# BUILDING A DEVICE THAT **CONVERTS ENERGY** FROM ONE FORM TO ANOTHER TO SOLVE A PROBLEM

## TEACHERS HANDOUT

Utah SEEd Standard PHYS.2.4
Next Generation Science Standard HS-PS3-3
Grade and Topic: High School Physics

THE UNIVERSITY OF UTAH
College of Education

UTAH FORGE
U.S. Department of Energy

# BUILDING A DEVICE THAT CONVERTS ENERGY FROM ONE FORM TO ANOTHER TO SOLVE A PROBLEM

Curriculum developed as a collaboration between the Utah FORGE project and the University of Utah College of Education, supported by the Department of Energy. This curriculum is aligned with national NGSS standards as well as the Utah SEEd standards. The curriculum provides support for diverse learners in diverse environments.

# Contents

# Overview

Energy and energy conversions are critical to solving human problems. Notably, power plants operate by converting the energy source into electricity, which is then converted to another form of energy in our homes or cars or places of business. Developing clean renewable energy resources is essential to our future. Students are interested in making positive contributions to our world; engaging in energy transformations is one way students can make a difference in the world.

In this lesson, students working in small groups of 3-5, will investigate a variety of devices that convert energy from one form to another. By analyzing how the devices work, students will be asked to brainstorm problems that may be solved through such devices. The small groups will then work together to create an engineering solution for this problem. Finally, the students will present their solutions to the class in a "shark tank" or crowdsourced funding format.

## *Grade and Topic:*

High School Physics

## *Standards:*

This lesson aligns with the following state and national standards:

**Utah SEEd Standard PHYS.2.4 - Design a solution** by constructing a device that converts one form of energy into another form of energy to solve a complex real-life problem. *Define the problem, identify criteria and constraints, develop possible solutions using models, analyze data to make improvements from iteratively testing solutions, and optimize a solution.* Examples of energy transformation could include electrical energy to mechanical energy, mechanical energy to electrical energy, or electromagnetic radiation to thermal energy. (PS3.A, PS3.B, ETS1.A, ETS1.B, ETS1.C)

**Next Generation Science Standard: HS-PS3-3.** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [*Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.*]

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

## *Overall Objectives for Student Learning:*

- Students will identify types of energy, and energy transformations in both complex and simple systems.

- Students will explore devices that convert energy from one form to another. At each station, students will be able to identify the type of energy conversion that is occurring, provide an explanation for how the device works, and ask questions about the device.
- Students will engage in the engineering process by defining an engineering problem, identifying criteria and constraints, researching the problem, developing possible solutions using models, analyzing data to make improvements from iteratively testing solutions, and optimizing a solution.
- Students will present a proposal to the class communicating their results.

### *Timeline:*

This should take approximately six 90-min block class periods. If needed, the teacher can reduce the number of energy transformation devices or the days spent iteratively testing solutions to reduce the total time to four 90-min block class periods.

### *Materials:*

Computers with internet access

See each section for the relevant material list

### *Support for Students with Disabilities:*

Students with Disabilities and at-risk learners benefit from specifically designed instruction that gives meaningful access to the general education curriculum (Individuals with Disabilities Education Act (IDEA), 2004). To ensure access to the core curriculum, evidence-based practices, including instructional scaffolding (Kim et al., 2018; Larkin, 2002) and explicit instruction (Archer & Hughes, 2010; Hughes et al., 2017), should be considered when developing lessons to meet individual student's learning needs. This document includes suggestions for teachers to individualize instruction when planning and implementing this lesson plan within each relevant section.

# Preparation

## *Before beginning*

- Read the entire lesson sequence.
- Decide which exploration activities to complete.
  - Collect necessary items.
  - Construct any desired devices.
- Begin collecting recycled items for the prototype phase of the project.
- Decide what modifications to make, if any.
- Decide how to organize small class groups (students select their own groups, the teacher assigns groups, the teacher assigns groups with input from students, etc.).
- Decide how to distribute materials.
- Decide how many days to spend on building and testing the devices.

- Decide the format of the final proposals and presentations.

### *Day 1*

- Prepare slides for presentation with the anchoring phenomenon, applicable web pages, and vocabulary words for class discussion.
- Prepare for Exploring Devices that Convert Energy from One Form to Another
  - Prepare slides with assigned groups.
  - Set up the stations around the room or online.
  - Prepare instructions (print out or post online).
  - Prepare questions for each station.
- Decide whether the students will need to submit a single group assignment or individual assignments.

### *Day 2*

- Set up the energy transformation stations that were not completed on Day 1
- Prepare slides for the presentation on Engineering Process and applicable web pages.

### *Day 3*

- Prepare student handouts for Engineering Process
  - Each group needs one copy of
    - "Building a Device that Converts Energy from One Form to Another to Solve a Problem" (2 pages)
    - "Step 1: Define the problem and Step 2: Identify criteria and constraints" (2 pages)
    - "Step 5: Analyze data to make improvements from iteratively testing solutions" (3 pages)
  - Each individual/pair of students needs one copy of
    - "Step 3: Research the problem" (2 pages)
    - "Selecting a Problem through Consensus" (2 pages)
    - "Step 4: Develop possible solutions using models" (4 pages)
- Prepare supplies to begin building prototypes.

### *Day 4-5*

- Prepare supplies for building prototypes and iteratively testing them.
- Prepare materials for creating posters/presentations, whether as physical posters or as electronic presentations.

### *Day 6*

- Upload student presentations.
- Prepare slides with students' expectations for being a good presenter and for being an active listener.
- Prepare slides with appropriate student responses.
- Prepare final assessment if desired.

# Engage: Energy Transformations Rube Goldberg Machines and Energy Transformation Applet (30-40 min total)

### *Student Objective:*

Students will identify types of energy and energy transformations in both complex and simple systems.

### *Overview:*

The engagement part of this lesson uses a Rube Goldberg machine to introduce and spark interest in energy transformations. Students will also use a PhET applet to explore a simple system with energy transformations. The teacher will: present an OK GO video of a Rube Goldberg machine to the class, lead a class discussion on energy and energy transformations, and introduce the PhET applet on energy systems. The students will: think about types of energy and energy transformations while watching the video; participate in the full class discussion; select a ~5-sec clip of the video to explicitly list each type of energy present as well as places where energy is transferred from one object to another, and places where energy is converted from one form to another, and explore the PhET applet.

For an in-person or broadcast class, this can be done as a full class presentation combined with individual/pair work. For asynchronous classes, this can be done as a prerecorded lecture or as a reading. For hybrid courses, it is best to begin the Exploration on an in-person day. Therefore, depending on the length of the in-person class, it might be beneficial to complete the Engage part of the lesson online or reorder the curriculum to allow time to begin the Exploration phase on an in-person day.

The teacher may also want to ask students to bring recycled materials from home for the build part of the lesson. Examples of useful items would be cardboard, paper board, fasteners, string, plastic and metal containers, fabric, duck tape, etc.

### *Materials:*

Computers with internet access

OK Go - This Too Shall Pass, Rube Goldberg video
https://www.youtube.com/watch?v=qybUFnY7Y8w

PhET Energy Changes Simulator applet https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

## *Introduction (5 min):*

The teacher will show the class the OK GO video.

### *Suggested teacher script:*

Today we are going to begin a lesson on energy transformations. The objective of this lesson is to design and build a device that solves a real-world problem by converting energy from one form to another. So, I want you to keep that objective in mind as we go through this lesson.

[Because I don't know what kind of device you will be building, I'd like to have an assortment of supplies for the build section. Many things can be constructed with cardboard and duck tape. Please look through your recycling and in the next couple of days, bring in items that we can use for the construction.]

To begin with, I want you to watch this really cool video in which we see some energy transformations. While watching this video, I want you to think about places where you see changes in energy. You might see energy being transferred from one object to another, energy being converted from one form to another, or energy being added or lost. You can take notes if you want, and if you see a section of the video that looks particularly interesting to you, make a note of the approximate time, because I am going to ask you to analyze a few seconds of the video, and you get to pick which seconds you want to analyze.

[Teacher shows the video to the class.]

