Teacher Guide
Exploring Greenhouse Gases, Global Warming, and Climate Change

Overview

This activity will introduce students to the topics of greenhouse gases, the greenhouse effect, global warming, and climate change. Students will create and test models to explore the greenhouse effect and the impact of greenhouse gases by tracking temperature change when heat is added to the model system. In addition, students will design and carry out sound experimental approaches in order to investigate how different environmental conditions influence the greenhouse effect and represent real-world conditions. This activity is designed for groups of 2-3 students.

Objectives

Students will:

- Understand greenhouse gases and the greenhouse effect, and their relationship to global warming and climate change.
- Apply their understanding of greenhouse gases and the greenhouse effect to design their own experiment.
- Construct, test, and evaluate models to investigate greenhouse gas effects and relate to real-world conditions.

Content Standards

This lesson is appropriate for high school students and addresses the following standards:

North Carolina Essential Standards

Earth/Environmental	EEn.2.61; EEn.2.6.2; EEn.2.6.3; EEn.2.6.4; EEn.2.8.1; EEn.2.8.4
Physical Science	PSc.2.2.4; PSc.2.2.5
Chemistry	Chm.2.2; Chm.3.1; Chm.3.2
Biology	Bio.2.1; Bio.2.2; Bio.4.2

Next Generation Science Standards

Grades 9-12, Disciplinary Core Ideas/Practices/Cross-cutting concepts:

DCI	HS-LS2 Ecosystems: Interactions, Energy, and Dynamics HS-LS4 Biological Evolution: Unity and Diversity HS-ESS2 Earth's Systems HS-ESS3 Earth and Human Activity HS-PS1 Matter and Its Interactions HS-PS3 Energy
Practices	Asking Questions and Defining Problems Developing and Using Models Planning and Carrying Out Investigations

	Analyzing and Interpreting Data Using Mathematics and Computational Thinking
Cross-cutting concepts	Patterns Systems and system models Energy and matter Stability and change

Time Requirements
Prep Time: *30 minutes*
Class Time: *2 x 45 minute class periods (Day 1:Engage, Explore Explain; Day 2: Elaborate and Evaluate)*

Materials
Included in the kit:
- 10 Light bulbs, 100w
- 10 heat lamps, 100W
- 20-30 16oz clear, plastic cups (can be reused for Parts 1 and 2)
- 1 roll of clear plastic wrap
- 1 small bag of soil
- 1 bag of sea salt
- 1 stack of construction paper
- 1 bag of black sand
- 1 bag of white sand
- 1 bag of light colored rocks
- 1 box of alka-seltzer tablets
- Small measuring cups
- Phenolphthalein
- pH strips

Needed, but not supplied:
- 10 lamp stands or ring stands
- 20-30 thermometers (temperature probeware sensors with corresponding software)
- Rulers
- Tape
- Data table printouts or laptops with Excel
- Optional: Plants, rocks, or other materials for Part 2 to modify models to relate to real-world conditions

Safety
Heat lamps may get hot to the touch. Wait 15 minutes after it is turned off before handling. Common household items such as water, salt, and alka seltzer are available for use in this lab. Students should be advised to not ingest any of these materials.
Ensure that students understand and adhere to safe laboratory practices when

performing any activity in the classroom or lab. Demonstrate the protocol for correctly using the instruments and materials necessary to complete the activities, and emphasize the importance of proper usage. Use personal protective equipment such as safety glasses or goggles, gloves, and aprons when appropriate. Model proper laboratory safety practices for your students and require them to adhere to all laboratory safety rules.

Background Information

Global climate change, a significant variation in Earth's average temperature and weather patterns over time, has occurred throughout the planet's history. However, in the past several decades, various climate data (e.g., an overall rise in surface air temperatures, the shrinking of ice caps, and rise of sea levels) have suggested that the planet is experiencing a period of rapid global warming. This is prompting scientists to examine the possible causes of this condition. One focus of these investigations is to examine the extent to which an increase in anthropogenic greenhouse gases in the atmosphere since the Industrial Revolution has affected global climate change. Mounting evidence suggests a correlation between increasing levels of carbon dioxide (a greenhouse gas) in the atmosphere and higher average global temperatures.

