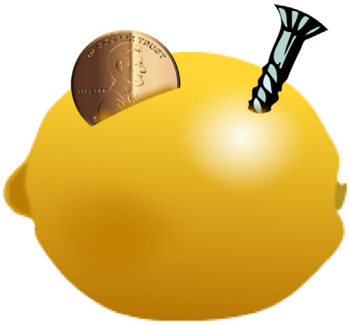
6 short electrical wires with alligator clips 

1 sharp knife 

LEDs 

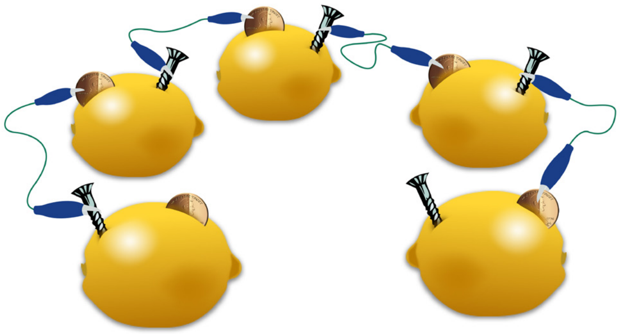
1. Roll each lemon gently on a table to break the cell walls and loosen up the juice inside. The sour juice is needed for the chemical reaction.
2. With your teacher's help, make a cut in a lemon with a knife. Cut a slit about one-half an inch from the center. Make the slit wide enough so the penny will fit and deep enough so that about half of the penny will be in the lemon.
3. Now push a penny firmly into the slit you cut.
4. Repeat Steps 2 and 3 for the other four lemons.
5. Mark a spot one-half an inch from the center on the other side, and insert a galvanized screw. Twist it in, clockwise, to secure it in the lemon flesh. Now repeat with the other four lemons.



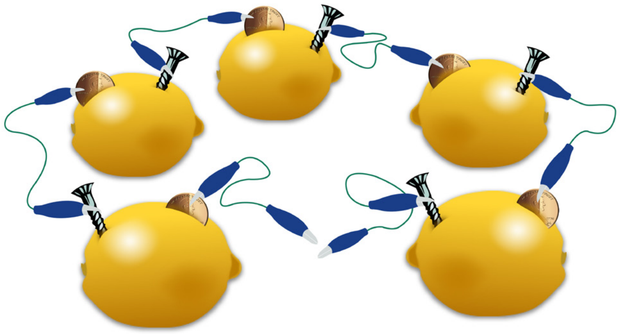


Station 5: How to Make a Lemon Battery (continued)

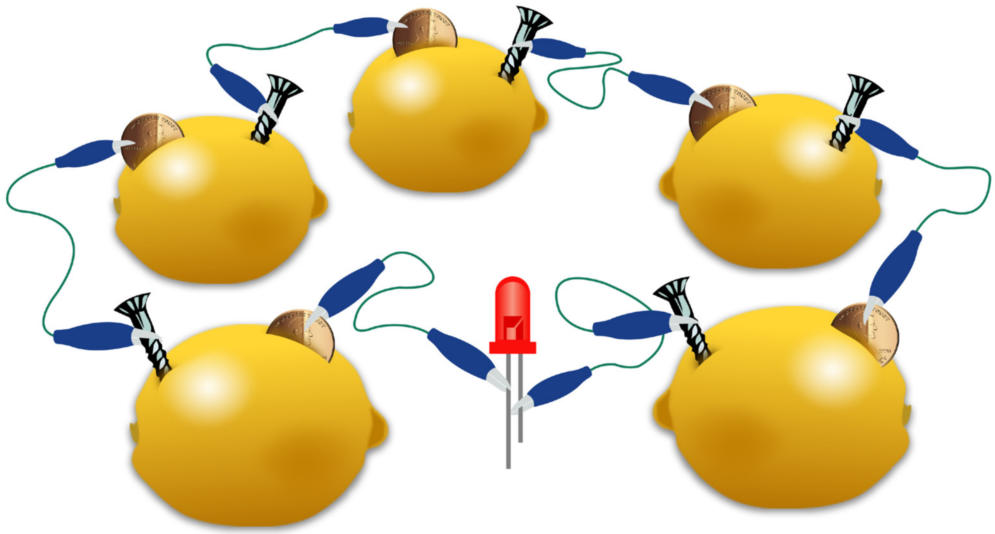
6. Now using the alligator clip wire, connect the screw in one lemon to the penny in the next lemon. Use four alligator clip wires to connect the five lemons. Arrange the lemons in a circle as shown.