## *Explanation/Integration (10 min):*

After the students watch the video, the teacher will lead a full class discussion about the types of energy seen in the video, as well as places where there are energy transformations. During the discussion, the teacher should collect the vocabulary words the students mention and introduce other relevant vocabulary words as needed. For in-person classes, the teacher can write these words on a whiteboard or a poster to refer to later or can prepare these in advance as part of a slide show presentation. For broadcast courses, the teacher can prepare these in advance as part of a slide show presentation or use an interactive technology such as Nearpod where students can post their observations to be shared with the full class. For asynchronous classes, the teacher may ask students to list their observations on a discussion board.

The teacher may wish to include a discussion on the concept of systems. If these are viewed as closed systems, the energy is not being added or lost. All of the energy that enters the system is stored within the system prior to starting the machine/generator. Energy is also not being lost from the system, as "lost" energy is converted to other forms of energy, and that energy is still within the system. On the other hand, if the system is viewed as an open system, then we are adding energy at each step, and losing energy constantly. When discussing systems, it is important to define the boundaries of the system.

As part of the full class discussion, the teacher will introduce the PhET energy systems applet. If the teacher selects the tea kettle, the generator, and a lightbulb or fan, this models an extremely simplified version of a steam-driven power plant. Geothermal, coal burning, methane burning, nuclear, and some types of solar power plants operate in a similar way to this steam plant. The teacher can tie the types of energy and the energy transformations in the PhET applet to the types of energy and the energy transformations seen in the Rube Goldberg machine. The teacher can also begin a conversation about how power plants operate and how developing clean renewable energy is essential to our future. By clicking on the "energy symbols" button the teacher can introduce heat as a form of energy, and discuss how heat is produced in all energy transformations through friction, and how reducing the heat produced in an energy transformation increases the efficiency of a device.

### *Key Terms:*

Energy -- the ability to do work

Kinetic Energy -- energy of motion

Thermal Energy -- heat energy, a type of kinetic energy

Potential Energy -- energy of position, stored energy

### *Additional Terms:*

Mechanical Energy -- the sum of the kinetic and potential energy of a system

Linear Kinetic Energy -- kinetic energy of objects with translational motion

Rotational Kinetic Energy -- kinetic energy of objects with rotational motion

Electrical Energy -- energy from the movement of charged particles (usually electrons)

Gravitational Potential Energy -- energy due to an object's position in a gravitational field

Chemical Potential Energy -- energy stored in chemical bonds of a substance

Electromagnetic Radiation -- energy in the form of electric and magnetic waves

Light -- visible electromagnetic radiation

Sound -- the movement of energy through a substance due to vibrations

## *Independent Exploration (10-15 min):*

After the discussion, the teacher will instruct the students to work individually or in pairs on a computer with internet access to further explore both the Rube Goldberg machine and the PhET applet.

The teacher will assign the students to select a few seconds of the video and write each type of energy observed and how it is transformed. When finished with the video, the student will explore the PhET applet, making observations about how the energy is converted from one form to another, and which types of energy are present at each step. The students can do this individually or in pairs.

### *Suggested teacher script:*

I told you to make a note of the time of sections of the video you thought were particularly interesting. I hope you did this because next, I am going to ask you to select about 5 seconds of video and list all the types of energy you see in this clip, and how the energy is transformed. Make sure you list where energy is transferred from one object to another, places where energy is converted from one form to another, and places where energy is stored in the system or places where energy is "lost" from the system. In this case, we are looking for places where the energy transformation produces heat or sound as a byproduct.

When you have finished with the Rube Goldberg video, spend some time exploring the PhET applet. I want you to make some observations about how the energy is converted from one form to another, and which types of energy are present at each step.

So, that you understand what your assignment is, I am going to show you an example.

[Play clip from 0.20 - 0.25, between the billiard ball rolling and the steel ball falling, you might want to play it more than once.]

We see the kinetic energy of the billiard ball being transferred to the record cover, causing the record to fall, which converts its gravitational potential energy to rotational kinetic energy. The falling of the record releases the counterweight that is holding the fulcrum in place. We see the gravitational potential energy of the counterweight being converted to kinetic energy as the counterweight falls, and the gravitational potential energy of the fulcrum being converted to rotational kinetic energy as the lever arm swings. The lever arm hits the iPod, turning it on. This converts chemical potential energy (in the form of a battery) to electrical energy, which is converted to the kinetic energy of the speaker oscillating which is then converted to sound. The oscillating speaker knocks the ball off of the speaker, this converts the ball's gravitational potential energy into kinetic energy as the ball rolls down the funnel, and back and forth through the spoons. There is also some production of sound here. There would also have been the production of heat as a byproduct as these changes occurred. So, in this 5-second clip, we see multiple energy transformations.

[Working with a partner/working on your own], you are going to select a 5-second clip and write down all the energy transformations you can see in that clip. You will have 10 minutes to complete this. Be prepared to share your clip with the class.

When you finish, I want you to go to the PhET applet and try different variations of the devices. Make some observations about how energy is converted from one form to another. Think about how this compares to the Rube Goldberg machine. What is similar, what is different?

The links are here [share slide with links] or you can search for "OK GO Rube Goldberg" on YouTube for the video and "PhET energy systems" for the PhET applet.

[Check to verify that the students understand the assignment.]

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While the students are working on this, the in-person teacher will walk around the class checking on the students' progress. For a broadcast class, the teacher can join various breakout rooms to do the same (if working in pairs) or communicate individually to the students via the chat function (if the students are working individually. Once all students have completed the Rube Goldberg assignment, give the students an additional couple of minutes to explore the PhET applied before starting a full class discussion.

For an asynchronous class, the teacher should require a written or recorded answer, and can then provide feedback.

Once all students have completed the Rube Goldberg assignment, give the students an additional couple of minutes to explore the PhET applied before starting a full class discussion. For in-person and broadcast classes, the teacher should signal this transition.

## *Integration/Reflection (5-10 min):*

Once the students have completed this activity the in-person and broadcast teacher can ask individual/pairs of students or call for volunteers to share their clips with the class. The teacher can also ask students to share observations about the PhET applet. The teacher should point out that heat is clearly illustrated in the PhET applet, while it is present, but hidden in the Rube Goldberg machine. The asynchronous teacher can post selected examples on the LMS or require students to upload their clips to a discussion page.

### *Suggestions for Specifically Designed Instruction in Engaging Students in the Lesson*

A. Post expectations and directions in a form that is visual, explicit, and easy to access throughout the lesson.
B. Explicitly Teach Content Vocabulary (Kennedy et al., 2017).
    a. Teach and practice vocabulary included in the lesson plan
    b. Teach no more than 3-5 per week
C. Provide graphic or advanced organizers to scaffold student learning and classify information.
    a. Provide an advanced organizer using a cloze procedure to note important information and main ideas.
    b. Reduce cognitive demand by assigning students to gather specific information rather than all information simultaneously.
D. Follow all accommodations and modifications listed on the IEP.
E. Post and display instruction for expectations for student response: Design a device that solves a problem by converting energy from one form to another.
    a. Explore devices that convert energy from one form to another.
    b. Select a problem to solve.
    c. Design, build and test a device that will solve that problem.
    d. Create a proposal and present their proposal to the class.

# Transitioning (5-10 min)

### *Student Objective:*

Students will have the knowledge and skills necessary to work meaningfully within a team.

### *Suggested Teacher script:*

For the next couple of class periods, you will be exploring devices that convert energy from one form to another in your small groups. At each station, you will be asked to identify the forms of energy and explain how the device converts energy from one form to another. You will also be asked to think about how you could use this device, and how you could improve this device. Remember, the overall goal is to design and build a device that solves a real-world problem by converting energy from one form to another.

[Remind students of relevant lab safety, as well as any additional considerations for the selected activities.]

[Give instructions on forming groups. Also instruct students on what they need to submit for this assignment (as a group, individually, no submission, etc.).]

Once students have formed their groups and understand the expectations, they will begin the explorations.