Greenhouse Gases. Land, water, clouds, water vapor, dust, and ozone can absorb incoming solar radiation as well as reflect and emit energy back into space. Greenhouse gases are gases in the atmosphere that allow relatively short-wave incoming energy to reach the surface, but trap longwave radiation near the surface. They absorb heat from the sun and trap it within the atmosphere. Examples include water vapor, carbon dioxide, methane, and nitrous oxide. Greenhouse gases comprise a fraction of the atmosphere, but they are essential for retaining heat. Without the greenhouse gas effect, most life forms on Earth could not survive. However, atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) have been increasing for decades, and continue to increase.

Carbon Dioxide. Carbon dioxide comprises approximately 0.0384% of the gas in the atmosphere, and is the second most abundant greenhouse gas. Although anthropogenic activity accounts for only about 5% of carbon emissions, the levels of atmospheric carbon dioxide have risen dramatically in the last 200 years due to the burning of fossil fuels (oil, coal, and natural gas) and the destruction of tropical forests and plants that take up carbon dioxide during photosynthesis.

Methane. Natural, anaerobic bacterial decomposition of organic matter produces methane, a colorless and odorless gas. Other natural sources of methane include wetlands, oceans, and termites. Human activities such as growing rice, raising cattle, using natural gas, mining coal, and burying waste in landfills add to the concentration of methane in the atmosphere. Melting of permafrost due to global warming can also be a source of methane released into the atmosphere. Methane is 20 to 30 times stronger than carbon dioxide at absorbing heat.

Nitrous Oxide. Anthropogenic nitrous oxide emissions originate from the use of agricultural fertilizers, the burning of organic waste, and the use and production of nylon. Human activity may account for up to 40% of total nitrous oxide sources, about 15 million tons per year. Nitrous oxide is 180 times more efficient than carbon at absorbing heat, and atmospheric levels continue to increase at a relatively uniform rate.

Carbon sinks. Plants, animals, and bacteria on land and in the oceans continually take up, release, and transport carbon. This creates sources and sinks of dissolved carbon that vary across ecosystems and through the seasons. Natural land-based carbon sinks include forests (absorbing 0.5 billion tons) and soils (net absorption of about 1.3 billion tons), and (absorbing about 2 billion tons of carbon).

Environmental conditions. When warming temperatures gradually melt sea ice over time, fewer bright white surfaces are available to reflect sunlight back into the atmosphere and back into space. More solar energy is absorbed at the surface and ocean temperatures rise. Warmer waters also hold less dissolved carbon dioxide (more atmospheric CO_2 remains).

There is also some evidence that shows the potential effects of “urban heat islands” to generate elevated heating in urban areas compared to rural areas (info here and here). The materials that comprise most city buildings and roads reflect much less solar radiation – and absorb more – than the vegetation they have replaced. They radiate some of that energy in the form of heat into the surrounding air. Fresh asphalt reflects only 4% of sunlight compared to as much as 25% for natural grassland and up to 90% for a white surface such as fresh snow. Some suggest adding more white, reflective surfaces as well as foliage to buildings and other city structures.

Additionally, when carbon dioxide gas (CO_2) dissolves in seawater, it combines with water molecules (H_2O) to form carbonic acid (H_2CO_3). The increasing amount of carbon in the oceans has led to oceanic acidification. Acidic oceanic conditions are detrimental to many ocean-dwelling organisms, in particular, marine plants and animals that utilize calcium carbonate to build shells and other hard structures. The acids react to dissolve calcium carbonate, making it more difficult for organisms to build these components. Many of the adversely affected organisms, including corals, sea urchins, phytoplankton, and pteropods, play a critical role in the ocean’s food web.