7. Attached the additional two alligator clip wires to the penny in the first lemon and the galvanized screw in last lemon.



8. The LED has two legs that are slightly different lengths. With the free wire that is attached to the penny, fix the clip to the slightly longer leg of the LED. Connect the free wire from last lemon to the other leg of the LED. If the light does not come on, check all your connections (alligator clips) or try a different LED.



Sentence Frames for Analyzing Our Data

Station 1

The system we observed was ________________. It had these parts ________________. They worked together to ________________.

I observed that the rice/beans ________________ when the speaker ________________. This means that the ________________ caused the ________________ to ________________.

I agree/disagree because I noticed ________________.

I think the source of energy for Station 1 was ________________ because ________________.

I agree/disagree because I noticed ________________.

I think the energy stayed the same/changed because I noticed ________________.

I agree/disagree because I noticed ________________.

Our observations are evidence that energy transformed from ________________ to ________________ as it moved from ________________ to ________________.

OR

Our observations do not support the idea that energy can be transformed because ________________.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
4-PS3-2	Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electrical currents. [*Assessment Boundary: Assessment does not include quantitative measurements of energy.*]

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Planning and Carrying Out Investigations
• 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~~.
Constructing Explanations and Designing Solutions
• Construct an explanation of observed relationships ~~(e.g., the distribution of plants in the backyard)~~. • Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.
Engaging in Argument from Evidence
• Compare and refine arguments based on an evaluation of the evidence presented. • Construct and/or support an argument with evidence, data, ~~and/or a model~~.
Obtaining, Evaluating, and Communicating Information
• Communicate scientific and/or technical information orally and/or in written formats, including various forms of media as well as tables, diagrams, and charts.
Analyzing and Interpreting Data
• Analyze and interpret data to make sense of phenomena, using logical reasoning, ~~mathematics, and or/computation~~. • Compare and contrast data collected by different groups to discuss similarities and differences in their findings.

Appendix 4.4

DISCIPLINARY CORE IDEAS (DCI)
PS3.B: Conservation of Energy and Energy Transfer
• Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. ~~In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced.~~ • Energy can also be transferred from place to place by electrical currents which can then be used to locally produce motion, sound, heat, or light.

CROSSCUTTING CONCEPTS (CCC)
Energy and Matter
• Energy can be transferred in various ways and between objects.
Systems and System Models
• A system can be described in terms of its components and their interactions.
Cause and Effect
• Cause and effect relationships are routinely identified, tested, and used to explain change.

Common Core State Standards (CCSS)

CCSS ELA WRITING
CCSS.ELA-LITERACY.W.4.7
Conduct short research projects that build knowledge through investigation of different aspects of a topic.

Appendix 4.4

California English Language Development (ELD) Standards

CA ELD		
Part 1.4.5 Listening actively to spoken English in a range of social and academic contexts		
EMERGING	**EXPANDING**	**BRIDGING**
Demonstrate active listening of read-alouds and oral presentations by asking and answering basic questions with prompting and substantial support.	Demonstrate active listening of read-alouds and oral presentations by asking and answering detailed questions with occasional prompting and moderate support.	Demonstrate active listening of read-alouds and oral presentations by asking and answering detailed questions with minimal prompting and light support.
In addition to the standard above, you may find that you touch on the following standard as well: **P1.4.1** Exchanging information and ideas with others through oral collaborative conversations on a range of social and academic topics		

Do-it-yourself Machines

4.5

Anchoring Phenomenon

A Rube Goldberg® machine stalls.

Lesson Concept

Design, test, and refine a device that transforms energy and that shows a cause and effect relationship between the design and the desired outcome.

Identified Problem

Use a Rube Goldberg® machine to solve a classroom problem.

Standards

Refer to Appendix 4.5 for NGSS, CCSS (ELA), and California ELD standards.

Storyline Link

This is the last lesson for the Energy learning sequence in which students apply their understanding of energy and its transfer/transformations in a design solution to meet human needs. Students use the principles of engineering to design a Rube Goldberg® machine that humorously solves a common classroom problem.

In the lesson, students use elements of several practices to inform and test their design. These include: defining a simple design problem that can be solved by the development of a tool using criteria and constraints; making observations to produce data to serve as the basis to test a design solution; applying scientific ideas and evidence to the design of a prototype tool; and comparing and evaluating solutions based on how well they meet the criteria and constraints of the design.

As students design, they continue to apply what they understand about cause and effect relationships as energy is transferred in various ways and between objects.

At the end of the lesson, students recognize that a Rube Goldberg® machine is a fun but impractical use of energy. Students link different cards to show energy being used for practical purposes.