### *Suggestions for Specifically Designed Instruction in Transition*

A. Explicitly teach and post directions and expectations in a format that is easily accessible for students to access throughout the lesson.
    a. Small-Group Learning Objective at stations
        i. Explore devices that convert energy from one form to another.
        ii. Identify the type of energy conversion that is occurring.
        iii. Provide an explanation for how the device works.
        iv. Ask questions about the device.
    b. Directions for Group Station Activity
        i. Read directions for each station.
        ii. Make and operate the device.
        iii. Answer questions at each station.
B. Suggestions for ensuring smooth transitions and procedures while working in small groups
    a. Post and be explicit with time. Use a timer and give a 5-minute warning. Explain procedures if students finish the task early or do not complete the tasks at each station.
    b. Be clear and consistent on the format of note-taking, how work should be to be turned in, and expectations for mastery.

# Explore: Exploring Devices that Convert Energy from One Form to Another (60-120 min total)

## *Student Objective:*

Students will work in small groups at rotating stations to explore devices that convert energy from one form to another. At each station, students will be able to identify the type of energy conversion that is occurring, provide an explanation for how the device works, and ask questions about the device.

## *Overview:*

In the exploration part of this lesson, each group of students will explore a variety of stations with simple devices that transform energy from one form to another. The teacher will select which stations to have the students explore based on need, time, and budget constraints. The stations have been selected to be as transparent as possible. For each station, ask the students to identify which form of energy is being converted to which other form of energy, identify intermediate steps if applicable, explain how the device is converting one form of energy to another, brainstorm ideas for how this device could be used, brainstorm ways the device could be improved, and ask questions about the device.

Students should spend approximately 10-15 minutes at each station. For a block schedule, students will be able to explore 2-3 stations on the first day. For a traditional schedule, students may only be able to explore 1-2 stations on the first day.

For an in-person class, the teacher should set up the stations in advance. Relevant COVID precautions could include: having students work in pairs rather than groups so that they can sit at opposite ends of the table and not face one another; having materials for all stations for each group, so that students are not handling materials previously handled by other students; sanitizing stations before students rotate from one station to the next.

For online (broadcast or asynchronous) and hybrid classes, the teacher will need to arrange for the students to obtain the supplies for the stations prior to beginning the lesson and should have electronic versions of the instructions available to the students, using LMS and educational environments approved by the district/school. For a broadcast class, once students have selected their groups, they can join breakout rooms to explore the stations. (If the district does not allow breakout rooms for students the teacher could decide to have full group discussions and individual answers, or arrange group discussions to occur online using the discussion board in the LMS or similar.) For asynchronous classes, once the teacher has assigned groups, students can use discussion boards or other district-approved meeting environments to explore the stations.

While the students are following the instructions at each station, the in-person teacher will walk around the class, dropping into the various discussions, highlighting productive ideas, asking probing questions. For a broadcast class, the teacher can join various breakout rooms to do the same. The teacher should decide if the students are required to submit written responses to the small group discussions; this might not be necessary for in-person and broadcast classes, as the teacher can check on each group's progress. For an asynchronous class, the teacher may require a written or recorded answer, and can then provide feedback to the group that highlights productive ideas and asks probing questions.

For in-person and broadcast classes, the teacher should signal the time to finish the current activity and transition to the next.

### *Suggestions for Specifically Designed Instruction In Small Groups*

A. Give the Students with Disabilities the instructions prior to the activity.
B. Allow students to see the questions to be answered before starting the station.
C. Highlight main ideas and essential information in the instructions before the station activity.
D. Provide graphic or advanced organizers to scaffold student learning and classify information.
E. Provide an advanced organizer using a cloze procedure to note important information and main ideas.
F. Reduce cognitive demand by assigning students to gather specific information rather than all information simultaneously.
G. Follow all accommodations and modifications listed on the IEP.

## *Station A: Converting Electrical Energy to Kinetic Energy -- An Extremely Simple Motor*

### *Background:*

In an electric motor, electricity is converted to kinetic energy through the Lorentz force. The Lorentz force is the force on a charge moving through a magnetic field. Since current is a flow of charges, a current-carrying wire will experience this force. The direction of the force is perpendicular to both the direction of the magnetic field and the direction of the current. The magnitude of the force is maximum when the magnetic field and electric current are perpendicular to each other. For a spinning motor, the Lorentz force needs to act such that it provides a torque.

At this station, the students will explore an extremely simple motor called a homopolar motor. To find out more about how this works and why it is called homopolar please see read the additional background in the first link. The use of a screw in the first link makes it a bit easier to get the motor to work, the second method is seen more often, and allows more creativity in how the motor is constructed, but also can be more challenging.

The battery provides the electric current, therefore, there is the additional energy conversion from chemical to electrical.

### *Materials:*

Each group of 4 students will need (each student builds their own motor)

4 AA or AAA batteries

4 pieces of ~20 gauge copper wire cut into 6" lengths

4 pieces of ~20 gauge copper wire cut into12" lengths

4 or more neodymium magnets

4 drywall screws

### *Teacher Preparation:*

Cut the wire into 6" lengths for the first activity and into longer lengths for the second activity.

### *Safety:*

The motor can get hot, so discuss safely handling hot objects. In addition, the wires can be sharp, so discuss safety with sharp objects. Neodymium magnets can pinch, so discuss magnet safety.

### *Directions for Building the Motors:*

https://www.evilmadscientist.com/2006/how-to-make-the-simplest-electric-motor/

https://www.instructables.com/Easy-DIY-Homopolar-Motor/

It only takes a few seconds to build the motor. Therefore, once the students have a working motor, they can explore different configurations.

### *Questions to be answered in lab notebook:*

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Which shapes did you try? Which one worked best?

How could you improve this motor?

What are some things you could do with this motor?

What questions do you have about this station?

### *Troubleshooting:*

If the students are unable to get the wire/screw to spin, the problem may be the battery, the circuit, or both.

The batteries run out quickly. Therefore, it will be more cost-effective to purchase higher-quality, longer-life batteries. Ideally, each group should also start with fresh batteries.

The wires must complete the circuit and be free to move. There is a bit of a trial and error process to this. Make sure the sections of the wire that are touching the battery are uncoated. Also, as the wires will get crimped and bent, if possible each group should start with new wires.

# Station B: Converting Kinetic Energy to Electrical Energy -- An Extremely Simple Generator

## Background:

In a generator, kinetic energy is converted to electrical energy through Faraday's law of electromagnetic induction, in which a changing magnetic field will induce an electric current. The direction of the electric current is determined by Lenz's law, which says that the electric current will flow such that it resists the change in the magnetic field. As most generators operate either by spinning an external magnetic field or by spinning in an external magnetic field, most generators produce an AC current.

In this station, the students create a simple generator that they operate by shaking the generator. This works in a similar way to a "shaking flashlight." Students interested in improving the generator may want to create a spinning generator, the principles are the same, but the build is more complex. Station C explores turbines, the most common type of spinning generator.

An LED is used to determine if the generator is creating electricity, so there is the additional conversion from electrical to electromagnetic radiation, ie. light. LEDs operate on DC, but this generator creates an AC current. Therefore, in the best of circumstances, the LED will flash as the current changes from the right way to the wrong way and back. (See the section on troubleshooting for more about this issue.)

## Materials:

Each group of 4 students will need (the students share the 3-4 generators and magnets)

3-4 35mm plastic film cans

cardboard

electrical tape

~2 Spools of 28 gauge ceramic coated copper wire

clear tape

3-4 red LEDs

solder (optional)

sandpaper

6 or more neodymium magnets

## Teacher Preparation:

Prepare the generators in advance. Prepare the spool using the film can, cardboard, and electrical tape as described in the instructions. It takes about an hour to build each generator, about half an hour is spent wrapping the coil; a 1000 turn generator uses most of a spool of wire. Secure the wire with clear tape, sand the ends of the wires, and attach the LED as described in the instructions.

Preassemble 3-4 generators with different numbers of turns of wire (ex. 500 turns, 750 turns, 1000 turns).

## Safety:

There is a risk of dropping and breaking the LED bulb, which may result in sharp edges, so discuss safety with sharp objects. Neodymium magnets can pinch, so discuss magnet safety.