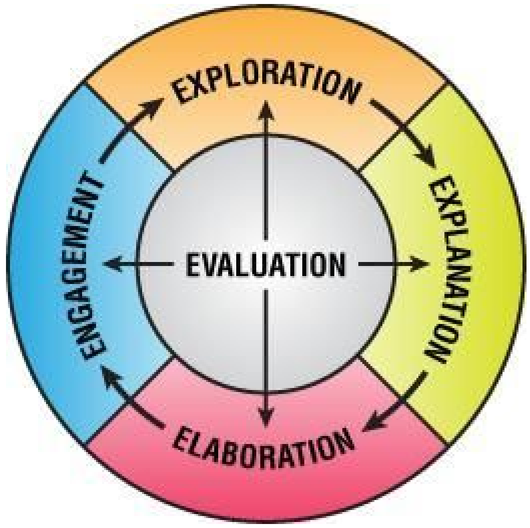
Preparation

1. (Days 1 & 2) Set up heat lamps: At each station, place a 100W bulb into the lamp. Clamp the lamp to a ring stand or similar surface. The bottom of the lamp should be nearly touching the lab surface. The cups should be 2 inches away from the lamp (you can place a strip of masking tape 2 inches from the lamp to indicate cup placement).

2. (Days 1 & 2) Give each group 2 thermometers, 2 16oz cups, a ruler, and a sheet to record data. Plastic wrap and tape can be shared between groups.

3. (Day 2) Place other materials in a centralized location for the students to share. These are optional materials for students to use to construct their models and design their experiments.

Guiding the lesson using the 5E Learning Cycle



Engage (Day 1 - 5 minutes)

1. Ask the class what how a greenhouse works to help plants grow, in their own words.
   Sample response: *Greenhouses are structures that keep plants warm by trapping heat from the sun.*
2. Introduce the greenhouse effect by asking students if they think Earth is a greenhouse, and why or why not. What makes the Earth like a greenhouse? Ask students what the Earth's equivalent of a greenhouse's glass/plastic is.
   Sample response: *Atmosphere*
3. Ask students what they already know about climate change. "How have you learned about it (news, social media, friends, family)? What do you want to know more about it?"
4. Show short video clip to introduce the activity.

Explore (Day 1 - 20 minutes)

1. Set up according to the steps outlined under **Preparation**.
2. Pass out the Day 1 procedure to each group. Each group will run the same experiment to model sound experimental design, replicate trials, and data analysis.
3. Assist groups as needed as they complete the first part of the lab.
4. As they finish, have them answer the provided questions for Part 1.
5. Students should graph their results either on graph paper or with Excel.
6. Optional: combine all collected data in Excel and graph as a class (as shown in the answer key).

Explain (Day 1 - 15 minutes)

1. Ask students: What does each cup represent? *Uncovered cup represents Earth with no atmosphere and no GHG. Covered cup represents Earth with an*

atmosphere and added capability of trapping heat under global warming conditions.

2. Ask a few students to share their observations, results, and conclusions. Ask if there were any inconsistencies in the class data and possible sources of error.
3. Ask students to try and explain what they think is happening in each of the cups and why they observed any differences.
4. Use the video, "How do Greenhouse Gases Work?" (link shown in supplemental materials) to explain the effect they saw and introduce greenhouse gases.
5. Optional: if you collected all class data in Excel, show the graph to the class and discuss any abnormal results. Use as an opportunity to discuss why researchers use multiple trials before accepting their results.
6. As a class, review the questions for Part 1 to ensure understanding.
7. Review any confusing/unclear concepts, referencing the experiment.
8. Ask if Earth's landscape is as simple as dirt and an "atmosphere".
9. Potential homework: Have groups start brainstorming environmental conditions that may affect the temperature change over time. Students can research to develop their own ideas, or the teacher can provide guiding questions (effect of light/dark sand or paper to simulate ice and dark water, or effects of urban heating; effect of elevated CO2 using alka seltzers, etc)

Elaborate (Day 2 - 35 minutes)

1. Groups will design a sound experiment and models to represent and test a real-world environmental conditions. Students should fill out the handout provided to design their experiment, and teacher should approve before students begin testing.
2. Have students use the materials provided to simulate their changes.
3. Assist groups as needed as they run their experiment and ensure they are following the same procedures as in Part 1.
4. As they finish, have them answer the remaining questions and begin clean up as needed.

Evaluate (potential idea)

1. In class, or as homework, have each group create a brief presentation on their second experiment. Students can present their results in class, relate to the real-world, and provide implications or recommendations for action.

Answers to Questions in the Student Guide

Part 1:

1. The cup system represents a simple model of the Earth. What do the cup, soil, and plastic wrap each represent in the model?

   Sample answer: Cup = earth. Soil = land. Plastic = Earth's atmosphere, with added capability of greenhouse gases trapping in heat.

2. What does the cup with no plastic wrap represent in a real-world context?

   Earth with no atmosphere and no GHG

What does the cup with plastic wrap represent in a real-world context?

Earth with an atmosphere, and added capability of greenhouse gases trapping in heat.

3. What variables are constant between both cups? Which variable differs?

   Sample answer: the amount of soil is constant; the amount of light/heat is approximately constant; the placement of the thermometer is close to constant; the plastic wrap differs

4. What happened when heat/energy was added to the cups? How did the CHANGE in temperature compare between the different systems while heating? While cooling?

   Sample answer: *The temperature increased more in the cup with the plastic wrap because less heat was escaping. The cup with the plastic wrap retained more heat even as the light was turned off and cooled.*

5. What are some possible sources of error in this experiment?

   Sample answers: *The cups aren't sealed completely so some heat/energy is escaping. The cups were slightly different distances from heat/energy source and therefore were not heated equally.*

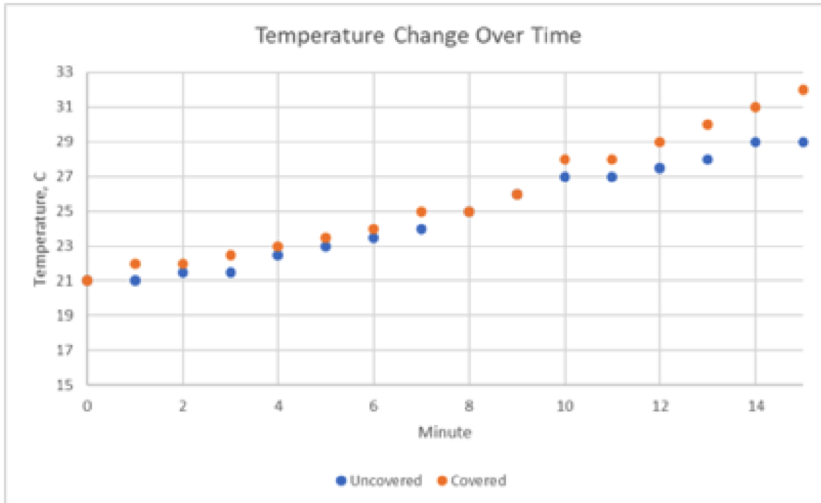
6. What are some benefits/advantages of using models? What are some disadvantages?

Part 2:

Answers are group specific, based on their choices of materials. See sample data for some results and explanations.