Throughout the unit, a flag (▶) denotes formative assessment opportunities where you may change instruction in response to students' level of understanding and making sense of phenomena.

Time

320 minutes (5 hours 20 minutes)

Part I	50 minutes	
	20 minutes	Engage
	30 minutes	Explore 1
Part II		
	60 minutes	Explore 2
Part III		
	60 minutes	Explore 3
Part IV		
	45 minutes	Explain
Part V		
	60 minutes	Elaborate
Part VI		
	45 minutes	Evaluate

Materials

Whole Class

- ❑ Chart paper
- ❑ 4.2.R1: Rube Goldberg® Cartoon (from Lesson 2: Oops!)
- ❑ 4.5.C1: Criteria and Constraints

Groups (Groups of 4)

- ❑ One half of a sheet of chart paper
- ❑ Chart markers
- ❑ Transparent tape
- ❑ Battery/solar panel
- ❑ Dominoes
- ❑ Motor
- ❑ Craft stick
- ❑ Eraser/pencil
- ❑ Toy cars
- ❑ Ramps
- ❑ Textbooks
- ❑ 4.5.G1: Rube Goldberg® Machine Rubric
- ❑ 4.5.G2: Energy Cards

Individual

- ❑ Science notebook

Teacher

- ❑ 4.5.R1: Relationship of Engineering Design Process and Science and Engineering Practices

Advance Preparation

1. Determine how to handle the design solution. (See Teacher Note below Step 5.)
2. Duplicate **4.5.G1: Rube Goldberg® Machine Rubric** for each student group.
3. Duplicate **4.5.G2: Energy Cards** and cut into sets of cards so that there is a set for each group of 4 students.
4. Gather materials and plan for distribution.
5. Have the **Our Questions** chart and the **Our Thinking So Far** chart from Lesson 1: What's Going On? available.

Procedure

Part I

Engage (20 minutes)

Communicate the cause and effect relationships of energy transfers and transformations in our daily lives.

1. Review the **Our Questions** chart looking for anything related to how energy is transferred/transformed in our daily lives. If there are no questions that specifically state this, refer to the stations students did in Lesson 4: Energy Transformation and ask them if they think that what they learned could be useful in the real world outside of the classroom.
2. Ask student partners to write or draw three ways in which energy transfers or transformations are useful in their everyday life. Conduct a classroom discussion using student ideas. *ESRs: Turn off a light. Pass in papers without getting out of my desk. Turn on the computer from another room. Make breakfast without having to stand in the kitchen.* Chart the students' ideas.
3. Listen for ideas that can be stated as problems to be solved, *ESRs: A student on the other side of the class needs my paper, but I can't get out of my seat; I need to cook breakfast, but can't get into the kitchen.* Select those ideas to discuss further, and/or select a couple of the ideas *ESRs: Turn on lights in a dark room.* Then work with the class to restate them as a problem to be solved. (*e.g., a movie is playing but no one can see it because the lights are too bright.*) Chart the problems to be solved.

Explore 1 (30 minutes)

Identify a problem to be solved using parts of a Rube Goldberg® machine system to transfer/transform energy.

4. Show students this prompt: "How might you design a device that converts energy for practical use in our classroom?"
    a. Say to students, "To help us think about this prompt, let's recall the **4.2.R1: Rube Goldberg® Cartoon** (from Lesson 2: Oops!). How is this similar to some of the things we have been studying? Can you identify any energy transfers (or transformations) in the cartoon?"
    b. "How can we think like Rube Goldberg to solve a classroom problem?"
5. Review the list from Step 3. If students suggest more problems to be solved, add them to the list.

TEACHER NOTE

In this lesson, the students address this problem: *A student on the other side of the classroom needs an eraser but you cannot get up from your desk.* For your classroom, you can use whatever problem statement you want and modify the lesson accordingly.

The solution design can be as open or as limited as you choose; allow the students to attempt solutions for a variety of problems or limit the problem to one students suggested.

6. Write the problem to be solved on the board: *A student on the other side of the classroom needs an eraser but you cannot get up from your desk*.

7. Conduct a brief discussion with students about what they have learned so far that may help them in designing a Rube Goldberg® machine (*e.g., energy can be transferred from place to place; energy can transform to sound, light, and electricity; the faster an object moves, the more energy it possesses*).

Part II

Explore 2 (60 minutes)

Use data/evidence of cause and effect relationships using science concepts as the basis for a design solution.

