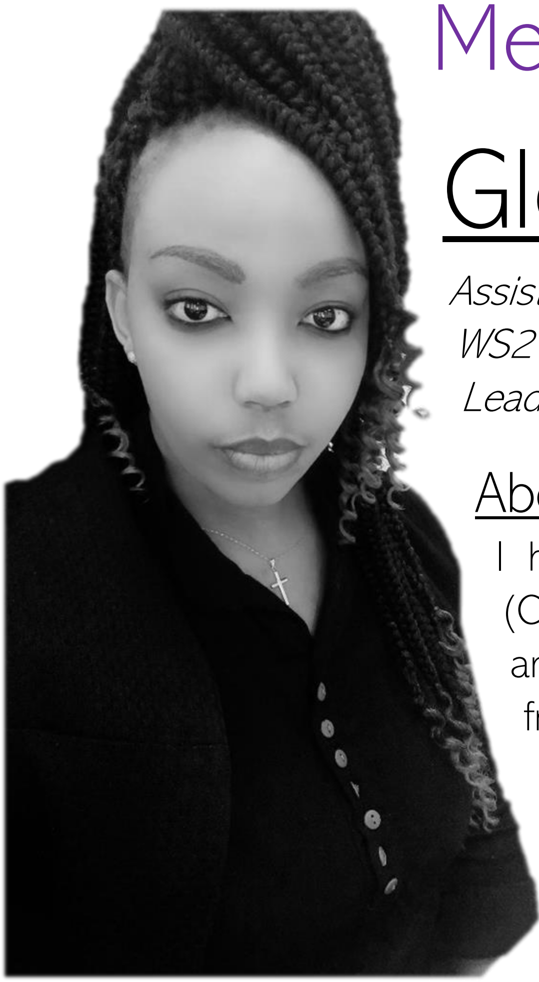
Energy Transfer:

Laboratory for Secondary Level Students

Student Manual

WOMEN SUPPORTING
WOMEN IN THE SCIENCES



Meet a Scientist

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About me:

I have a Bachelor of Science in Informatics (Computer Science) and Master of Information and Communication Science and Engineering from the University of Dodoma. My research is focused on machine learning and natural language processing, and I support STEM initiatives that promote gender equality and inclusion. Fun fact about me: I am a great singer and dancer!

When I was young ...

I wanted to be like one of my sisters whom I admired very much. Now we are both academicians and researchers although I never thought I would become one! I have always wanted to make change and leave a legacy, which is why I enjoy my work because I get to impact people's lives though knowledge sharing and solve societal problems through research.

My advice for students interested in science:

Continue pursuing your dreams no matter what other people say. Be prepared to be invested in your work: solving global challenges with science requires creativity and problem-solving skills.

Mission Statement

This laboratory will teach energy transfer concepts to a target audience of middle and high school/secondary-aged students (ages ~12-18) through experiments related to energy transformation, energy conservation, and thermodynamics.

Contents

1. Introduction to WS2 Laboratories

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to 5000 primary and secondary school students, predominantly in eastern Africa. The lab kits are intended to utilize local resources and include topics that are especially relevant to young girls in order to spur their interest in STEM subjects. The international teams, which designed the content found in these laboratory manuals, worked with WS2 Partners in eastern Africa in order to successfully deliver and teach the science lab kits to their local communities through 2022. WS2 gratefully acknowledges the hard work of the teams in the creation of this lab kit content. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 Partners receiving lab kits are representatives from Makerere University (Uganda), Masinde Muliro University of Science and Technology (Kenya), Mbeya University of Science and Technology (Tanzania), Mkwawa University College of Education (Tanzania), Nelson Mandela African Institution for Science and Technology (Tanzania), University of Dar es Salaam (Tanzania), University of Dodoma (Tanzania), and University of Rwanda (Rwanda). The APS, Materials World Modules, SciBridge, and Projekt Inspire have provided valuable input on WS2 lab kit design. WS2 especially thanks WS2 Partner representatives (John Bakayana, Pendo Bigambo, Daudi Mazengo, Lawrence Robert Msalilwa, Celine Omondi, Marcellin Rutegwa), Tom Coon and students of Haile-Manas Academy (Debre Birhan, Ethiopia), and Carla Johnston and students of Frank Bergman Elementary School (Manhattan, KS, USA) for piloting the lab kits with small focus groups in late 2021. WS2 also tremendously thanks the virtual lab kit design team that created the content for this lab manual.