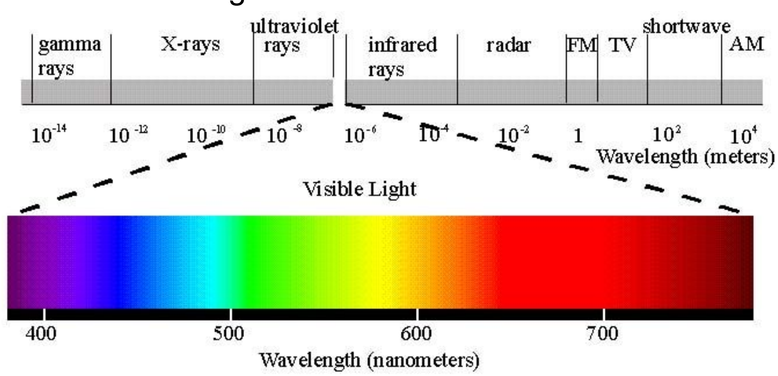
Sample Results for Part 1: Standard Procedure for "Explore" using soil in cups

Minute	Uncovered	Covered
	Temperature, C	
0	21	21
1	21	22
2	21.5	22
3	21.5	22.5
4	22.5	23
5	23	23.5
6	23.5	24
7	24	25
8	25	25
9	26	26
10	27	28
11	27	28
12	27.5	29
13	28	30
14	29	31
15	29	32

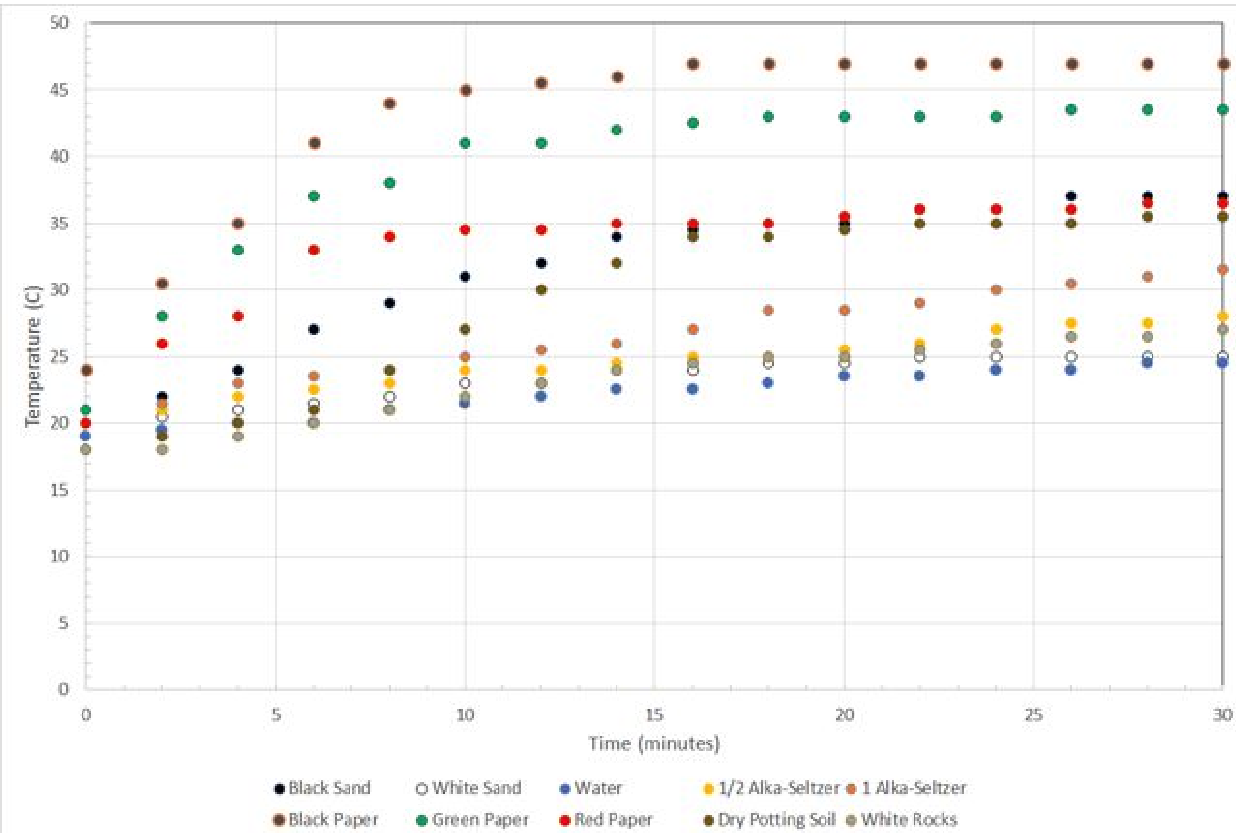


Sample Results for Part 2: Testing Different Variables During "Elaborate"