TEACHER NOTE

Students should have some experience with the engineering design process from previous problem solutions. If this is their first attempt at designing a solution, review with them the engineering design process as described in the CA Science Framework Chapter 1, pp. 65–66. http://www.cde.ca.gov/ci/sc/cf/scifwprepubversion.asp Refer to **4.5.R1: Relationship of Engineering Design Process and Science and Engineering Practices** for more information.

8. Remind students that to solve problems, we brainstorm ideas and designs based on science concepts. Engineers use this type of thinking all of the time in their work because they get paid to solve problems. When solving problems, engineers build prototypes to test, evaluate, and redesign.

9. Show the students the materials that they can use.

    a. Explain that the goal is to solve the problem using energy transfers. In this case, the problem to be solved is how to pass the eraser to a classmate by creating a Rube Goldberg® machine.

    b. Remind students that engineering design considers criteria for the design. Ask students what they think would make the design successful. Chart their ideas.

c. Remind students that engineering design considers constraints for the design. Ask students what they think would be limitations to the design. Chart their ideas.

TEACHER NOTE

Criteria are defined as what makes the design successful; constraints are limitations imposed on the design. Use **4.5.C1: Criteria and Constraints** as a reference to help guide the discussion, particularly for the criteria: it must include at least two energy transfers, one energy transformation (e.g., source is solar—action is mechanical; source is electrical—action is mechanical), and one instance where speed and collisions are factors.

If students have not done engineering, explain that often the criteria and constraints are given by the company that wants the design.

10. Ask students to work with a partner to discuss possible design ideas for a Rube Goldberg® machine (tool) to solve the problem of a student needing an eraser, making sure to incorporate the criteria and constraints.

TEACHER NOTE

You might want to provide the materials to the students to manipulate before they think of something they want to test.

11. Have partners share their ideas with another set of partners (now a group of 4). Have the group create a drawing of a design idea (a prototype of a proposed tool) that indicates where the energy transfers, transformations, and speed/collision occur.
12. Encourage students to review their science notebook to look for scientific ideas and data to support their design ideas. *ESR: We learned that a high ramp will increase the speed and the energy of an object. Therefore, we are going to use a high ramp with a marble that will collide with the eraser to move it.*
13. Have groups share their ideas and their data/evidence for those ideas. Create a class chart of the evidence. *ESRs: What makes something move? Move faster? How can one energy source cause a different action?*
14. Have groups compare the proposed solutions, and allow groups time to modify their ideas based on the class discussion. Have them draw their proposed Rube Goldberg® machine in their science notebook.

Part III

Explore 3 (60 minutes)

Test the design of a Rube Goldberg® machine system to solve the problem.

15. Ask groups to build their Rube Goldberg® machine according to their design plan. Encourage them to test several times, noting what works and what needs adjustment.

16. Ask groups to record their data in their science notebook.

Part IV

Explain (45 minutes)

Analyze data for evidence of better materials or process (cause and effect) to be used in the design.

17. Partner two groups to discuss the strengths and limitations of their designs. As they confer, they should consider: Does the design meet the criteria? Does the design meet the constraints? How effective/efficient is the design? What might they consider changing before the next testing?

18. Have partner groups offer suggestions to the other group for improvements for their design.

19. Ask the original groups to redesign based on feedback, and record the new design in their science notebook.

Part V

Elaborate (60 minutes)

Redesign, critique, and communicate how the Rube Goldberg® machine system is best designed to solve the problem.

20. Allow groups time to retest their devices and record the new data in their science notebook.

21. Have groups use the **4.5.G1: Rube Goldberg® Machine Rubric** to evaluate their redesigned machine.

22. Ask a couple of groups to share the results of their improved design by demonstrating how the machine works for the class.

23. ▶ Explain that a company is looking for this type of machine. "Why should they choose your design?" Write a paragraph, using evidence, to explain why your machine is effective and efficient in transferring energy to pass an eraser to another person.

24. Collect student paragraphs as a formative assessment of their understanding.

Part VI

Evaluate (45 minutes)

Communicate an understanding of cause and effect and systems to the practical uses of energy transfers and transformations.

TEACHER NOTE

This evaluation serves as an assessment/summary of what students understand about energy transfers. It addresses many of the three dimensions in this learning sequence.

25. Celebrate with the class their amazing Rube Goldberg® machines. Then conduct a brief conversation about the utility and efficiency of these machines, having students recognize that although they are fun, they are not practical ways to solve problems.

26. Ask students to recall conversations where they discussed energy transfers/ transformations in their daily lives. Any ideas are OK! *ESRs: Use gas to boil water to make a hard-boiled egg. Eat food to get energy to ride their bike. Put gas in the car to make the car go. Plug in the hair dryer to dry their hair. Play with a game system.*

27. Build on their conversations, saying that they will have an opportunity to link energy transformation and transfers for practical applications using a deck of cards.

28. Arrange students in groups of 4; distribute one set of **4.5.G2: Energy Cards**, a half sheet of chart paper, markers, and tape to each group. Ask groups to discuss the image on each energy card by asking, Is the object on card a source of energy? What is an action the energy does? How does the energy move?" Encourage students to use their notes from the previous lessons to add to their conversation. *There are multiple answers to this discussion. Possible ESRs: The sun is a source of energy that makes plants grow; the energy moves from the sun to the plant. The sailboat can move (action), but it needs the wind (energy source) to do so. An electric guitar can make music, if it has electricity (source) and a person to move the strings. A bicycle can move, but needs a person to pedal it, etc.*

29. Ask groups to think about a problem they would like to solve, then select the appropriate cards and use the images to create a chain reaction to solve the problem. If students struggle, suggest that they pick a card, and then select other cards that are related to the original card. *There are multiple possibilities to this activity. Possible ESRs: I need a light for camping, so I select the battery to provide the energy for my flashlight. I want to lift a pile of books from the bottom floor to my bedroom, so I select the motion card to create a pulley. I need an electrical outlet on another wall so I select the electricity card as the source, then select several other cards that can use that electricity (guitar, light, etc.).*

30. ▶ When the groups think they have a good chain reaction, ask them to tape the cards in order on the chart paper, labeling where the energy comes from, what it does, and where it goes (students may want to use arrows). Students must explain the transfer or transformation of energy in their chain reaction. *ESRs: Sun to plant to food to human or duck. Wind to kite or sailboat. Wind to windmill to electricity to guitar. Solar panel to electricity to light.*

31. Challenge groups to create additional chain reactions that could be built from their original chain reaction.

32. ▶ Select a few groups to share their chain reaction charts, noting the source of energy, how it is transferred or transformed, and the action it does. Ask the whole class if they agree with what is presented and if they have another idea of how the energy might flow. *ESR: The wind could push the sailboat, but it could also power the windmill.*

33. As a final closing to this learning sequence, ask students to review the **Our Thinking So Far** chart. What, if any, adjustments would they make to this chart?

References

Rube Goldberg. (2012, March 10). How to Get Rid of a Mouse! Retrieved from https://www.rubegoldberg.com/artwork/how-to-get-rid-of-a-mouse-2/.

California Department of Education, 2016 Science Framework. http://www.cde.ca.gov/ci/sc/cf/scifwprepubversion.asp.

Toolbox Table of Contents

Criteria and Constraints

Criteria

The design must include at least

- 2 energy transfers,
- 1 energy transformation (for example, source is solar—action is mechanical; source is electrical—action is mechanical), and
- 1 instance where speed and collisions are factors.

Constraints

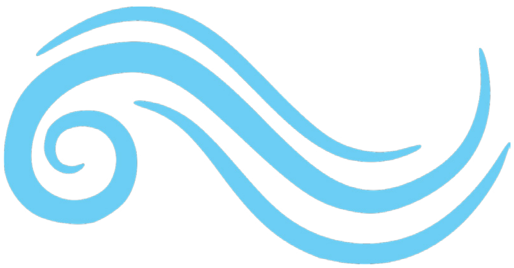
The design must

- use only the materials that are provided,
- be no larger than the top of two desks, and
- be built in _____ minutes.

Rube Goldberg® Machine Rubric

Score	4	3	2	1
Overall Design	Identifies energy transfers and transformations, labeling where the energy comes from, what it does, and where it goes.	Identifies where energy comes from, what it does, and where it goes without transfer or transformation labels.	Either labels energy transfer/ transformation OR indicates where energy comes from, what it does, and where it goes.	Uses arrows to indicate the movement of energy.
Constraints of Design	Adheres to all 3 constraints.	Adheres to 2 constraints.	Adheres to 1 constraint.	Does not adhere to any of the constraints.
Criteria for Design	Meets all 3 criteria for the design.	Meets 2 criteria for the design.	Meets 1 criterion for the design.	Does not meet the criteria for the design.