1.2. Key Vocabulary

- Energy: The ability to do work; may exist in many forms (e.g., thermal, kinetic, chemical)
- Energy transfer: The movement of energy from one location or object to another
- Energy transformation: The change of energy from one form to another
- Energy conservation: The principle that the total energy of a system does not change, and energy can only be transferred or transformed
- Thermodynamics: The study of the movement of heat between different objects
- Updraft: An upward current of air
- Conductor: A material or substance through which heat moves easily
- Insulator: A material or substance through which heat does not move easily and often maintains its original temperature when exposed to heat

1.3. Key Questions

- What are different forms of energy?

- What is the law of energy conservation?

- What are ways in which energy can be transferred and transformed between different objects?

1.4. Purpose

The purpose of this lab is to demonstrate the power of energy transformations when energy changes from one form of energy to another. Energy is part of our lives every day; it is constantly changing and moving. Like when we eat and digest food or when we burn wood for fire, energy is transformed for practical purposes all around us every day.

2. Background on Main Topics

2.1. Energy and its Transfer and Transformation

The Sun is an extremely powerful source of energy; for centuries people have used the Sun as a source of reliable and renewable energy to cook food and warm themselves. Energy is the ability to do work or make something move or change in some way. Have

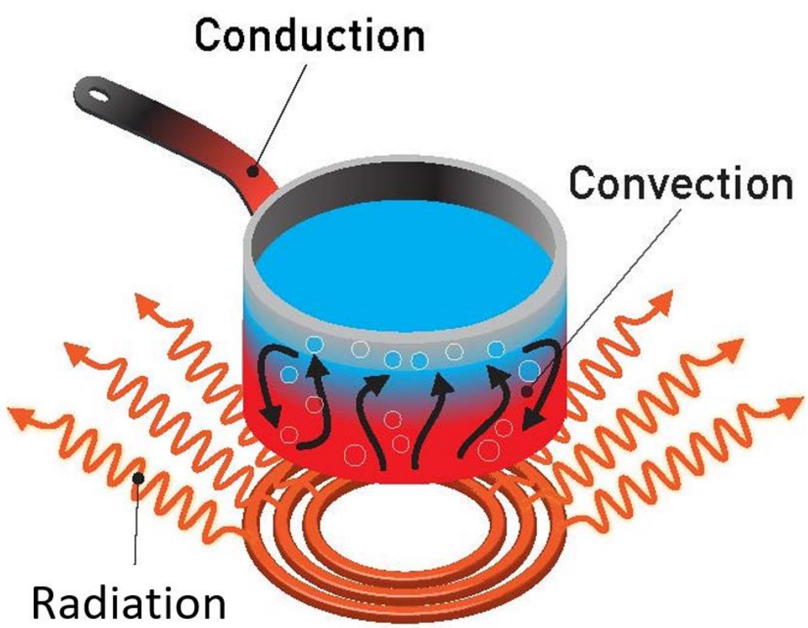

Figure 1. Heat transfer through conduction (direct contact with hot object), convection (flow of hot fluids), and radiation (transfer through space via waves) with a pot of liquid on a hot surface. This Photo by Unknown Author is licensed under CC BY.

you ever been chilly in the shade or indoors, but when you go outside you feel an instant warmth? That is the power of the Sun's energy! The Sun's energy gets to you by energy transfer, which is the movement of energy from one location or object to another. This transfer of energy, especially thermal energy like heat, can occur in different ways like through conduction, convection, or radiation. Conduction is the transfer of energy through a material, so if you touch something very hot, like a pot on the stove, the heat moves through the pot to your finger. Convection is the transfer of energy through fluids (i.e., moving water or air), like blood moving through your body to regulate your body temperature or a breeze that forms near an ocean or lake. Radiation is the transfer of energy through space by waves, like the transfer of the Sun's energy to you (this happens through light waves). Examples of these types of heat transfer are shown in Figure 1.