## Directions for Building the Generator:

Even though the generator is mostly prepared by the teacher prior to the students interacting with the station, it is beneficial for the students to read this page to understand what is happening, and for instructions on how to get the generator to work. Encourage the students to try different combinations of turns of wire and number of magnets, and how vigorously they shake the generator.

http://www.creative-science.org.uk/gensimple1.html

Students interested in creating a spinning generator should read this page:

http://www.creative-science.org.uk/gen1.html

## Questions to be answered in lab notebook:

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Which combinations of turns and numbers of magnets did you try? Which one worked best?

How could you improve this generator?

What are some things you could do with this generator?

What questions do you have about this station?

## Troubleshooting:

Most of the troubleshooting is done by the teacher in preparing the generator.

It is important to not tangle the wire while winding it, tangles can result in kinks. This can be avoided by keeping both spools taut while winding the generator, which is easier with two people, one to hold the spool of wire and one to wind the wire onto the generator.

The insulating layer can be removed from the ends of the wire prior to attaching the LEDs by sanding lightly. It is most effective to solder the wire and LED leads together, if possible. Wrapping the 28 gauge wire around the LED leads and securing them with electrical tape also works. Red LEDs are recommended as they require the least amount of current to operate. Attaching 2 LEDs with reversed polarity will make it more likely that at least one LED will light.

Securing the whole system with clear tape both keeps things in place and allows students to see how the generator is constructed.

It is difficult to get the LED to light. The students will need to shake the generator vigorously. Try adding more magnets and using the generator with more coils. Also, the direction of the magnet matters. As the magnet flips over while shaking, the misaligned magnet will not generate an electric current.

## *Station C: Converting Kinetic Energy to Electrical Energy -- A Wind Turbine Electric Generator*

### *Background:*

The physics is the same as in Station B. In a generator, kinetic energy is converted to electrical energy through Faraday's law of electromagnetic induction, in which a changing magnetic field will induce an electric current. The direction of the electric current is determined by Lenz's law, which says that the electric current will flow such that it resists the change in the magnetic field. This station works in a way similar to a wind turbine.

In this station, the students use an electric fan run in reverse to create the turbine. The students provide the kinetic energy to turn the turbine through their own breath. An LED is used to determine if the generator is creating electricity, so there is the additional conversion from electrical to electromagnetic radiation, ie. light.

Since this fan is designed to operate in a DC system, when run as a turbine, it produces a DC current. Therefore, unlike the prior generator, the LED will not flash as the AC current changes, and will not light at all if connected incorrectly.

### *Materials:*

Each group of 4 students will need (each student explores their own device)

4 5V brushless DC cooling blower fans

4 red LEDs

other colored LEDs (optional)

drinking straws

duct tape

single hole punch

hot glue (optional)

### *Teacher Preparation:*

Prepare the blowers in advance. Secure the wires with hot glue as described in the instructions. Punch a hole in the duct tape and cover the opening to the blower with this duct tape, as described in the instructions. Cut straws into ~2" lengths.

### *Safety:*

There is a risk of dropping and breaking the LED bulb, which may result in sharp edges, so discuss safety with sharp objects. Each student should have their own straw to reduce disease transmission. This activity may not be appropriate if the risk of covid transmission is high. Otherwise, follow district safety guidelines for times when it is necessary for students to be unmasked (for example, during lunch or during band practice).

### *Directions for Building the Generator:*

The students will complete Activity 1 -- Breath into light

https://docs.google.com/document/d/1seJxEyp22fr9UHuQebXqARZXGXfNXrUOKJqvSqtQAEQ/edit

Activity 2 could be done as part of a lesson on Utah SEEd Standard PHYS.2.1 (or NGSS Standard HS-PS3-1).

### *Questions to be answered in lab notebook:*

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Which colors of LED lights were you able to get to light? For how long were you able to light them?

How could you improve this generator?

What are some things you could do with this generator?

What questions do you have about this station?

### *Troubleshooting:*

If students are unable to get the light to turn on, it is likely connected wrong. Try reversing the polarity.

The straw needs to fit snugly in the hole. A standard hole punch fits a standard straw reasonably well, if the straws or hole punch is not standard there may be issues with airflow.

## *Station D: Converting Thermal Energy to Electrical Energy -- A Peltier Device*

### *Background:*

From thermodynamics, we know that heat flows from places with higher temperatures to places with lower temperatures. Once the temperatures are equal, the flow of heat stops. Therefore, to be able to get useful work from heat, we need a temperature difference. In a Peltier device electricity can be used to create this temperature difference or a temperature difference can be used to generate a flow of electricity.

Peltier devices take advantage of the properties of semiconductors. In a semiconductor, impurities are added to the silicon crystal that either allow the semiconductor to donate electrons (n-type, for negative) or to accept electrons (p-type, for positive). By connecting an n-type semiconductor to a p-type semiconductor across a temperature gradient, we can induce a flow of electrons. For more details on how these devices work, see the Background for Teachers section in the instructions link.

In this station, the students use their hands as a heat source, and a block of ice as a heat sink to power a Peltier device. An LED is used to determine if the generator is creating electricity, so there is the additional conversion from electrical to electromagnetic radiation, ie. light.

## *Materials:*

Each group of 4 students will need (the students work together to make the device work)

4-8 4 cm x 4 cm peltier devices

1 red LED

wire nuts, alligator clips, electrical tape, or solder to connect wires from Peltier devices

1 shallow plastic container

water

## *Teacher Preparation:*

Prepare ice blocks by freezing water in shallow plastic containers. Connect Peltier devices in series as described in the instructions. Alternatively, the students can wire the device themselves at the station.

## *Safety:*

There is a risk of dropping and breaking the Peltier devices and the LED bulb, which may result in sharp edges, so discuss safety with sharp objects. If the students will be wiring the devices themselves the wires may be sharp. The ice will be cold.

## *Directions for Building the Generator:*

The students will complete “Demonstration Activity”

https://docs.google.com/document/d/1Xnn2P6hM8n8FC8QsvAp0rWdXy52WREG-xc7GuULjH1Y/edit

The “Quantitative Activity” could be done as part of a lesson on Utah SEEd Standard PHYS.2.1 (or NGSS Standard HS-PS3-1).

## *Questions to be answered in lab notebook:*

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Were you able to get the LED to light? What did you try to increase the temperature gradient? What worked best?

How could you improve this generator?

What are some things you could do with this generator?

What questions do you have about this station?

### Troubleshooting:

The Peltier device needs to be oriented correctly on the ice, and the LED needs to be wired correctly as well. If the students are unable to light the LED, try turning the Peltier devices over. If that doesn't work, try reversing the polarity of the LED (there is a small possibility that the LED is wired incorrectly). If that doesn't work, try both turning the device over and reversing the polarity.

## Station E: Converting Mechanical Energy to Electrical Energy -- A Piezoelectric Device

### Background:

Piezoelectric devices work from the piezoelectric effect in which stress applied to a crystalline solid will cause a voltage difference across the material. Piezoelectric materials work in reverse as well, a current applied to a piezoelectric material will cause the material to vibrate, quartz watches and solid-state speakers work by using the piezoelectric effect.

In this station, the students use their hands to provide the pressure that produces the current in a piezoelectric element/transducer. An LED is used to determine if the generator is creating electricity, so there is the additional conversion from electrical to electromagnetic radiation, ie. light.

### Materials:

Each group of 4 students will need (the students work together to make the device work)

8 piezoelectric elements/transducers

1 red LED

wire nuts, alligator clips, electrical tape, or solder to connect wires from piezoelectric elements

### Teacher Preparation:

Connect piezoelectric elements/transducers in series as described in the instructions. Alternatively, the students can wire the device themselves at the station.

### Safety:

There is a risk of dropping and breaking the LED bulb, which may result in sharp edges, so discuss safety with sharp objects. If the students will be wiring the devices themselves the wires may be sharp.

### *Directions for Building the Generator:*

Connect the piezoelectric elements in series. Connect the red wire to the long LED lead. Connect the black wire to the short LED lead. These devices are wired in the same way as Station D: A Peltier Device

At the same time, all students need to press on the devices.

### *Questions to be answered in lab notebook:*

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Were you able to get the LED to light? What did you try to increase the pressure? What worked best?

How could you improve this generator?

What are some things you could do with this generator?

What questions do you have about this station?