Above: Sample cups that may be tested, what they are testing is shown in table below. Sand (black/white), water (no alka-seltzer, 0.5 alka-seltzer, and 1 alka-seltzer), colored paper, gravel, and potting soil. These correspond to the results in the figure below.

Sample Cups	What is it testing? How can this relate to climate change?
Black vs White Sand	Black absorbs color and heats up quicker than white, which reflects light. As the polar caps (white) melt, less light is reflected and more is absorbed into the ocean/land (dark). This causes a temperature rise.
Water with varied amounts of alka-seltzer	When alka-seltzer reacts with water, CO_2 is released. CO_2 is the most well known and common greenhouse gas, so this experiment is a direct representation of how CO_2 can trap heat in our atmosphere. The cup with no alka-seltzer is a control, a normal atmosphere. As you add more alka-seltzer to water (in a SEALED cup), more CO_2 is released. A greater temperature change should be measured when more alka-seltzer is used.
Colored Paper	This experiment is similar in concept as the black vs white sand. This one, however, can begin to introduce different wavelengths and energy associated with the color spectrum. Perfect for a physics/chemistry course. See image below:  The smaller, higher energy, waves on the left cause a greater change in temperature than the larger, lower energy, waves on the right. Remind students doing this experiment what color is (you see the waves that a material is REFLECTING, so those are the waves trapped in your cup during the experiment, the rest are being absorbed by the paper).
Soil/ Gravel/ Other natural materials	This combination of materials can show the effect the landscape has on climate change. At this scale, the

	temperature changes observable will be based on color like the previous experiments. However you can begin a connection between this and the Heat Island effect (see supplemental resources). A dark gravel, representing asphalt or dark roof tops, versus light gravel/grass can help depict why cities tend to be warmer than rural areas, see articles in supplemental resources for additional information.



Above: Results of various materials heated for 30 minutes when 4 inches from heat source. They all tend to level off around 15-20 minutes.

Supplemental Resources

Carolina Biological Supply Company: Understanding Climate Change activity and kit	https://www.carolina.com/inquiry-science-human-influence/inquiries-in-science-understanding-climate-change/FAM_251417.pr
Carolina Biological Supply Company: Understanding Climate Change Teacher Manual	http://www.imsports.com/corporate/portfolio/Carolina%20Biological/Carolina%20Bio%20Manuals/251417%20Understanding%20Climate%20Change%20(Reader).pdf
Introduction to the Greenhouse Gas Effect	https://climatekids.nasa.gov/greenhouse-effect/
Video: How Do Greenhouse Gases Work?	https://www.youtube.com/watch?v=sTvqIijqvTg
EPA greenhouse gases website	https://www.epa.gov/ghgemissions/overview-greenhouse-gases
NASA Global Climate Change Website	https://climate.nasa.gov/evidence/
Introduction to the Heat Island Effect	https://www.nationalgeographic.org/encyclopedia/urban-heat-island/
Article: Urban Heat: Can White Roofs Help Cool World's Warming Cities?	https://e360.yale.edu/features/urban-heat-can-white-roofs-help-cool-the-worlds-warming-cities
How does sea ice affect global climate?	https://oceanservice.noaa.gov/facts/sea-ice-climate.html
NASA Satellites See Arctic Surface Darkening Faster	https://www.nasa.gov/content/goddard/nasa-satellites-see-arctic-surface-darkening-faster/
Albedo and climate change	https://energyeducation.ca/encyclopedia/Albedo
Creating a line chart in Excel	https://www.excel-easy.com/examples/line-chart.html

Name ______________________ **Student Guide**
Date _______________________

Overview
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Part 1

Materials
1 heat lamp, with 100W bulb
1 ring stand
2 16oz clear plastic cups
12 tbs soil
Plastic wrap to cover one cup
1 ruler
Tape
2 thermometers (standard or Vernier probe connected to device)
Data sheet or computer to record data

Procedure

1. Set up heat lamp if it is not already prepared: place a 100W bulb into the lamp. Clamp the lamp to a ring stand or similar surface. The bottom of the lamp should be nearly touching the lab surface. The cups should be 2 inches away from the lamp (you can place a strip of masking tape 2 inches from the lamp to indicate cup placement).
2. Grab two clear 16oz cups and fill both with equal amounts of soil, ~6 tbs each.
3. Cover one cup with plastic wrap, ensure it is sealed well so no air can escape. Tape may be used to help keep the plastic wrap sealed.

4. Poke a thermometer through the plastic wrap and have tip of thermometer touch soil in the center of the cup. Do not let it hit the bottom of the cup. You may need to add more plastic wrap around the thermometer to keep it air tight.
5. Place the two cups next to each other about 2 inches away from the heat lamp. Make sure they are both the same distance away from the light bulb.
6. Put the other thermometer in the uncovered cup. If the thermometer keeps sliding off, wrap tape, sticky side out, around ruler to hold in place.
7. Record initial temperature, then turn heat lamp on. **Caution:** lamp and materials will get hot, do not touch during experiment.
8. Record temperature every minute for 15 minutes. Begin answering questions.
9. After 15 minutes, turn off heat lamp and let cool. Continue recording temperature every minute for 15 minutes.
10. Finish answering remaining questions.
11. Graph data.
12. Clean out cups to use again in part 2.

Questions

1. The cup system represents a simple model of the Earth. What do the cup, soil, and plastic wrap each represent in the model?

2. What does the cup with no plastic wrap represent in a real-world context? What does the cup with plastic wrap represent in a real-world context?

3. What variables are constant between both cups? Which variable differs

4. What happened when heat/energy was added to the cups? How did the CHANGE in temperature compare between the different systems while heating? While cooling?

5. What are some possible sources of error in this experiment?

6. What are some benefits/advantages of using models? What are some disadvantages?

Part 2

Materials

1 heat lamp, with 100W bulb
1 ring stand
2 16oz clear plastic cups
Plastic wrap to cover one cup
1 ruler
Tape
2 thermometers (standard or Vernier probe connected to device)
Data sheet or computer to record data
Shared classroom materials to construct models (sand, gravel, paper, etc).

Procedure

1. As a group, decide what materials you are going to test. Use the handout to design your experiment. Remember that it should be controlled. Think about what variable you are testing. Make sure you can relate it to a real-world condition. Get these approved by the instructor before proceeding.
2. Set up your experimental cups. Cup 1 should be a control. Cup 2 should be your experimental cup.
3. Run experiment using steps 4-11 from Part 1.
4. Answer remaining questions.
5. Clean up materials as directed.

Questions

1. What are you adding to the cup? What are you trying to find out? What does this represent in real life?

2. Predict how your model will affect the temperature. What do you think will happen? Why?

3. Create a sketch or make an outline of how you will set up your experiment.

4. What happened? Did you observe anything surprising? Why did the temperature change (or not)? Think of possible scientific explanations ie insulation, absorption, reflection, etc.

5. What conclusions can you draw from your experiment?

5. If you had to re-design and re-test your models, what would you modify? Why?

Name ______________________

Date _______________________

Student Data Sheet

Part 1: Label Graph and Record Data Below

Part 2: Label Graph and Record Data Below