Of course, the Sun provides more than just heat, as it helps give plants the energy to grow and then we get energy from plants by eating them! This is called energy transformation, which is the process by which one type of energy (solar) is changed into another type (chemical energy), resulting in sugar or food that we can eat. There are multiple forms of energy, including kinetic/mechanical, thermal, electrical, chemical, radiant, and nuclear (Figure 2). The ways that these different forms of energies

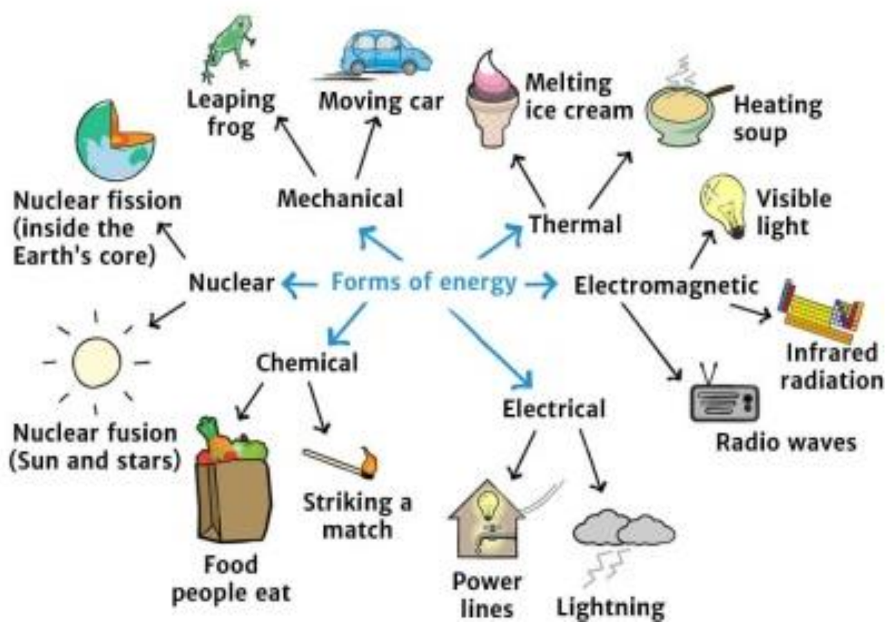

Figure 2. Many examples of forms of energy, including thermal, electrical, and chemical, and examples from everyday life, including lightning, food, and moving cars. Source: solarschools.net.

transform into each other is very useful in understanding cooking, animal growth, movement, and more! In recent years, there have been many technologies trying to use solar energy and transform it to electricity. This type of solar energy transformation, a technology called a solar panel, could help reduce carbon emissions that result from making electricity from fossil fuels by providing an alternate pathway to producing electricity.

One important scientific law, which is a description of observed phenomenon, is that energy cannot be created or destroyed. Instead, energy can only be transformed from one form to another. This is called energy conservation. The law based on the principle of energy conservation is known as the first law of thermodynamics. Thermodynamics is an important field of study that investigates the movement of heat between objects. Another important law related to thermal energy transfer is the second law of thermodynamics, which states that heat will flow from a hot object to a cold object. At some point, both objects will reach a balance of temperature, called a temperature equilibrium.

In various parts of our lives, we use specific materials for different purposes, especially when we want to transfer heat. When cooking, a pot made of metal is used because metal is a good conductor of heat. Something that conducts heat well means that the temperature equilibrium is reached quickly (i.e., there is no net flow of heat) when that object is placed near another object of differing temperature. A material that behaves opposite to a conductor is an insulator. An insulator does not transfer heat very well and thermal equilibrium is reached slowly when placed next to an object of differing temperature. Plastic is a good example of an insulator. Different materials have these varying properties, and we can use those properties to move heat more efficiently (or less) depending on the application for which we plan to use them.

In this lab kit, we are going to make use of energy transfer and thermodynamics concepts, which will end in the building of a solar tower. In a solar tower, energy is converted from solar energy to thermal energy to kinetic energy. First, solar energy hits the tower, which causes the air inside to heat up. Hot air rises, so the hotter air moves to the top of the tower. This updraft, or upward motion of air, causes the pinwheel to spin. The tower that is built in this experiment is a small demonstration of real technology, a solar thermal collector, which could be used for renewable energy conversion in the future.

2.2. Sources

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2.3. Supplies List

- Paper cups
- Plastic or Styrofoam cups (alternative: ceramic cups)
- Metal cans (should be empty and clean, some will require the tops and bottoms taken off per the experiment)
- Water, cool or chilled
- Tape
- Wire
- Needle/pin/thumbtack (alternative: sharpened pencil)
- Paper
- Books of similar heights
- Pen or pencil

- Scissors
- Black paint (optional)
- Paintbrush (optional)
- Thermometer (optional)

2.4. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- The needle/pin/thumbtack used can be sharp, so students should use caution when handling it so they do not accidentally prick themselves.
- Cutting the bottom and top of the metal cans can also be dangerous. Take caution if using a sharp razor. It is recommended that the teacher or facilitator perform this task for students ahead of time, if possible. Instead of a razor, teachers can use a can opener to remove the top and bottom of the cans or try another metal can, like aluminum, that is easier to cut.