### *Troubleshooting:*

The piezoelectric devices need to be wired in series. If the students are unable to light the LED, check the wiring. The students may need to push harder

## *Station F: Converting Electromagnetic (Light) Energy to Electrical Energy -- a Solar Panel*

### *Background:*

Solar panels work from the photoelectric effect in which a photon is absorbed by a material and that material ejects an electron. In this station, the students use a solar panel to light an LED. Since the LED is used to determine if the generator is creating electricity, so there is the additional conversion from electrical to electromagnetic radiation. Students may wish to wire several solar panels together in parallel to increase the current.

### *Materials:*

Each group of 4 students will need (each student explores their own device, and the students work together to run the blower fan)

4 handheld solar panels

4 LEDs (assorted colors)

sunlight

wire nuts, alligator clips, or electrical tape to connect the solar panels

1 5V brushless DC cooling blower fan (optional)

### Teacher Preparation:

No advance preparation is needed.

### Safety:

There is a risk of dropping and breaking the solar panels and the LED bulb, which may result in sharp edges, so discuss safety with sharp objects. The wires may be sharp.

### Directions for Building the Generator:

Connect the red wire to the long LED lead and the black wire to the short LED lead. Place the solar panel in direct sunlight. The LED should light. Try other colors of LEDs.

Try connecting the solar panels in parallel. How does this affect the LED? Do some colors of LED work better than other colors?

Try connecting the cooling fan (red to red, black to black). Can you get it to operate? What else could you try?

### Questions to be answered in lab notebook:

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

Were you able to get the LED to light? What happened when you connected several solar panels in series? Were you able to get the fan to run?

How could you improve this generator?

What are some things you could do with this generator?

What questions do you have about this station?

### Troubleshooting:

The solar panels work better in direct sunlight but can work with classroom lighting if sunlight is not available, there will be less current, and higher current LEDs may not light. It might not be possible to get the fan to work depending on the size of the panels.

## Station G: Converting Thermal Energy to Kinetic Energy -- A Heat Driven Turbine

### Background:

A turbine converts linear motion into rotational motion. Turbines require asymmetry to provide this torque. In this heat-driven turbine, rising columns of air provide the force.

At this station, the students create a turbine using a sheet of heavy paper, and a ring stand, then power this turbine using a hotplate.

## Materials:

Each group of 4 students will need (each student builds their own turbine)

4-8 sheets of heavy paper

4 ring stands

2 hotplates

scissors

## Teacher Preparation:

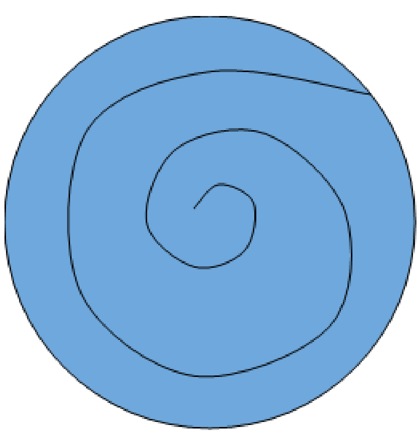
No advance preparation is needed.

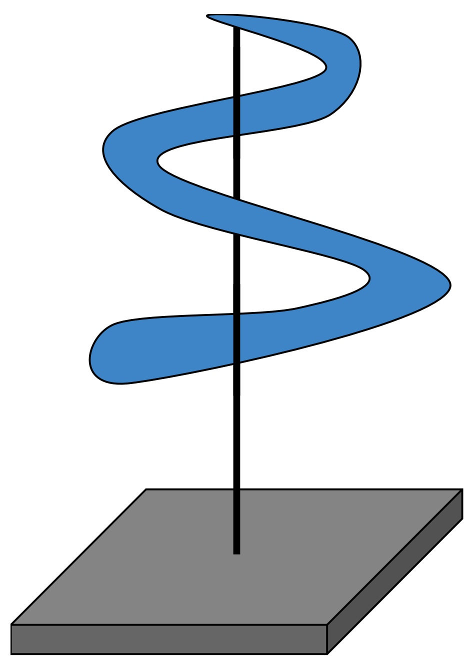
## Safety:

The hotplate will be hot, so discuss safely working with hotplates. Scissors are sharp, so discuss safety with sharp objects. As the paper may fall off the ring stand and onto the hotplate, students should not leave their turbines unattended, as this may increase the risk of fire.

## Directions for Building the Turbine:

Draw and cut a spiral shape out of the paper, as shown. Don't cut the spiral all the way to the center.





Balance the paper on the ring stand, as shown.

Place the hotplate under the paper, near the edge of the outer spiral, such that 2 turbines can operate with one hotplate.

Turn on the hotplate, the paper should start spinning as the hotplate heats up.

### *Questions to be answered in lab notebook:*

What is happening at this station? Identify the forms of energy and the energy conversions that are taking place here.

Explain why you think this is happening?

What did you try? What worked well?

How could you improve this turbine?

What are some things you could do with this turbine?

What questions do you have about this station?

### *Troubleshooting:*

If the spiral is too tight, the paper may not get close enough to the hotplate to be affected by the current. Alternatively, if the spiral is too loose the paper may hang down too far, this can be remedied by cutting off the part that is too low. Students may struggle with balancing the spiral on the ring stand and might need to try a couple of spiral shapes to get one that is stable.

## *Station H: Converting _________ Energy to _________ Energy*

### *Background:*

There are devices that can be constructed to convert nearly any form of energy to nearly any other form of energy: wind-up toys (spring potential energy to kinetic energy), speakers (electrical energy to kinetic energy in the form of sound), GravityLights (gravitational potential energy to electrical energy), battery chargers (electrical energy to chemical potential energy), musical instruments (one type of kinetic energy into a different type of kinetic energy), pendulums (gravitational potential energy to kinetic energy), candles (converting chemical potential energy to thermal and light energy), etc.

Many of these devices have simple instructions for how to build them from simple materials online, or can be purchased as electrical components for a few dollars, and can be wired with other devices to explore the energy transformations.

Teachers who are interested in additional energy transformations should be encouraged to find instructions online and create any device they would like their class to explore. It is recommended that teachers troubleshoot the device before using it as a station in the classroom.

# Transitioning: Integration/Reflection (10 min)

Once the students have completed exploring the stations the teacher will lead a full class discussion about student observations and to introduce the next phase of the lesson. The in-person and broadcast teacher can ask student groups to share their observations and questions about the stations. The asynchronous teacher can require students to share observations and questions on a discussion page. During the discussion, the teacher should highlight energy transformations and suggestions on how the devices could be improved and used.

### *Suggestions for Specifically Designed Instruction for Integration/Reflection*

A. Provide graphic or advanced organizers to scaffold student learning and classify information.
B. Provide an advanced organizer using a cloze procedure to note important information and main ideas.
C. Follow all accommodations and modifications listed on the IEP.

# Explain: Engineering Solutions, part 1 Inspiration from GravityLight (100 min total)

### *Student Objective:*

Students will brainstorm ideas for engineering problems, define a few problems, research these problems, then select a final problem to begin the process of engineering a solution.

### *Overview:*

The Explain and Elaborate parts of this lesson are embedded in the engineering process. In the engineering stage of this lesson, the students will design and build a device to solve a real-world problem. GravityLight, a company that makes gravity-driven lights for use in remote regions of the world, is used as a motivating example of how an engineering solution can solve a real-world problem.

As with the "scientific method," the actual process of engineering a solution is much more complicated and intricately interwoven than the steps listed in most textbooks. However, in the same way as the scientific method in a textbook has clear steps to help students navigate the process, there are steps that most engineers agree are essential parts to the process.