Energy Cards

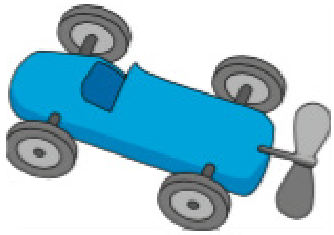


Wind

Candle

Sun

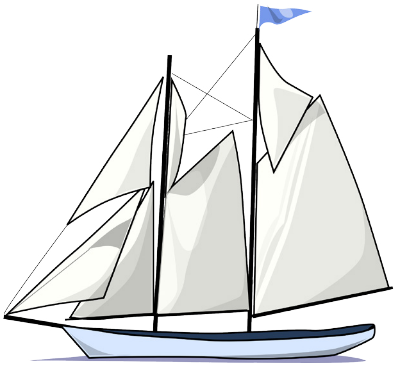
Battery



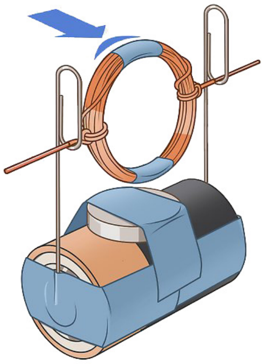
Wind-up Toy

Windmill

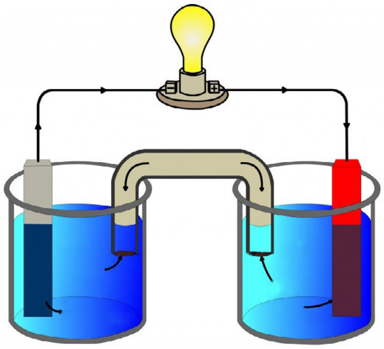
Energy Cards (continued)



Sailboat

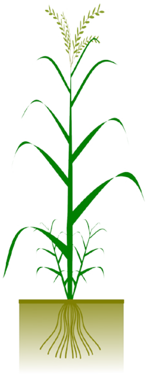


Motor

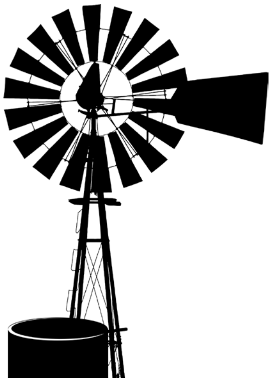


Electrical Cell

Heat

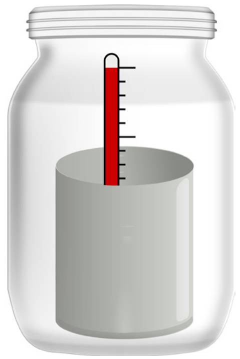


Plant



Water Pump

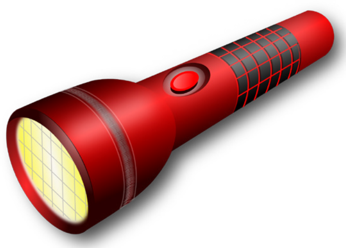
Energy Cards (continued)



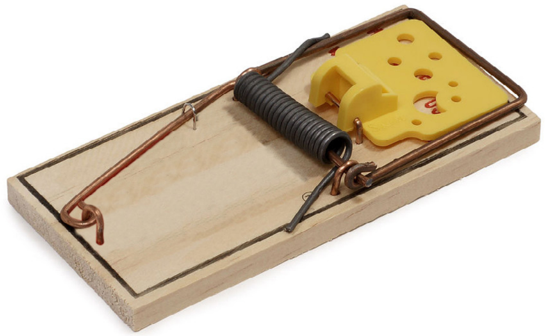
Solar Collector

Solar Panel

Guitar



Flashlight



Mousetrap

Falling Water

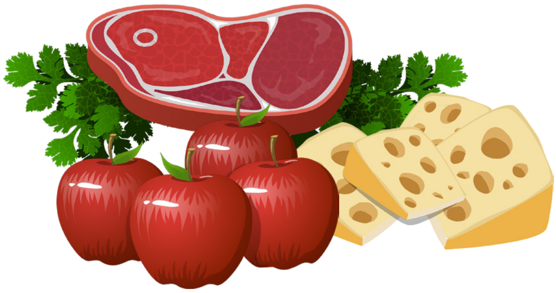
Energy Cards (continued)

Magnnifier

Light

Drill

Chemicals

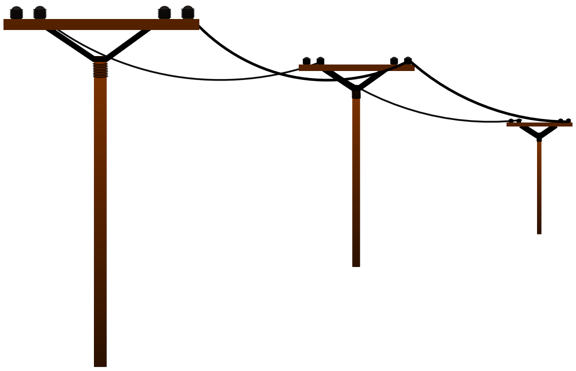


Food

Bicycle

Energy Cards (continued)

Duck

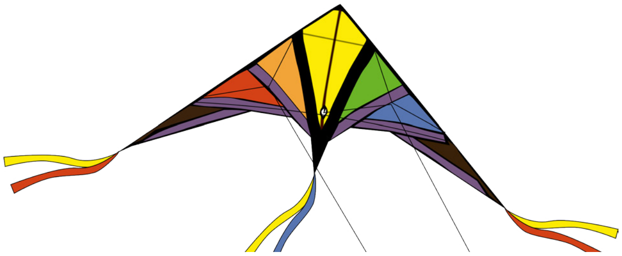


Electricity

Fire

Television Set

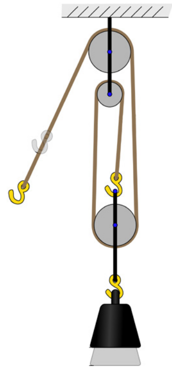
Person



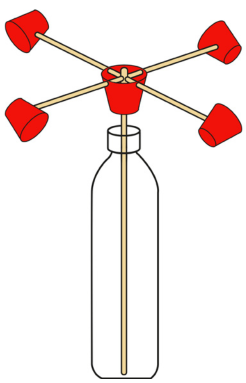
Kite

Energy Cards (continued)

Boom Box



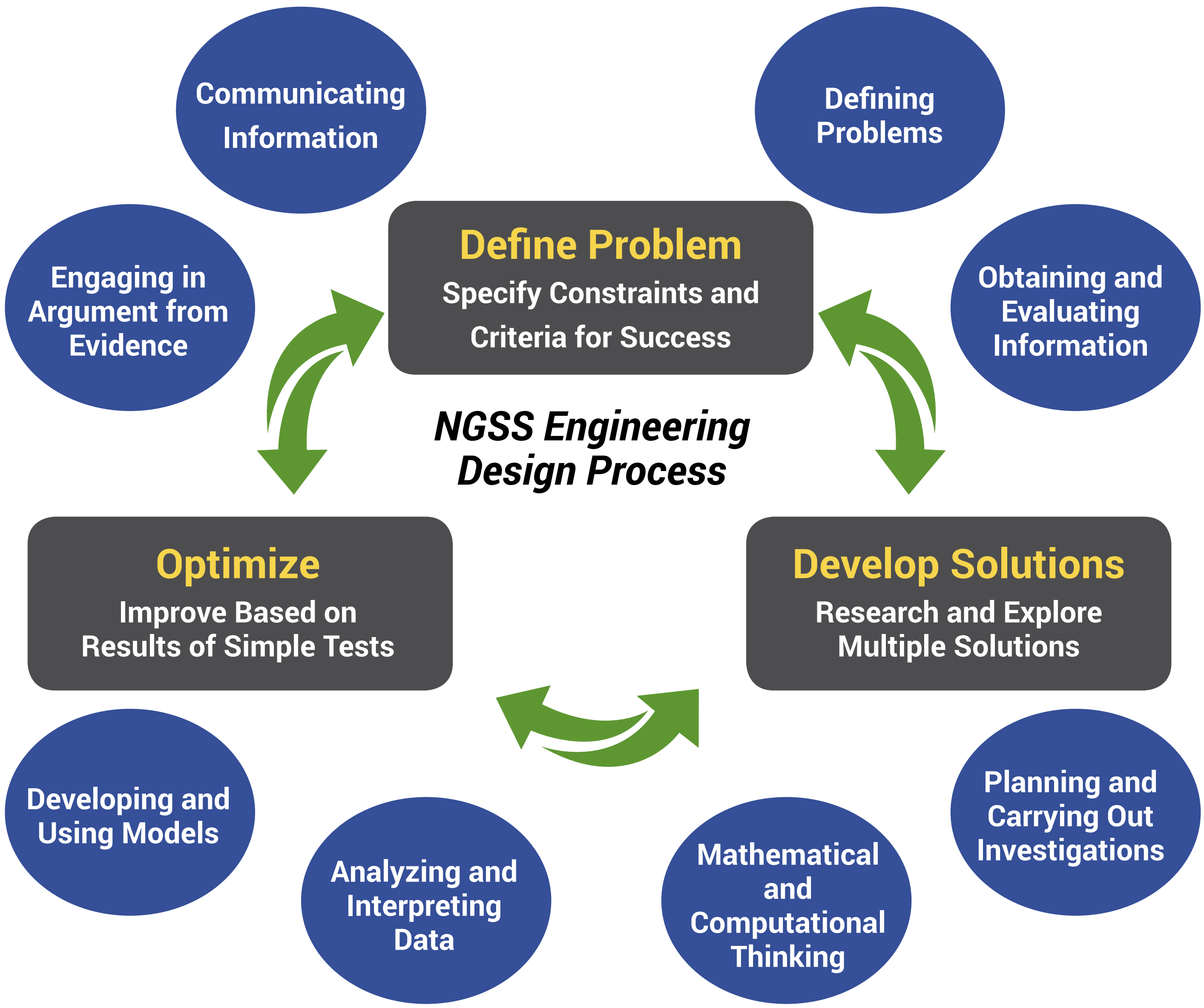
Motion



Motion Wheel

Steam

Relationship of Engineering Design Process and Science and Engineering Practices



California Department of Education, 2016 Science Framework. Chapter 1, page 55.

Next Generation Science Standards (NGSS)

This lesson is building toward:

PERFORMANCE EXPECTATIONS (PE)	
4-PS3-4	Apply scientific ideas to design, test, and refine a device that converts energy from one form to another.* [Clarification Statement: Examples of devices could include electric circuits that convert electrical energy into motion energy of a vehicle, light, or sound; and, a passive solar heater that converts light into heat. Examples of constraints could include the materials, cost, or time to design the device.] *[Assessment Boundary: Devices should be limited to those that convert motion energy to electric energy or use stored energy to cause motion or produce light or sound.]*

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

SCIENCE AND ENGINEERING PRACTICES (SEP)
Constructing Explanations and Designing Solutions
• Apply scientific ideas to solve design problems. • Use evidence (e.g., measurements, observations, patterns) to ~~construct or support an explanation or~~ design a solution to a problem. • ~~Generate and~~ compare ~~multiple~~ solutions to a problem based on how well they meet the criteria and constraints of the design solution.
Asking Questions and Defining Problems
• Define a simple design problem that can be solved through the development of ~~an object,~~ tool~~, process, or system~~ and includes several criteria for success and constraints on materials, time, or cost.
Analyzing and Interpreting Data
• Use data to evaluate and refine design solutions.
Developing and Using Models
• Develop a ~~diagram or~~ simple physical prototype to convey a proposed ~~object,~~ tool, ~~or process~~.
Planning and Carrying Out Investigations
• Make observations and or measurements to produce data to serve as the basis for evidence for an explanation of a phenomenon or to test a design solution.

Appendix 4.5

DISCIPLINARY CORE IDEAS (DCI)
PS3.A: Definitions of Energy
• Energy can be moved from place to place by moving objects or through sound, light, or electrical currents.
PS3.D: Energy in Chemical Processes and Everyday Life
• The expression “produce energy” typically refers to the conversion of stored energy into a desired form for practical use.
ETS1.A: Defining and Delimiting Engineering Problems
• Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria).

CROSSCUTTING CONCEPTS (CCC)
Cause and Effect
• Cause and effect relationships are routinely identified, tested, and used to explain change.
Energy and Matter
• Energy can be transferred in various ways and between objects.
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.

Common Core State Standards (CCSS)

CCSS ELA WRITING
CCSS.ELA-LITERACY.W.4.2 Write informative/explanatory texts to examine a topic and convey ideas and information clearly.
CCSS.ELA-LITERACY.W.4.8 Recall relevant information from experiences or gather relevant information from print and digital sources; take notes, paraphrase, and categorize information.

Appendix 4.5

California English Language Development (ELD) Standards

CA ELD		
Part 1.4.3 Offering and supporting opinions and negotiating with others in communicative exchanges		
EMERGING	**EXPANDING**	**BRIDGING**
Negotiate with or persuade others in conversations using basic learned phrases (e.g., *I think . . .*), as well as open responses, in order to gain and/or hold the floor.	Negotiate with or persuade others in conversations using an expanded set of learned phrases (e.g., *I agree with X, but . . .*), as well as open responses, in order to gain and/or hold the floor, provide counter-arguments, etc.	Negotiate with or persuade others in conversations using a variety of learned phrases (e.g., *That's a good idea. However . . .*), as well as open responses, in order to gain and/or hold the floor, provide counter-arguments, elaborate on an idea, etc.
In addition to the standard above, you may find that you touch on the following standard as well: **P1.4.1** Exchanging information and ideas with others through oral collaborative conversations on a range of social and academic topics **P1.4.9** Expressing information and ideas in formal oral presentations on academic topics **P1.4.10** Composing/writing literacy and informational text to present, describe, and explain ideas and information, using appropriate technology.		