3. Experiments

3.1. Part I. Heat Transfer

3.1.1. *Summary*

In this experiment, we are going to test how heat from cups/cans is transferred to water poured into the cups/cans and the impact of the cup/can materials in this transfer.

3.1.2. *Pre-Experiment Questions*

1. How does heat from a fire or the Sun warm you (or something else) up? Explain in your own words as best as you can.

2. How well does heat flow through different materials? Does heat flow through metals faster than plastics?

3. What types of objects would you want heat to flow through quickly and easily?

3.1.3. *Materials*

- 1 plastic/Styrofoam cup
- 1 metal can (empty and clean)
- 1 paper cup
- Water, chilled or cool, enough to fill cups/cans
- Optional: thermometer

- Optional: 1 additional metal can, black paint, paintbrush

3.1.4. *Procedure (work in groups of 2-4)*

If you have the optional additional metal can, black paint, and paintbrush, paint the outside of one metal can with black paint and let dry.

1. Place cups/cans ("vessels") outside in the direct sunlight on their sides or upside down. Leave the vessels in the Sun for at least ~10 minutes.
2. Measure the temperature of the cool water either with a thermometer or with your finger and record the temperature/description of temperature in Results. If you are using your finger, use descriptive words such as hot, warm, cool, cold, or rate the temperature on a scale from 1 to 10 where 1 is cold and 10 is hot.
3. Feel the outside of the vessels in the sunlight and record the description of temperature in Results.
4. Remove vessels from the sunlight and add the same amount of water to each cup/can.
5. Return the vessels to the sunlight.
6. After 1 minute in the Sun, measure with a thermometer or with your finger:
   - the temperature or description of temperature of the water
   - the temperature or description of the temperature of the outside of the vessel
7. Repeat the measurements in step 6 after 5 minutes in the Sun. Record all your results below.

3.1.5. *Results*

Vessel material	Water temperature before adding to vessel	Vessel temperature before adding water	Water temperature after 1 min	Vessel temperature after 1 min	Water temperature after 5 min	Vessel temperature after 5 min
Paper						

Plastic/Styrofoam						
Metal						
Metal with black paint						

3.1.6. *Post-Experiment Questions*

1. Which vessel caused the water to heat up the fastest? Which vessel was the slowest to heat up the water? Why do you think this was?

a. Extension question: Did the initial temperature of the outside of each vessel impact which vessel heated the water the fastest or heated the water the most at the end of 5 minutes? Especially consider the color of the outside of the vessel and what you know about light absorption.

2. At the end of 5 minutes, what do you notice about the temperature of the water and the feel of the outside of the vessels? Describe your observations in terms of heat flow (thermodynamics).

a. Extension question: What ways are the flow of heat in this experiment conducting? Radiating? Convective?

3. Consider a future experiment that <u>only tests one variable</u> about the vessel and this impact on the heating of the water. Describe what this experiment could be.

3.2. Part II. Solar Tower

3.2.1. *<u>Summary</u>*

In this experiment, we are going to show how energy transformations take place in a solar tower that you build.

3.2.2. *<u>Pre-Experiment Questions</u>*

1. Rub your hands together really quickly. What do you observe? Describe how energy is being transformed and transferred.

    a. <u>Extension question:</u> Based on what you know about energy and thermodynamics, what can you say about the total energy of this process? Was thermal energy created?

2. Look at the solar tower you will build in this experiment (see Figure 3). Once placed in the Sun, what impact do you think the Sun's energy will have on the solar tower? Consider the flow of energy from the Sun to the solar tower. What will happen next?

