Do-it-yourself Machines

4.5

Image via iStock.com/peepo

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.

A project of CA NGSS K–8 Early Implementation Initiative.

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

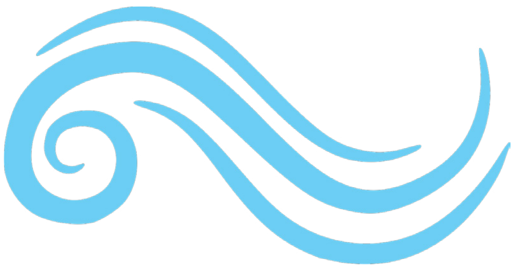
The design must

- 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

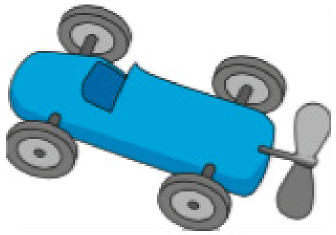


Wind

Candle

Sun

Battery

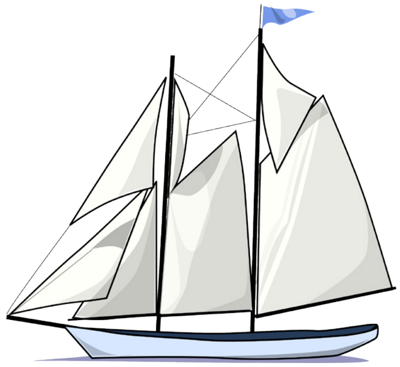


Wind-up Toy

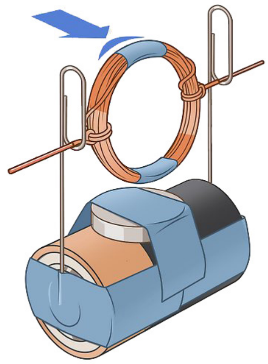
Windmill

Group Handout

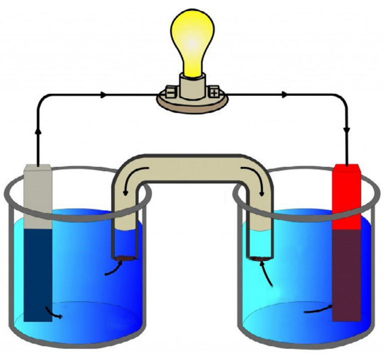
Energy Cards (continued)



Sailboat

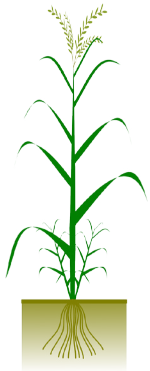


Motor

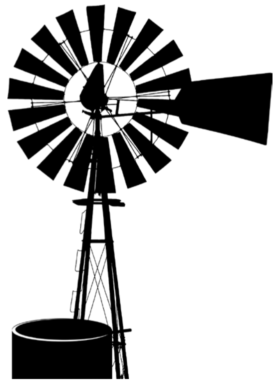


Electrical Cell

Heat

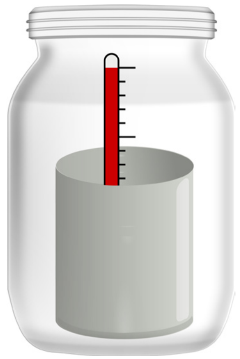


Plant



Water Pump

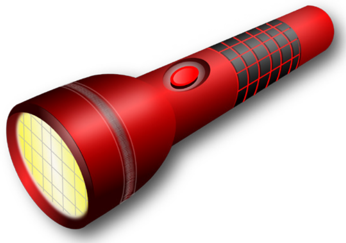
Energy Cards (continued)



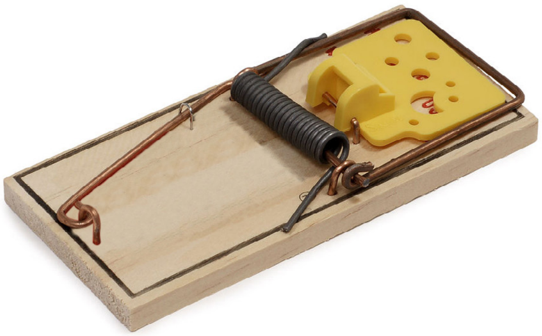
Solar Collector

Solar Panel

Guitar



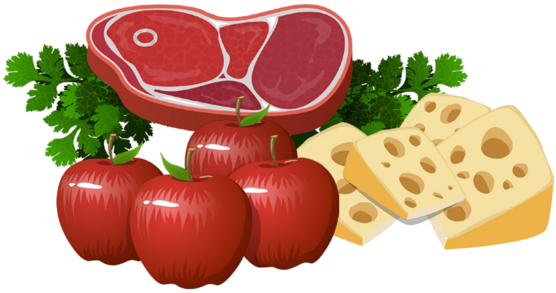
Flashlight



Mousetrap

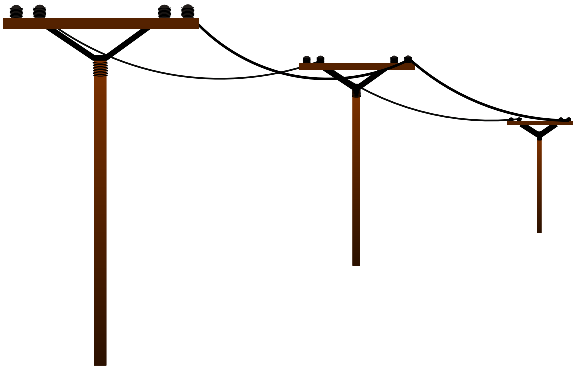
Falling Water

Energy Cards (continued)

 Magnnifier	 Light
 Drill	 Chemicals
 Food	 Bicycle

Energy Cards (continued)

Duck

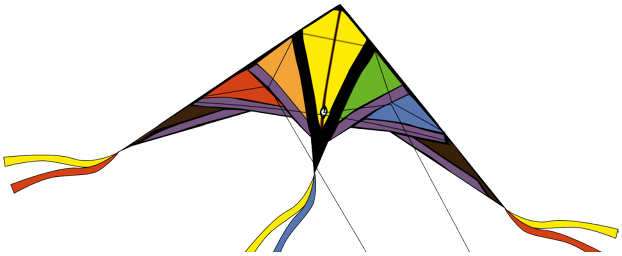


Electricity

Fire

Television Set

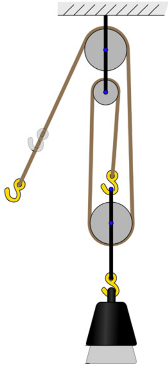
Person



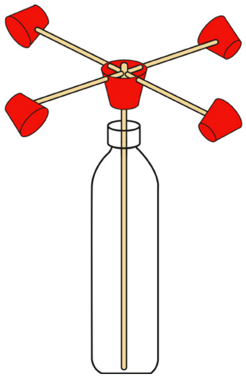
Kite

Energy Cards (continued)

Boom Box



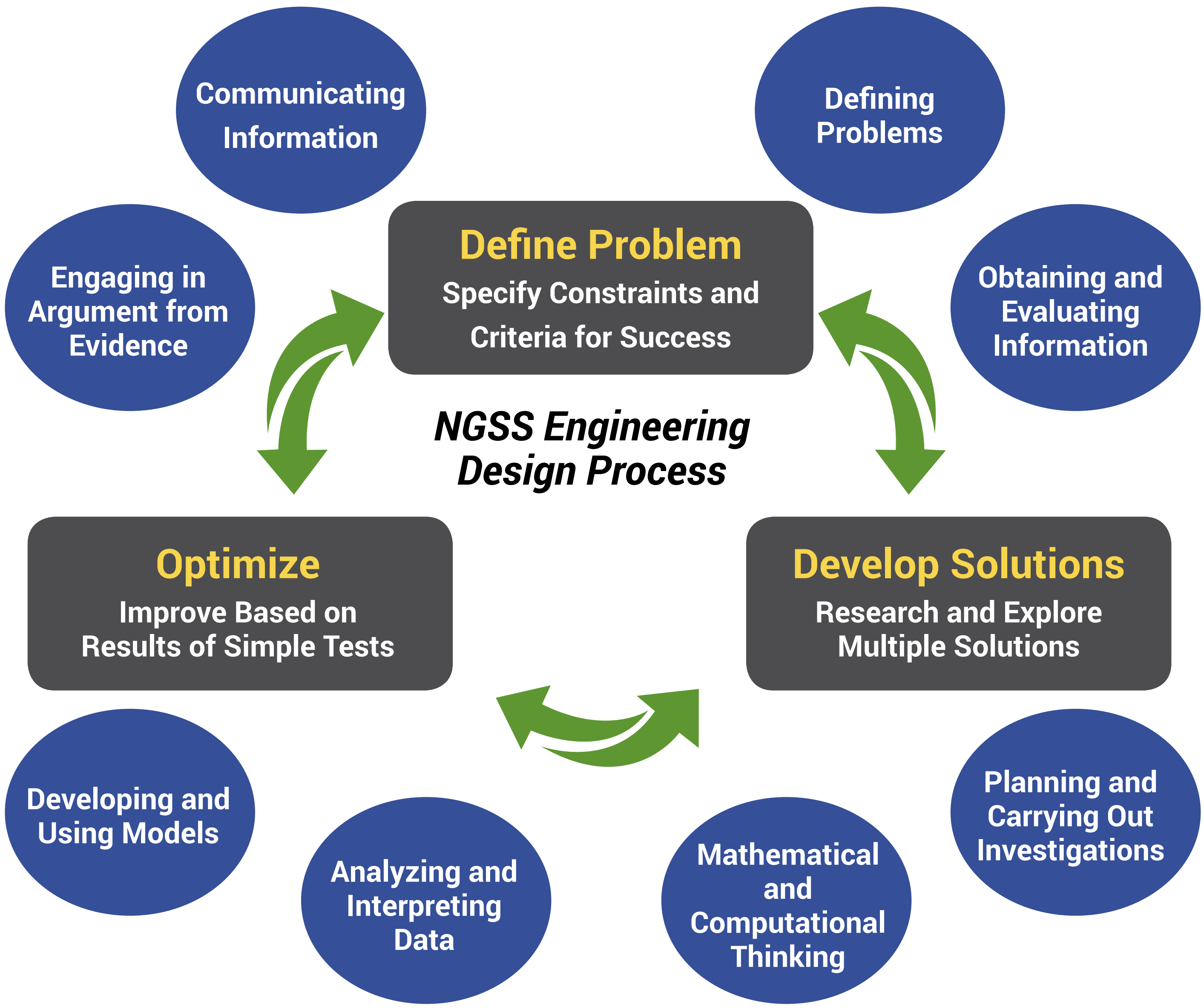
Motion



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.		