In this lesson, we break the engineering process into the following seven steps:

1. Define the problem -- to construct an engineering solution, there needs to be a well-defined problem. “End the use of fossil fuels” is not a well-defined problem, it is too broad and too vague. However, it is possible to define a smaller problem that will contribute to the overall goal of ending the use of fossil fuels. In the GravityLight videos, the problem was not to end fossil fuel use. The problem is people who are not connected to the electrical grid do not have a safe and effective means of lighting their homes. Students interested in solving broad world problems should be asked if there are smaller steps that can contribute to solving global problems.
2. Identify criteria and constraints -- there will always be criteria and constraints. The criteria are usually that the engineered solution is better/cheaper/faster at solving the problem than the current method. The constraints are often financial, but may also be societal. In the first GravityLight video, he discussed the financial constraints and mentioned some of the societal constraints. In the second video, we see more of an emphasis on the societal implications. In this lesson, the criteria are that the solution needs to convert energy from one form to another. The teacher may want to include additional criteria. The constraint is that the students need to construct the device using materials available in the classroom or by recycling other materials from home or the school. The teacher may wish to include additional constraints.
3. Research the problem -- What if you solve a problem, but discover that someone else has already done that, and done it better? What if you solve a problem but discover that no one wants to use your solution? (In the GravityLight video, the fact that people did not trust their solution was a major issue.) For any problem, it is almost certain that others have worked on this problem. In addition, for any problem, it doesn’t matter how good your solution is if no one will use it. Therefore, students need to research both what people actually need, and what other people have already done.
4. Develop possible solutions using models -- before building a final project, engineers will draw schematics and make prototypes. In the Gravity Light video, he shows us multiple prototypes that they constructed. Modeling multiple solutions helps identify the best one as well as reduces a lot of time, money, and frustration in building something that doesn’t work. It is important to note that these engineering models are different from the science models described in the NGSS standard “developing and using models” which are models of the mechanism behind the phenomenon.
5. Analyze data to make improvements from iteratively testing solutions -- this is the heart of engineering, trying and trying and trying again. In the Gravity Light video, we see the engineers running multiple tests on their prototypes to make the best-designed light they can make. When engaging in this step of the lesson, encourage students to make systematic changes to their design record every change made, and collect data on how the device performed after each change in order to determine which iteration was most successful.
6. Optimize a solution -- once the students have completed their iterative testing, and taken excellent notes on their process, it should be fairly straightforward to pick the optimal solution. However, often there are conflicting optimizations, we are both trying to reduce the cost and increase the efficiency. However, the more efficient battery costs more. The optimal solution must make a judgment call on which of these conflicting needs to optimize.
7. Communicate the results -- essential to both engineering and science. If you don’t communicate your results, your solution is meaningless. In this lesson, students will present

their solutions to the class "Shark Tank" style, or in videos such as the fundraising video from GravityLight.

In this step of the lesson, the teacher will lead the students in a discussion to introduce the engineering stages of the lesson. The students will then conduct the first three steps working in their small groups from before.

## *Materials:*

computers with internet access

projector

GravityLight - lighting a billion lives: Jim Reeves at TEDxWarwick 2014 (~20 min)

https://www.youtube.com/watch?v=qwEmgwrVUag

GravityLight: Made in Africa (fundraising video for GravityLight v.2) (~4 min)

https://www.youtube.com/watch?v=TvWHDXafXtQ

## *Introduction (35 min total -- 25 min for video, 10 for discussion):*

The teacher will introduce the next stage of the lesson, engineering solutions. For an in-person or broadcast class, this can be done as a full-class presentation. For asynchronous classes, this can be done as a prerecorded lecture or as a reading.

The teacher will ask the students if they can think of any problems that could be solved by using a device that transforms energy from one form to another. The teacher may want to highlight a relevant problem in the school or larger community (temperature in the classroom, street lights in the parking lot, etc.).

After this discussion, the teacher will introduce GravityLight, which is a really amazing engineering solution, by showing the students videos of the inventors discussing their work. In the first video, one of the inventors of GravityLight discusses the whole process of designing this solution; in doing so, he describes many of the essential steps in the engineering process. Therefore, this video is a nice way to transition to discussing the engineering process. The second video is a short clip that discusses what the next steps are for the company. As the students will be presenting their solutions to the class at the end of the unit, this is an example of how to make such a presentation.

## *Suggested teacher script:*

Those are some really great problems that you brought up. I love how you [relevant comments about the discussion]. I want to show you a couple of videos about a problem that people used some pretty good engineering skills to solve.

While you watch these videos, look for steps that the engineers describe as being essential to the work they're doing.

[Teacher shows the videos to the class.]

## *Explanation (10-15 min):*

After the students watch the video, the teacher will lead a full class discussion about the pieces of the engineering process that the inventors brought up in the videos. While this lesson is focused on the design process, the engineers included financial and social considerations; the teacher should recognize and validate these issues.

Next, the teacher will describe the steps in the engineering process as used in this lesson:

1. Define the problem
2. Identify criteria and constraints.
3. Research the problem.
4. Develop possible solutions using models.
5. Analyze data to make improvements from iteratively testing solutions.
6. Optimize a solution.
7. Communicate the results.

These steps can be written on the whiteboard or a poster or slide posted on the LMS to refer to during the lesson. In addition to identifying the steps, the teacher will explain how these steps will be used in this lesson, but also encourage the students to think about how these steps would be used in general.

### *Suggested teacher script:*

Remember the other day when we began this lesson, I told you that the objective is to design and build a device that solves a real-world problem by converting energy from one form to another? Okay, so we have reached the point of the lesson where we will be working on designing and building a device.

[Show slide with the steps written on it.]

1. The first step in the engineering process is to define the problem. You get to do this. This is on you. I am not giving you a problem. You need to figure one out. There are actually a couple of steps to this.
    a. The first part requires some imagination; brainstorming some problems that you would like to work on solving. Brainstorm some ideas for how to solve them. I want you to think of as many ideas as you can.
    b. The second part needs to be very specific. To build a device that can solve a problem, you need a problem that is well-defined. Remember in the GravityLight video, the problem is that millions of people don't have access to electricity. That is not a well-defined problem. He pointed out that the expansion of the grid will only help 4% of these people, and won't help people who can't afford electricity in the first place. Instead, he focused on the well-defined problem that there must be a better way for remote people to light their homes than kerosine lanterns.

2. The second step is to identify criteria and constraints. For this lesson, I am giving you the criteria and constraints. The primary criteria is that the device must convert one form of energy to a different form of energy. The primary constraint is that you must be able to construct the device from materials that we have in the classroom or that we can recycle from home or the school. We have a limited budget to purchase additional items if needed, but mostly, this must be constructed using things already available.

[The teacher may wish to add additional criteria or constraints.]

This does limit the problems that you can work on, which is one of the reasons I wanted you to brainstorm many ideas for problems. A filter that removes giardia from the drinking water is an excellent real-world problem, but it is not one that converts one form of energy to another, so would not meet the criteria for this assignment. In the GravityLight video, he had the financial constraint that the light needed to cost less than $6 to make. You have a similar constraint on the cost of your solution.

[Check for understanding.]

3. After you have defined a problem and made sure that it is possible to engineer a solution that meets the criteria and fits within the constraints, you will need to research the problem. There are also 2 parts to this:
    a. First, you need to research what people need. In the GravityLight video, people needed light. They didn’t need cell phone chargers. If he had spent all that time and money on providing cell phone chargers, it would have been a waste. Make sure you understand the needs of the people whose problem you are working on.
    b. Next, you need to research what others have already done. In the Gravity Light video, he talked a lot about research he did on providing electricity to people who are off-grid, and ultimately decided he needed to design a solution that did not use a battery to store energy.
4. After researching the problem, you are going to work on step 4, develop possible solutions using models. Basically, draw up some ideas for how to build your solution. You will need to get your design ideas approved before beginning to build them. [The teacher might want to describe how the term model is being used differently here than how it's used when students develop a model to explain the mechanism of a phenomenon.]
5. Remember how the engineer in the GravityLight video said engineering is an iterative process. That is the bread and butter of engineering. Engineering is really about trying and trying and trying again. You’ve heard the stories about how often Edison and the Wright Brothers failed before getting their inventions to work? Yup. So, as you are engaged in building your prototype, you are going to take copious notes about what you tried, and how effective it was, and what you did next, and how did that work. You will need to make measurements, collect data, analyze that data, and try and try again. That is the 5th step in our outline, analyze data to make improvements from iteratively testing solutions.
6. Once you have collected that data, you will be able to complete step 6, which is, optimize the solution. Basically, this will be your model or prototype that worked the best, met the criteria, and fit within the constraints.
7. Finally, you communicate results. To do this, we are going to be sharing our results with the class as a “Shark Tank” type presentation. Remember the second video, which was a

fundraising video for GravityLight v.2. That is what you'll be doing, convince our class to invest in your engineering design.

Alright, that is a lot. Right now, we are just going to work on the first 3 steps, defining a problem, identifying the criteria and constraints, and researching the problem.

To begin, I'd like you to brainstorm problems in your small groups and select 2-3 of these problems to work on. Once you have selected a topic, you need to define the problem. As you are working on this, I will be checking on your progress. Let me know if you are struggling with finding problems or defining the problem.

Once you have selected 2-3 problems that are well enough defined that you can engineer a solution, let me know. I will check to make sure that you have a well-defined problem. You need my approval before moving on to the next step, researching the problem.

After you get approval, you can begin working on your research. We will be spending the [rest of the class, the next class period, etc.] working on research. Remember you need to research both the needs of the people and other solutions to your problem.

Once you have done research on all three problems, you will need to decide, as a group, which one your group will actually work on for the next several days.

[Check to verify that the students understand the assignment. Once the students understand the requirements they can begin working in their small groups.]

## *Suggestions for Specifically Designed Instruction for Teacher-Led Class Discussion*

A. Provide clear directions for student expectations during the lecture, including behavior and academic expectations.
B. Explicitly teach and review specific content vocabulary.
C. Provide an advanced organizer for students to take notes. Include the following in the advanced organizer:
    a. Steps of the engineering process
    b. How each step applies to this lesson
    c. Student expectations for each step for this lesson
D. Provide students with higher needs a completed copy of teacher notes to decrease cognitive load
E. Use a Cloze or graphic organizer to classify information.
F. Follow all accommodations and modifications listed on the IEP.

## *Small-Group and Individual Exploration (50 min total -- 20 min for small group work, 30 min or more as needed for research):*

After the teacher has checked that the students understand their requirements, they will work in their small groups to:

- Brainstorm problems
- Select 2-3 problems to work on
- Define these problems
- Obtain approval from the teacher to begin research on the problems
- Begin researching the problems individually or in pairs

While the students are working on this, the in-person teacher will walk around the class checking on the students' progress. For a broadcast class, the teacher can join various breakout rooms to do the same. For an asynchronous class, the teacher should require a written or recorded answer, and can then provide feedback.

The teacher will want to check that the students are brainstorming ideas that are real problems that can be solved by engineering a device that converts one form of energy to another. Some students may want to work on a problem that is too large and vague for the constraints of this class (see the example from the lecture). The teacher should help these students narrow their problem to something manageable. Some students might quickly select well-defined problems, such as developing a way to use a solar panel to charge their cell phone. Other students might just want to play with and improve on the electric motor. The teacher will need to help these students do some reverse engineering with this. This electric motor is cool, but does it solve a real-world problem? Sometimes the problem leads to the solution, and sometimes the solution leads to the problem. If the students just want to play with a certain device and work on improving it, the teacher can help them figure out what advantages an improved device will be, and maybe this will help figure out the problem.

Once the teacher has approved the problems, individually or in pairs, the students will begin researching the problems using computers with internet access. Students need to research both the needs of the people the solution is for and what others have done to solve this problem. The teacher can provide additional instructions before the students begin research. For example, the teacher might require the students to find at least 3 web pages that address their problem or instruct the students to take notes on what is already commercially available, and identify the ways their solution will be better, etc.

The teacher should check on the students' progress while they are researching the problems to determine if they have had adequate time to conduct the research. The in-person and broadcast teacher should instruct the students to transition to small group discussions to decide which problem to work on.

## *Integration/Reflection (10 min):*

Once the students have researched the problem, they will need to decide which problem to work on. The research may have ruled out some problems that are too large or too small to solve in the time allowed with the resources available.

The teacher might want to lead a discussion on how to navigate this process.

- Each student should have the opportunity to present their preferred problem to work on and why. They may wish to argue that the problem is an important problem. They should argue that it is possible to solve with the time and resources available. They should argue that it meets the criteria.

- Talk moves are provided to help students navigate this process.
- After each student has presented their case, the group votes using consensus voting: Students signal their vote with their thumbs.
    - Thumbs-up indicates "yes, I want to do that!"
    - Thumbs-down indicates "absolutely not! I will never do that!"
    - Thumbs-sideways is "I'm not enthusiastic about that, can we talk about my concerns?"
- If a vote has any thumbs down or thumbs sideways, the discussion must continue with students presenting their arguments.
- The process continues until there is consensus.

The asynchronous teacher can require students to make their cases on a discussion page and vote virtually.

## *Suggestions for Specifically Designed Instruction in Small Groups*

A. Explicitly teach and post directions and expectations in a format that is easily accessible for students to access throughout the lesson.
    a. Small-Group Learning Objective in the engineering process
        i. Brainstorm ideas for engineering problems.
        ii. Define 2-3 problems.
        iii. Research these problems.
        iv. Select a final problem to begin the process of engineering a solution.
B. Suggestions for specifically designed instruction while working in small groups
    a. Give the Students with Disabilities the instructions prior to the activity.
    b. Allow students to see the questions to be answered before starting the station.
    c. Highlight main ideas and essential information in the instructions before the station activity.
    d. Provide graphic or advanced organizers to scaffold student learning and classify information.
    e. Provide an advanced organizer using a cloze procedure to note important information and main ideas.
    f. Reduce cognitive demand by assigning students to gather specific information rather than all information simultaneously.
C. Follow all accommodations and modifications listed on the IEP.
D. Suggestions for ensuring smooth transitions and procedures while working in small groups
    a. Explain and allow students to practice talk moves before working within their group.
    b. Describe and allow students to practice the actions of active listening before working in groups.
    c. Post and be explicit with time. Use a timer and give a 5-minute warning. Explain procedures if students finish the task early or do not complete the tasks at each station.
    d. Be clear and consistent on the format of note-taking, how work should be to be turned in, and expectations for mastery.

### *Suggestions for Specifically Designed Instruction for Online Research*

A. Post and provide the directions and expectations for the students.
   a. Select one problem to research.
   b. Find two websites that have information about solutions to this problem.
   c. List one solution for this problem from each website (two solutions total).
   d. Share your findings with your group members.
   e. Discuss with your group members the feasibility of creating these solutions in class.
   f. Based on your research, brainstorm other solutions that might work.
B. Provide acceptable web pages in advance by bookmarking the website or link in a google document or email.
C. Assign students a problem to investigate or decrease the number of choices.
D. Clear expectations for time and post and display a classroom timer.
E. Consider allowing students to work in pairs or with a peer.
F. Consider response types (e.g., verbal, written, paired).
G. Demonstrate model of expectation.
H. Extended guided practice with a teacher, paraprofessional, or peer.
I. Read aloud the information found on the website.
J. Follow all accommodations and modifications listed on the IEP.

# Elaborate: Engineering Solutions, part 2 Building a Device (90-150 min)

### *Student Objective:*

Students will design and build their solution by drawing a model showing how the device will be built, building a prototype, and iteratively testing the prototype, before selecting the optimal solution.

### *Overview:*

The elaborate part of the lesson completes steps 4-6 of the engineering process: Develop possible solutions using models. Analyze data to make improvements from iteratively testing solutions. And optimize a solution.

This part of the process is largely student-driven, the teacher will support the students by approving the diagrammatic models before the students start building prototypes, by providing resources to build prototypes, by brainstorming changes that can be made as part of the iterative testing process, by requiring the students keep notes on what changes they made and the results of these variations, and by providing insight into which iteration is optimal. However, the actual solutions being designed and tested will be varied.

## Materials:

Devices and other materials from the Explore section of the lesson

Additional building materials as available, ex. Cardboard, tape, glue, wires, motors, canisters, etc.

The teacher will give instructions on completing the next stage of the lesson, building and iteratively testing the engineering solutions. For an in-person or broadcast class, this can be done as a full-class presentation. For asynchronous classes, this can be done as a prerecorded lecture or as a reading. For hybrid courses, it would be best to begin this on an in-person day to verify that students understand their assignment and are able to progress on their online days.

For online (broadcast or asynchronous) and hybrid classes, the teacher will need to arrange for the students to obtain the supplies for the build and test part of the engineering process prior to beginning the lesson, and should have electronic versions of the instructions available to the students, using LMS and educational environments approved by the district/school. For a broadcast class, once students can join breakout rooms to design and test their devices. (If the district does not allow breakout rooms for students the teacher could decide to have full group discussions and individual answers, or arrange group discussions to occur online using the discussion board in the LMS or similar.) For asynchronous classes, students can use discussion boards or other district-approved meeting environments to discuss progress and assign tasks.

## Suggested teacher script:

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Now that we have identified our problems, done some research on our problems, and selected the one that we will be working on, we are going to start designing and building our solutions. Remember that engineering is a multistep, iterative process, so we are not jumping in and building immediately. You will need to draw up a couple of models of your solution. We are going to use the same process of consensus building as we just used to pick the problem to decide which design to build. Once you have consensus about your design, I need to approve it before you can start building.

Once you start building, you will need to make some measurements and test variations on your design. Once you have figured out an optimal design, you will need to create a presentation for the class about why we should invest in your design.

[Check to verify that students understand instructions, check that students are on track to begin this stage. Once the teacher has verified that students are ready, the students can begin working in their groups.]

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While the students are working on this, the in-person teacher will walk around the class checking on the students' progress. For a broadcast class, the teacher can join various breakout rooms to do the same. For an asynchronous class, the teacher should require a written or recorded answer, and can then provide feedback.

The teacher should provide support for the students as needed to progress in their engineering designs.

## *Suggestions for Specifically Designed Instruction in Small Groups*

A. Explicitly teach and post directions and expectations in a format that is easily accessible for students to access throughout the lesson.
   a. Small-Group Learning Objective in the engineering process
      i. Create 2-3 drawings of ways that your group can solve your problem
      ii. Choose one way of solving the problem.
      iii. Build a prototype of that solution
      iv. Iteratively test the solution
      v. Choose the best attempt
B. Suggestions for specifically designed instruction while working in small groups
   a. Give the Students with Disabilities the instructions prior to the activity.
   b. Allow students to see the questions to be answered before starting the engineering step.
   c. Highlight main ideas and essential information in the instructions before the engineering step.
   d. Reduce cognitive demand by assigning students to one consistent role during the engineering process.
C. Follow all accommodations and modifications listed on the IEP.
D. Suggestions for ensuring smooth transitions and procedures while working in small groups
   a. Explain and allow students to practice talk moves before working within their group.
   b. Describe and allow students to practice the actions of active listening before working in groups.
   c. Post and be explicit with time. Use a timer and give a 5-minute warning. Explain procedures if students finish the task early or do not complete the tasks at each station.
   d. Be clear and consistent on the format of note-taking, how work should be to be turned in, and expectations for mastery.

# Evaluate: Student Presentations (60-80 min)

## *Student Objective:*

The students will create an engineering solution proposal and present their proposals to the class.

## *Introduction (5 min):*

Once the students have finished prototyping their device, they will create a proposal to present to the class that explains their problem, why it is important, how their device solves this problem, and who their solution is for. This can be done "shark tank" or as a crowdsourced fundraising campaign.

The teacher needs to determine what format to use for the proposals and presentations. Any of the possibilities listed could work for an in-person class. For online (broadcast or asynchronous) classes, a prerecorded Powerpoint or Prezi presentation might work well. For a broadcast course, the Powerpoint can be made in advance but presented to the class during the synchronous meeting. For an asynchronous class, the teacher might require students to post feedback on some or all of their peers' presentations. For a hybrid class, students can create the presentations on an online day, and present these on an in-class day.

For an in-person class, students need at least one computer with internet access per group. Relevant COVID precautions could include: having students work in pairs rather than groups so that they can sit at opposite ends of the table and not face one another; having students access the online resources using their dedicated Chromebook or similar device rather than sharing a computer.

For online (broadcast or asynchronous) and hybrid classes, the teacher should have electronic versions of the materials available to the students, using LMS and educational environments approved by the district/school. For a broadcast class, students can join breakout rooms to work on the proposals. (If the district does not allow breakout rooms for students the teacher could decide to have full group discussions and individual answers, or arrange group discussions to occur online using the discussion board in the LMS or similar.) For asynchronous classes, students can use discussion boards or other district-approved meeting environments to discuss how they will create the proposal.

While the students are preparing their presentations, the in-person teacher will walk around the class, dropping into the various discussions, highlighting productive ideas, asking probing questions. For a broadcast class, the teacher can join various breakout rooms to do the same. For an asynchronous class, the teacher may require a written or recorded answer, and can then provide feedback to the group that highlights productive ideas and asks probing questions.

## *Suggested teacher script:*

The final step is to communicate our results. We are going to do this as a fundraising campaign. You will present your solution to the class and ask them to fund your idea!

[Give instructions on the format for the final presentation.]

Your poster/presentation should answer each of these questions:

- What is the problem you are solving?
- Who is this solution for?
- Why is this problem important?
- How does your device work?
- What energy conversions is it doing?
- How does this solve the problem?

You will have the rest of the class today to work on this, we will do presentations tomorrow.

[Remind students to upload their presentations before leaving class.]

## *Small-Group Presentation Preparation (20-30 min):*

Once students understand the instructions they can begin creating their proposals.

### *Suggestions for Specifically Designed Instruction for Presentation Preparation*

A. State and post expectations for preparing a PowerPoint presentation
   a. Expected time
   b. Tools that may be accessed (e.g., computer, completed notes, team member) to prepare the presentation.
   c. Independent vs. Group notes
B. Prepare advanced organizer of presentation with fillable document and/or slides that include:
   a. The problem you are solving.
   b. Who this solution is for.
   c. Why this problem is important
   d. Explanation of how the device works
   e. Description of energy conversions
   f. Description of how the device solves the problem
C. Post or create a representation of talk moves students may use when working in a group.
D. Assign students with disabilities the section of the presentation they will be responsible for preparing.
E. Narrow the presentation options (e.g., PowerPoint, Prezi, written document, oral presentation without visual representation).
F. Match the information with the pertinent section of the PowerPoint.
G. Limit the content to the information that has previously been researched and discussed.
H. Provide models and guided practice with a gradual release of learning to the student.
I. Provide a checklist to be completed of each task in the preparation process.
J. Follow all accommodations and modifications listed on the IEP.

### *Transition (5 min):*

Before beginning the student presentations, the teacher should set the classroom expectations. Students should listen actively during the presentations, and be prepared to contribute to the discussions following the presentations. All responses should be polite and respectful. During the full class discussion after the presentations, students should be prepared to respond to the presentations. Here are some possible responses:

- Students may agree with the presentations, and provide reasons to support the ask.
- Students may disagree with the presentations, and provide reasons for the disagreement.
- Students may ask questions about the proposals.

## *Presentations (30-50 min):*

The teacher will determine how to do this. This could be done as full class presentations, as online presentations, or in a "poster session" format. Whichever way this is done, the students who are the "audience" should engage with the "presenters" in the ways described above.

The teacher can use these presentations as the final assessment for this unit. Alternately the teacher can create a separate assessment where the students are assigned a device and a problem and asked to create a model that uses this device to solve that problem.

## *Suggestions for Specifically Designed Instruction for Proposal Presentation*

A. Create an advanced organizer with a script that includes:
   a. The problem you are solving.
   b. Who this solution is for.
   c. Why this problem is important
   d. Explanation of how the device works
   e. Description of energy conversions
   f. Description of how the device solves the problem
B. Allow the student to practice the presentation before presenting in class.
C. Consider alternate forms of presentation (e.g., just to the teacher, record in private and submit, oral presentation only, a visual demonstration only).
D. Provide clear grading requirements before the preparation and presentation of the proposal.
E. Explicitly teach and model expectations when being an audience member during peer presentations.
F. Follow all accommodations and modifications listed on the IEP.

## *Suggestions for Specifically Designed Instruction for Evaluation*

A. Follow grading expectations and give feedback for grading procedures.
B. Evaluate only the learning objectives of the lesson (e.g., reading, spelling, and quality of presentation skills are not a learning target in this lesson).
C. Consider holistic scoring.
D. Follow all guidelines in the student's IEP.

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