3.2.3. *Materials*

- 3 metal cans (should be empty and clean, with the top and bottom removed)
- Tape
- 15 cm (~6 inches) of wire
- 1 needle/pin/thumbtack (alternative: sharpened pencil)
- 13x13 cm (~5x5 inch) piece of paper
- 2 books (alternative: any two items of the same height that can be used as a platform to rest the tower on)
- Scissors
- Optional: black paint and paintbrush

3.2.4. *Procedure (work in groups of 2-4)*

1. Stack 3 tin cans vertically and tape them together. Make sure that the tape completely covers the gaps in between cans.
2. Lay two books side by side, leaving around 2.5 cm (1 inch) of gap in between them. Place them in an area that has sunlight.
3. Place the stack of 3 tin cans onto the books, so that the 2.5 cm (1 inch) gap is directly underneath the tower (see Figure 3a).
4. Bend wire into the shape of a semicircle.
5. Tape one end of the wire to the edge of the top metal can, tape the other end to the opposite edge of the same can.
6. Tape thumbtack onto the highest part of the wire with the point facing upward (see Figure 3b).
7. Fold paper into a pinwheel.

   a. Cut a piece of paper into a 13x13 (~5x5 inch) cm square.
   b. Mark the center of the square with a pencil.
   c. Cut 4 diagonal lines from each corner, stopping about 2.5 cm (1 inch) from the center of the square.
   d. Fold outer points of the square into the center of the square. Secure with a small amount of tape. See Figure 4 for reference.
8. Place the center of the pinwheel onto the thumbtack but do not push the thumbtack all the way through the pinwheel. The pinwheel should freely spin if you blow on it. The pinwheel should be perpendicular to the thumbtack. A completed solar tower is shown in Figure 3c.
9. Wait for several minutes while the solar tower is in sunlight and observe what happens. If the pinwheel turns, record the number of turns in one minute.

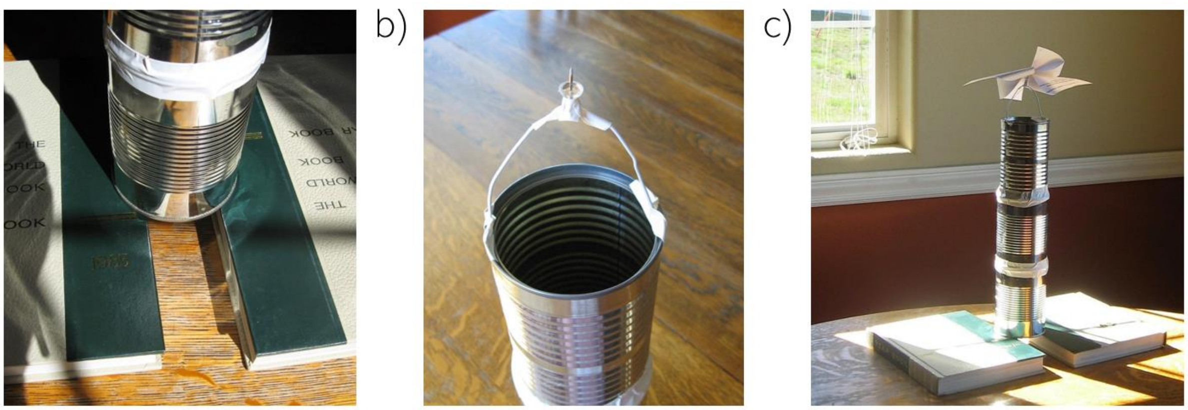

Figure 3. Solar tower construction. (a) Placement of tower on books. (b) Securing thumbtack to the top of the solar tower. (c) Final solar tower. Source: almostunschoolers.blogspot.com.

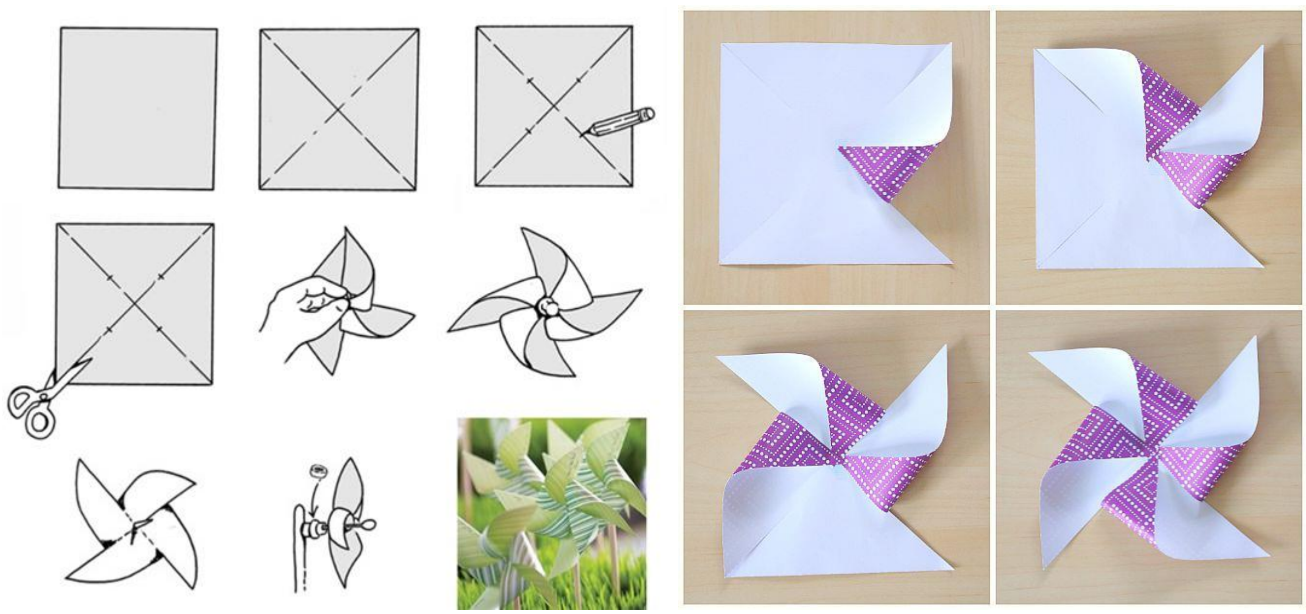

Figure 4. Construction of pinwheel by folding square piece of paper and securing points with tape. Sources: wonderfuldiy.com and buggyandbuddy.com.

3.2.5. *Results and Further Investigation*

Record your observations from the original solar tower configuration. Then, pick 3-4 questions to investigate the solar tower further. Before you change anything on your solar tower, make a prediction of what will happen.

Note: If the box has an "X" in it, you don't need to fill anything in.

Scientific Question?	How will energy transfer/transformation be changed?	Prediction of what will occur	Observations	Number of Pinwheel Turns per Minute
Original configuration	X	X		
What would happen if the tower was not on the books?				

What would happen if the tower was taller?				
What would happen if the tower was shorter?				
What would happen if the tower was not made from cans? What other material would be good to use?				
How would you change the pinwheel to spin faster?				
What if you used a smaller pinwheel?				
What if you used a larger pinwheel?				
What if the tower was painted black? White?				

What happens if you change how many books the tower sits on?				
What do you think would happen if you change the width of the tower to be smaller or larger?				
Your own question:				

3.2.6. *Troubleshooting*

Here are a few tips for getting the solar tower to work well:

- Make sure there are no gaps in between cans.
- There should be a small gap in between the two books.
- Pinwheel should be lightly resting on top of the thumbtack. If the pinwheel can't stay on the thumbtack, make a slight indentation in the center of the pinwheel (this will allow the pinwheel to balance better on the thumbtack). The thumbtack should not be pushed through the pinwheel.
- If it is a cold day or not very sunny, it may take some time for the pinwheel to turn, so be patient.

3.2.7. *Post-Experiment Questions*

1. What forms of energy were involved in this experiment? Explain how the energy was transferred and transformed. Was any energy created or destroyed?

2. What was the purpose of placing the tower on top of the two books? What happens if you don not have a gap between the table and the book?

3. When you modified the experiment, what happened? Why did this happen?

4. If this solar tower were a large-scale item (say, the size of a house or several houses), how could you imagine the spinning pinwheel could be used to do important tasks?

5. What are some other examples of the transformation of energy that you have seen in everyday life?

4. Design Challenge

The Challenge: Now that you have learned a bit more about energy transformation and transfer, let's consider a practical application: cooking! Since we know that the Sun is a powerful source of energy and have learned about ways to manipulate its energy into other forms, you can consider ways to use solar energy to cook food. Typically cooking requires some form of fuel: burning wood, gas, or using electricity. Since you learned a lot about how to transform energy and how energy is transferred, we want you to think about how to design a cooker!

4.1 Design Questions

1. If you were going to design a way to cook food, how would you build it? Think about two different ways you can do it.
    a. Consider:
        i. What materials would you use?
        ii. What form(s) of energy would you need?
        iii. How would you transform the energy?

iv. Is there a way to not use typical means of cooking? (i.e., no wood, gas, electricity)

v. Where would you want the heat to come from?

2. Will this design be useful for cooking food for a single person or family? Could it be used to cook food at larger scale for communities? How could you modify your design?

4.2 Design Sketch

Try out your designs by sketching it on paper. You can also color it in with markers, pens, pencils, and crayons. Be creative!

My methods for cooking food: