

Topic

2

**Modeling
Hot and Cold
Planets**

Activity A Modeling Hot and Cold Planets

Activity B Experimenting with Computer Models

**Activity C Approximating the Average Surface
(optional) Temperature of the Earth**

Topic 2

Modeling Hot and Cold Planets

Overview

Investigative teams are presented with a challenge to construct physical models of hot and cold planets in a way that will maximize the temperature difference between the two models. The aim is to design an experiment using physical models to evaluate the relative importance of some of the variables in a planetary system that influence average surface temperature.

Science Content

In Topic 1, several factors or variables that produce warming or cooling effects were identified. Comparing the surface and atmospheric features found on other planets in our solar system provided further evidence of these factors. Why does the average surface temperature on Venus hover around 430°C while that of Mars is approximately -45°C ? Such extremes are hardly found even in Earth's most inhospitable areas, the Sahara and the Antarctic. Earth's average surface temperature is 15°C . How can the planets in our solar system most similar to Earth have surface temperatures so vastly different from each other or from the earth? By the end of this study, teams will theorize about the relative importance of variables that influence temperature and habitability. Discovering ways the sun's energy interacts with a planet's surface to produce an average temperature will provide students with evidence to support their hypotheses.

Science Skills

Experimental design and measurement

An experimental proposal is prepared, including design plans for planetary models, a testable hypothesis, measurement protocols, and identification of independent and dependent variables. After the first round of experiments collecting temperature data, teams evaluate and modify their model and conduct a second round of experiments.

Data analysis and mathematical reasoning

Data collected from the hot and cold planet model experiments is used to compute the change in temperature from the start to the finish of the experiment. These data are plotted to observe the behavior of the temperature over time. Team results are compared to analyze the significance of each variable in influencing temperature and to prioritize variables. Students must use experimental evidence to justify their conclusions. To clarify the concept of average surface temperature, an optional activity is provided for students to use a global temperature data set to derive a value for Earth's average surface temperature.

Systems thinking, modeling, and technology

Preparing physical models of hot and cold planets requires thinking about the system inputs, variables, and outputs that interact to produce planetary surface temperature. Each team will evaluate their model's strengths and weaknesses. Computer software is introduced for students to simulate the physical model experiment. Strengths and limitations of this computer-based model are also discussed. The optional activity requires students to calculate the average surface temperature of the earth using their data collected. The instructor can decide to ask students to calculate the average by hand, using a calculator, or by using a computer spreadsheet program such as Microsoft Excel, to record data and calculate the result.

Considering a Real World Problem

Preparing for Mars Living in an Arctic Outpost

One of NASA's long-term goals is to create a human habitat on Mars. Great interest in this mission has led to a funded project to construct an experimental facility at the Haughton Crater on Devon Island, Nunavut, Canada. Here, scientists and engineers are developing and testing technical and human capabilities to live on a Mars outpost.

By the time students complete Topic 2, they will have identified and prioritized several factors that are needed to produce a habitable climate. Now they are presented with a real world problem to apply these preliminary ideas in the roles of researchers on engineering or science teams designing and constructing the Flashline Research Station to address several questions.

Is the Haughton Crater the best Earth location for an experimental Mars human habitat? What geologic and atmospheric conditions exist on Devon Island, Canada, that may have led to the decision to construct the facility here? What materials would you use to construct the habitat? How would your design produce habitable conditions for researchers to spend extended periods of time at the facility? Students will have to justify their plans and responses using evidence derived from the planetary modeling experiments they conduct in Topic 2.

Activity A

Modeling Hot and Cold Planets



4 class periods

Based on their Knowledge Maps from Topic 1, students are asked to design their own experiments to test hypothesized relationships about factors that influence planetary temperature and habitability.

A challenge is presented to the student investigative teams to design and construct models of two planets, one hot and the other cold, using a variety of materials. The aim is to produce the greatest temperature difference between these models using all the materials available. After the first round of experiments, teams reconvene to describe their findings and discuss the ramifications of their results.

A second round of experiments may be conducted after teams evaluate and redesign their experiments to improve their results. Based upon the results of all teams, students prioritize the factors tested from those with the greatest to least effect upon planetary temperature.

This activity concludes with a discussion of the strengths and limitations of physical models in describing real world phenomena and an introduction to mathematical computer models.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ Design an experiment to answer a specific question and test a hypothesis.
- ✓ Differentiate independent and dependent variables.
- ✓ Evaluate the results and suggest modifications to an experiment.
- ✓ Prepare a synthesis of experimental results to prioritize a set of parameters.
- ✓ Explain a conceptual relationship among temperature, energy inputs, and surface features.
- ✓ Describe strengths and limitations of physical models.

Materials

2 small plastic containers (to hold the models)
2 light sources (150 Watt light bulbs)
2 digital thermometers per team
Various colors of aquarium gravel
Various colors of modeling clay
Water
Sand
Rolls of cotton

Transparency sheets
Rolls of clear plastic wrap
Bag of aquarium moss

Engagement

Class Period 1

Teams examine the Knowledge Maps they prepared in Topic 1 and consider which of the factors would have the greatest effect upon the temperature of a planet. After some discussion, presentations are made concerning choices and rationale. The various suggestions are listed on the board. Pose the question: How can we decide which group is right? The ensuing discussion should produce the idea to conduct an experiment to test various hypotheses. At this point the experimental challenge and competition is presented to the class.

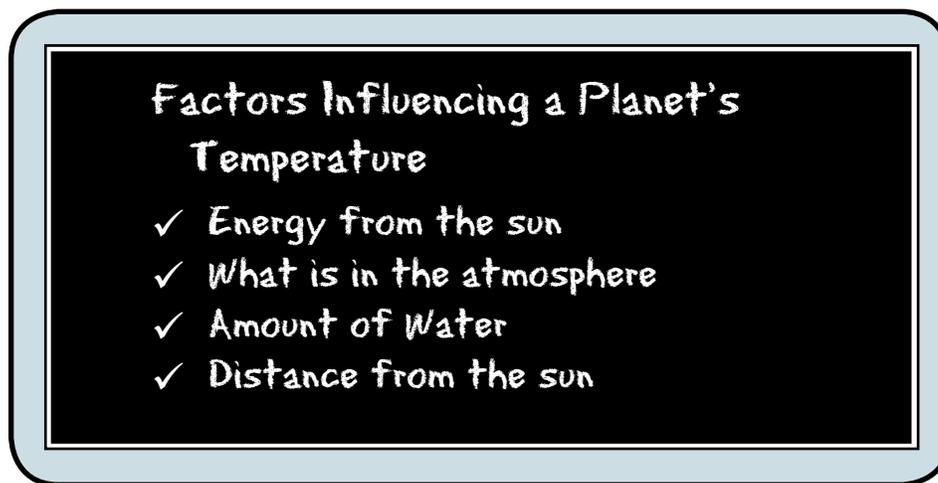


Figure 2.1. List suggestions from students on the board for factors that would have the greatest influence upon the temperature of a planet.

Procedure

Investigative teams with about five students each are organized. Each team is charged with the task of designing an experiment that tests their hypothesis about the variable with the greatest influence on planetary temperature. Before separating into teams, a brief discussion is held about what materials will be needed to conduct the experiment. This list is compared to the materials available to the class. If possible, additional materials requested by students should be added in time for the next class period.

The first two handouts, Investigation Overview and Investigation Team Members are given out so that teams can organize how their experiments will be carried out. Each team selects a Lead Researcher. There are also Materials and Data Managers and Experimental Communications roles for the hot and cold planets. An Experimental Design Proposal and Methodology for a Controlled Experiment is completed by each team.

Remind teams that the aim of the experiment is to maximize the temperature difference

Teacher Notes

between their hot and cold planet models; with the constraint that only one factor can be varied between their models. All other factors must be identical.

Investigative teams set up their experiments based on their proposals. The common measurement protocol for all teams is to record temperature over a 20 minute period for both the hot and cold planet models. Measurements are recorded on the Data Sheet. As the experiments are being set up and conducted, the teacher visits each team to observe procedures and answer any questions. At the end of the experiment, students complete the handout: Experimental Results. Also, it's a good idea for the teams to re-examine their Methodology for a Controlled Experiment and make any necessary revisions based on what they learn in the experiment.

Class Period 2

Consensus

Teams reconvene to present and discuss their experimental results and suggested design improvements. The next handout is distributed, Investigative Team Consensus. Results of all the experiments are described on the board. A discussion is held to prioritize the factors affecting planetary temperature based on the results. Have teams explain their reasoning, considering the rate and magnitude of temperature change and the dependent and independent variables. The discussion should end with a consensus on the priority of factors. The handout, Priority of Experimental Parameters, should be completed at this time. Teams can conduct a second round of experiments to implement modifications they think may achieve greater temperature differences.



Figure 2.2. Setup of the experiment.

Optional: Teams perform redesigned experiments and complete Investigation Questions.

Class Period 3

Synthesis

Class Period 4

Several questions are posed and discussed. The Viewgraphs from Topic 1 can be used as a reminder of these planetary conditions.

1. What are the strengths and limitations of physical models?

Teacher Notes

2. How well do you think physical models simulate the actual temperature differences found on real cold and hot planets, in particular - Venus and Mars?
3. How well does your energy source simulate the sun's energy? Is your energy source the only source of energy in the room?
4. Why are the physical models unable to show the magnitude of difference observed between the real planets?
5. What could be changed in the physical models so that they can better mirror real planets?
6. What alternative ways of modeling are there?

Question 6 above provides a context to introduce the idea of using a computer model as a tool for understanding how a system works. See Reference: Mathematical Models.

A Word of Caution to the Teacher: If the students use the plastic wrap to cover one of the containers and observe an increase in temperature in the container be careful during the discussion that follows. The plastic wrap does behave in the same way as a blanket or the roof of a greenhouse in that all three of these stop heat from moving out from under them by preventing convection. The air beneath these objects is warmed, becomes less dense, and tries to rise, but the plastic/greenhouse roof/blanket blocks this rise and the hot air stays where it is. This is *not* however the way the atmosphere works. The atmosphere does not prevent convection, and in fact, encourages it. Certain gases in the atmosphere (the Greenhouse gases) absorb the heat emitted by the earth's surface, and in turn emit heat on their own. Some of the emitted heat is directed back towards the surface, and increases the amount of energy absorbed at the surface, warming it. While this effect is named "The Greenhouse Effect", it does not work in the same way as a greenhouse, blanket or the plastic wrap. The students will get a full explanation of the Greenhouse Effect in Topic 4, Activities A and B. At this point it would probably be best to avoid saying that the atmosphere acts like a Greenhouse to warm the earth. A better statement at this time would be "The plastic wrap causes the temperature to increase in the container. The atmosphere of some planets causes the temperature of the planet to increase, but the mechanism/process is not the same. We will learn how this works at a later time."

Activity B

Experimenting with Computer Models



3 class periods

To familiarize students with the functions of a mathematical model, computer courseware that simulates an experiment similar to the one conducted in Activity A can be used. Experiments can be run with the Radiation Balance Model found at the web site: <http://icp.giss.nasa.gov/education/modules/eccm/model/>. For this investigation, we are primarily concerned with Experiments 1 and 2. Experiment 3, which deals with the relationship between molecular speed and temperature is included as advanced study or an extra credit problem. Experiments 1 and 2 engage students in an investigation of the ability of an object, particularly the planetary physical model they constructed, to maintain an equilibrium temperature.

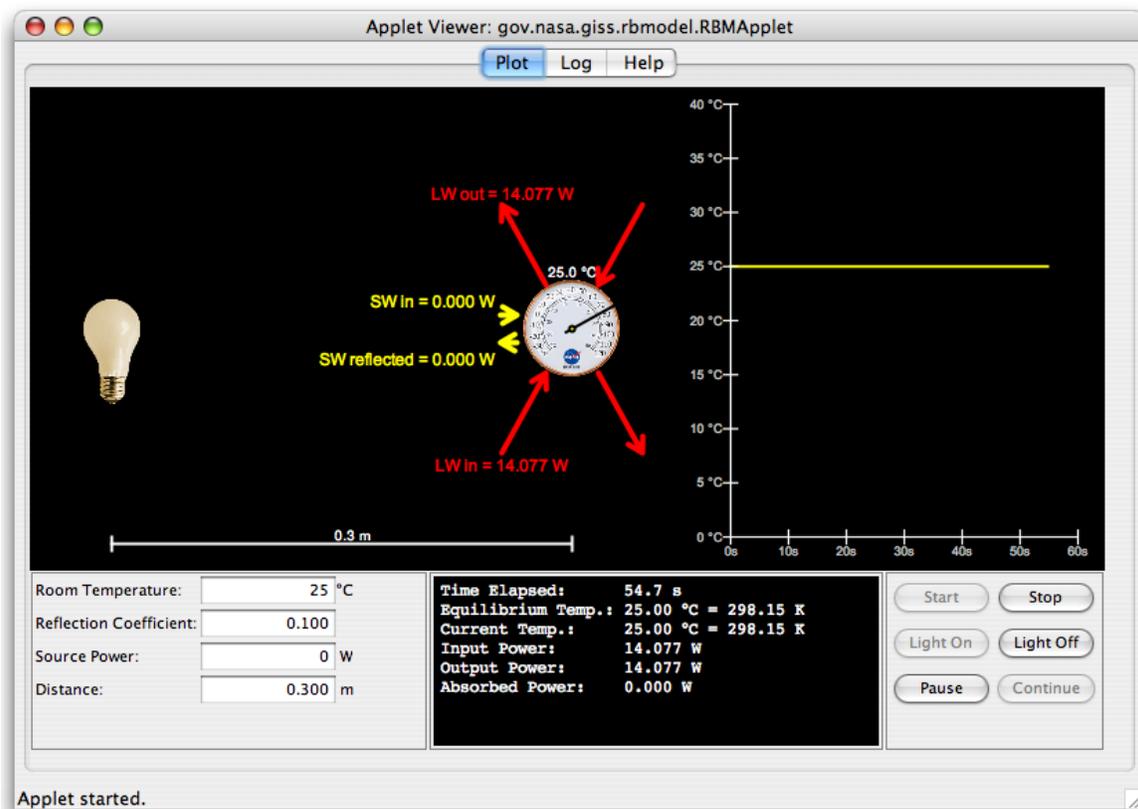


Figure 2.3. Screen shot of the Local Radiation Balance Computer Model. No energy is emitted from the source, during this experimental run, resulting in a constant temperature for the object.

The Radiation Balance Model is a tool that can be used to examine the energy inputs and outputs of a simple system. Specifically, the simulation provides a means to study the relationships between the equilibrium temperature of an object and its distance from an energy source. It can also be used to determine how equilibrium temperature and the reflectivity of a surface are related. These relationships provide a qualitative understanding of the Inverse Square Law. (Refer to <http://www2.jpl.nasa.gov/basics/bsf6-1.html> for a definition of this law.)

Experimental results will enable students to discuss implications of conservation of energy and the factors that establish equilibrium temperature. The activity concludes with a comparison of physical and computer models, evaluating their strengths and limitations in simulating the conditions on Mars and Venus.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ Describe an equilibrium temperature.
- ✓ Identify the factors leading to an equilibrium temperature.
- ✓ Relate the temperature of an object to the energy it emits.
- ✓ Relate the temperature of an object to the reflectivity of its surface.
- ✓ Identify major energy inputs and outputs of a system.
- ✓ State and apply the Law of Conservation of Energy.
- ✓ Qualitatively relate “distance from the source” to the “energy incident upon an object.”
- ✓ Describe relative strengths and limitations of physical and computer models.

Materials

Computers to run the Radiation Balance Model. It is suggested to have a maximum of two or three students per computer.

To use this model, you will need:

- ✓ A Windows or Apple based PC
- ✓ A web browser enabled with Java Version 1.3 or higher (Any Mac with OS X version 10.2 or better will include Java 1.3. Windows users may have to download and install the runtime version of Java from <http://www.java.com/>. You will need Administrator rights for this installation.)
- ✓ The courseware (a Java applet) loaded into your web browser: available at <http://icp.giss.nasa.gov/education/modules/eccm/model/> – see Education Tools, Earth Climate Course Computer Models for Module 1.

Engagement

Class Period I

Start by discussing the limitations of the physical box models that were used in the previous activity to simulate hot and cold planets. The box models were used in a room that was already warmed or cooled by a radiator or an air-conditioner. What would have happened to the box model temperatures if the room temperature was changed? Each experiment was run for a certain length of time and then the light was switched off. What would have happened to the temperature if the lights were kept on? Would the temperature keep rising?

Discuss possible outcomes (the model melts, temperature keeps going up, temperature

Teacher Notes

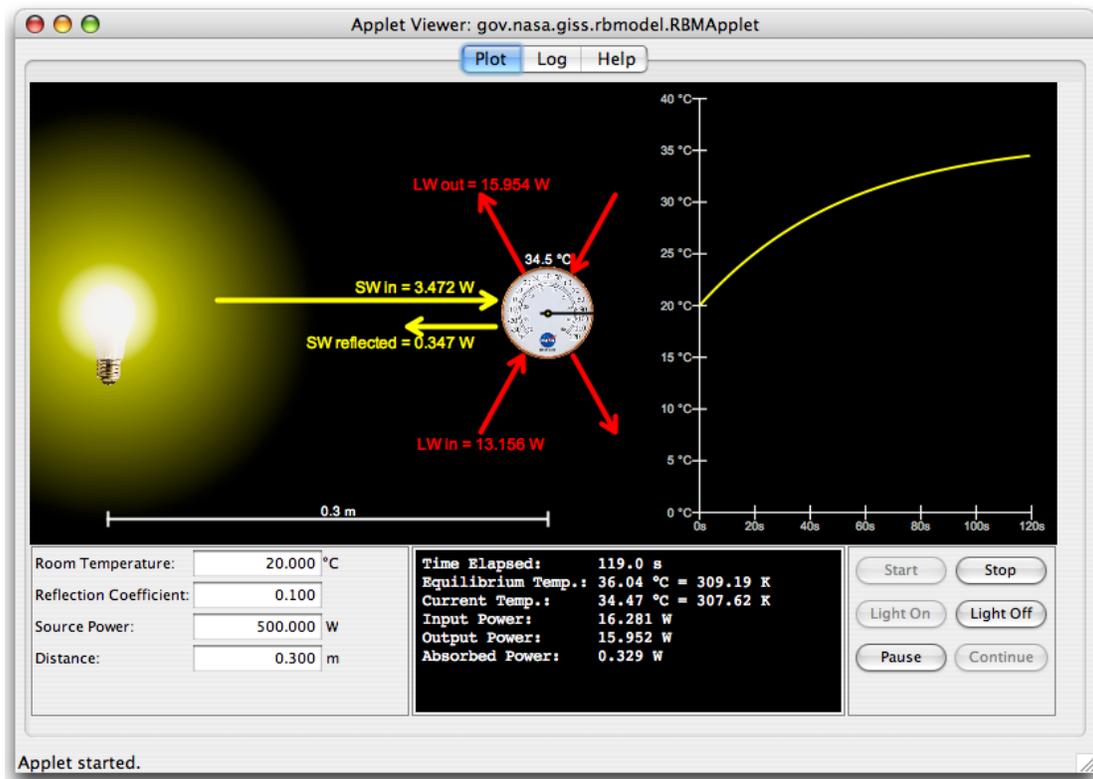


Figure 2.4. An experiment in progress using the Local Radiation Balance Computer Model.

remains constant, temperature goes up and then down, etc.). Write students' hypotheses on the board and ask them how we can determine which hypothesis is correct. A student should suggest performing the physical model experiment in Topic 1 and leaving the light on for a longer time. This is an excellent idea, however it will take too long (more than the class period) to see any meaningful results. Ask students to consider the Reference: Mathematical Models. Could such a model allow us to simulate a lengthy physical modeling experiment in a short amount of time?

Procedure

Suggestion: Conduct this class session in a computer lab. Students are introduced to the Radiation Balance Model. The Reference: Introduction to the Radiation Balance Model should be reviewed first to explain the model's features and experiments. Instead of doing the proposed experiment with the physical model, the class will use this computer simulation of the experiment to test out their hypotheses and determine the usefulness of the computer model. The model allows the student to vary the reflection coefficient (albedo) of the object, the room temperature, and the distance between the light source and object.

Divide the class into groups of two to three students each to run the Radiation Balance Model. Distribute Experiment 1: Data Sheet that provides the experimental procedure and space to record observations of the resulting "final" or equilibrium temperature. Emphasize that only one variable is being changed at a time in each experiment.

Have the different groups in class describe and compare results. They should observe that the model temperature eventually stops rising and maintains a constant temperature. Elicit hypotheses as to why this occurs. Even though energy is continually supplied to the model, the model maintains a constant temperature. By examining the graph produced by the model, the user should observe that the total energy entering the simulated object is equal to the total energy leaving it. Elicit: Why do different distances produce different equilibrium temperatures?

Please note that the Radiation Balance Model expresses its inputs and outputs in terms of power while most of the questions ask about energy. The teacher should define Power (Watts) as the amount of Work (Joules) done each second, so that a 400 Watts input would mean that 400 Joules of energy come into the system each second. When dealing with the energy questions, have the students consider the amount of energy involved each second, and that the total amount of energy increases over time.

Class Discussion

Class Period 2

Suggestion: Conduct this class session in a computer lab. Review explanations for constant temperatures of the model despite a constant supply of energy. Elicit: Can students think of other examples of equilibrium temperatures?

Possible answers:

Temperature of human body

Room temperature

Temperature of an oven while baking

In each of these cases we have a system with a source of energy (Energy Input). Have the students identify energy sources for each of these systems.

We must ask ourselves, where does the energy go? What does it do? In the case of an oven, possible answers may include that some energy goes to raising the temperature of the stove and its contents. Why do they “feel” hot to the touch? They emit energy to their surroundings because they are at a higher temperature than their surroundings. This is the energy output of our system.

Distribute Experiment 2: Data Sheet, and have groups conduct computer model simulations to study the relationship between equilibrium temperature and the reflection coefficient (albedo) and the temperature-distance relationships leading to the Inverse Square Law.

At the end of this class period, the Investigation Questions, can be assigned as homework. This will be discussed during the next class period to facilitate students reaching a consensus about what was learned.

Because the temperature of the models (or other systems) remains constant, what must be true about the energy inputs and outputs of the system? Possible answers may include that these values must be equal. Why?

If Energy Input = Energy Output, then the temperature will remain constant.

If Energy Input > Energy Output, temperature will increase until inputs and outputs are equal.

If Energy Input < Energy Output, the temperature will decrease until they are equal.

What happens to the energy going into the system?

The object reflects some of the energy.

The object absorbs some of the energy.

The energy absorbed by the object causes the particles within it to move faster. This corresponds to an increase in kinetic energy of these particles and an increase in the temperature of the object. (One form of energy is transformed into another type of energy.)

Synthesis

During this portion of the class, what was learned in the computer modeling activity can be related to the Law of Conservation of Energy, (See the reference at http://en.wikipedia.org/wiki/Conservation_of_energy for background on this law) the importance of the Inverse Square Law, and the use of computer models in studying the earth system.

Once the object's temperature is higher than its surroundings, it begins to release energy to those surroundings in the form of electromagnetic radiation (visible and non-visible light waves: for example, heat or infrared waves). The higher the temperature of the object, the higher will be the frequency of emitted radiation and the greater the amount of energy released.

The temperature is related to the energy input by:

$$T = \frac{1}{2} \sqrt[4]{\frac{(1 - \alpha) E_{\text{source}}}{\pi \delta D^2}}$$

where:

α is albedo,

E_{source} is total energy outputted by the source,

δ is the Boltzmann constant ($5.67 \times 10^{-8} \text{ W}/(\text{m}^2\text{deg}^4)$), and

D is distance between the source and the object.

In any system, the total amount of energy entering the system must be taken into account. Energy cannot be created or destroyed. It can only be transported and transformed. This is the Law of Conservation of Energy. In terms of our systems:

$$\begin{aligned} \text{Energy into a system} &= \text{Energy } \mathbf{reflected} \text{ by the system} \\ &+ \text{Energy } \mathbf{absorbed} \text{ by the system} \\ &+ \text{Energy } \mathbf{emitted} \text{ by the system.} \end{aligned}$$

And since this must be true each second, these relationships can also be expressed in terms of Power:

$$\begin{aligned} \text{Power into a system} &= \text{Power } \mathbf{reflected} \text{ by the system} \\ &+ \text{Power } \mathbf{absorbed} \text{ by the system} \\ &+ \text{Power } \mathbf{emitted} \text{ by the system.} \end{aligned}$$

Approximating the Average Surface Temperature of the Earth



1 class period

After studying some of the relationships that play an important role in determining the temperature of a planet, it is a good time to introduce the concept of average surface temperature. This activity can either be conducted in the computer lab using the Internet or by using the Reference: Global Temperature Data.

Learning Objectives

By the end of this activity, students should be able to:

- ✓ Utilize a data source from the Internet.
- ✓ Determine the average temperature of the earth.
- ✓ Specify the characteristics of a sampling necessary to achieve an accurate average.

Materials

Computer with access to the Internet. If you do not have Internet access, use the Reference: Global Temperature Data provided on page 56 in the Student Activities.

Engagement

What is the average temperature of the entire earth? This value, 15°C, was discussed in Topic 1. A range of answers may be given. These may include the current temperature outside, room temperature, etc. After listing these temperatures on the board, pose the question: How do we determine which value is correct? After some discussion, the students will realize that at any given instant there are a variety of temperatures existing over the earth's surface.

Refer to the map, figure 1.1, in Topic 1 entitled, Global Measured Temperature Extremes. Identify a range of temperature extremes, as well as more comfortable or typical temperatures. The class is presented with a challenge to report a single temperature value that represents the temperature of the earth. What value should be reported? A decision to calculate the average temperature should be made.

Procedure

In the Computer Lab

Groups of two to three students are directed to the USA Today web site to obtain global temperature data: <http://www.usatoday.com/weather/forecast/wglobe.htm>. A minimum of 20 temperatures should be recorded on the Data Sheet, representing a variety of locales

around the world. Individual groups average data values and report them to the class so that a class average can be computed. How close did the class get to Earth's average surface temperature of 15°C?

Note: The actual value for the average temperature of the earth can be obtained by several different ways. For example:

1. from infrared temperature measurements of the bottom 15,000 feet of the earth's atmosphere, taken by NASA satellites, or
2. averages of readings from thermometers at the surface.

In the Class

Groups of two to three students are given the Reference: Global Temperature Data. A minimum of 20 temperatures should be recorded on the Data Sheet, representing a variety of locales around the world. Individual groups calculate average data values and report them to the class so that a class average can be computed.

Consensus

The Investigation Questions are completed prior to conducting a class discussion concerning the following two questions: How close did the class get to Earth's average surface temperature of 15°C? How many data points do we need to derive a "good" average temperature?

Synthesis

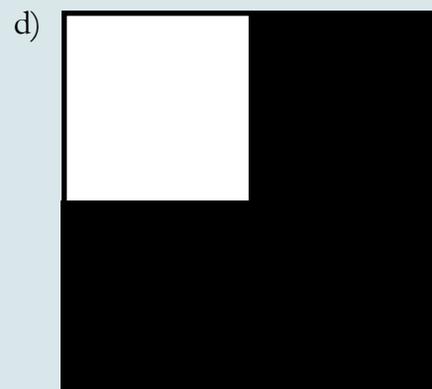
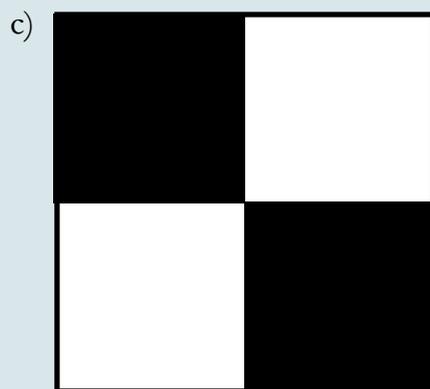
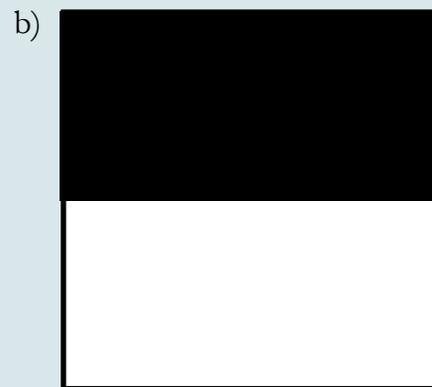
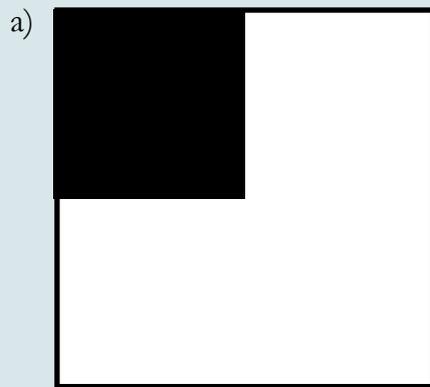
Researchers are constantly in a position where they have to determine how much data is needed to study a problem and derive credible results. In calculating an average surface temperature for Earth using several data points around the globe, students can gain an appreciation for scientific decision-making, and the type and number of measurements that need to be taken.

Evaluating Student Work

Topic 2. Modeling Hot and Cold Planets

Activity A – Investigation Questions

1. The following diagrams represent four parking lots in New York City. With all other factors being equal, which of these lots would have the highest daytime temperature?



2. The temperature in New York City is projected to rise in the next few decades. Suggest ways to make the city a ‘cooler’ place to live.
3. A student wants to know how changing the material of a surface affects the temperature of the surface. She performs identical experiments, each time only changing the material. She uses sand, cement, glass, ice, polished aluminum, dry soil, and soil with grass. In each case, she places the surface 50 cm below a 250 Watt light source and measures the temperature of the surface every 30 seconds for 10 minutes. She records the results in a data table in her notebook.

Which of these factors is the independent variable in her experiment?

- a) the light source
b) the type of material
c) the temperature
d) the time taken

4. A student prepares four different models of planets using small plastic cups to represent the planets. The four models are constructed from different materials and placed at different distances from different light sources. The descriptions of the models appear in the table below.

Which two models could be used to determine the effect of a single factor on the model temperature?

- a) I and II
 b) II and III
 c) III and IV
 d) I and III

Model	Light Source	Distance	Material
I	250 W	20 cm	Red Clay
II	100 W	20 cm	Green Gravel
III	250 W	50 cm	Red Clay
IV	100 W	50 cm	Red Gravel

5. You are an architect who has been asked to design a new library for a small town on the north shore of Hudson Bay in Canada. Based upon the ideas you have developed in these activities, what features might you consider including in your design so as to make the library comfortable for its patrons with the least expense?
6. During the planning of NASA's Apollo missions that took humans to the moon, the design engineers had to ensure that the habitability of the spacecraft would be maintained throughout the week-long mission. Based on the concepts you have learned in this activity, what would you expect were some of the features incorporated into the spacecraft's design so that a comfortable temperature was maintained? Explain each of your choices. If necessary, use an extra sheet of paper.

Answer Guide – Questions 1, 3, 4, and 6

1. d.
3. b.
4. d.
6. The student should realize that solar radiation would be a primary source of heating, mention that light-colored materials were used for the body of the spacecraft in order to prevent overheating from solar radiation, and explain the relation between a body's color, its reflectivity, and its temperature. More complete answers that deal with thermal isolation of the spacecraft from the cold outside temperatures should receive extra credit.

With sufficient research, students should also discover that it is common practice to rotate spacecraft while they are in space so that no particular part of the spacecraft is continuously exposed to sunlight. They may also note that in the future, as spaceships are sent further out into the solar system, these issues will be less important with the increasing distance from the sun.

Activity B – Investigation Questions

1. A Bunsen burner is used to gently heat a beaker of water initially at room temperature. After several minutes, the temperature of the water is observed to stop increasing and remains constant. This final temperature is well below the boiling point of the water.
 - a) What conclusions can you make about the energy inputs and outputs of the beaker under these conditions? Explain your reasoning.
 - b) What would you expect to happen if the strength of the flame of the Bunsen burner is increased slightly? How do the energy inputs and outputs of the beaker/water system differ from your answer in question (a)? Explain your reasoning.
 - c) What will happen to the beaker/water system if the flame of the Bunsen burner is turned off? Explain your reasoning.
2. A caffeine dependent inventor has developed what she considers to be the perfect thermos. Before leaving for work she fills her new thermos with coffee and observes the temperature of the coffee to be 50°C . Several hours later she opens the thermos to take her first drink and observes the temperature of the coffee to be 49.6°C .
 - a) Is the thermos perfect? Justify your answer.
 - b) Is the coffee/thermos system in equilibrium? Again, justify your answer.
 - c) What are you able to conclude about the energy inputs and outputs of the coffee/thermos system?

Answer Guide

The answers to these questions should reflect the knowledge gained by the physical model experiment and the computer simulation of that model. If a system is in thermal equilibrium, its temperature is constant, and the total energy entering the system must equal the total energy leaving the system. If more energy enters the system, the temperature of the system will increase until the energy leaving the system again equals the energy entering the system.

Question 1

- a) Since the temperature is constant, the system is in equilibrium. The energy inputs (heat from surroundings, heat from Bunsen burner, visible light) must equal the energy leaving the system (heat lost to the surroundings).
- b) The input energy has increased, so the temperature will increase until the output energy is equal to the new input energy. A new, higher equilibrium temperature will be achieved.
- c) When the Bunsen burner is turned off, the input energy will decrease. The temperature of the system will decrease until the output energy once again equals the new input energy. A new, lower equilibrium temperature equal to the temperature of the surrounding environment will be achieved.

Question 2

- a) To be a perfect thermos, there should be no change in the temperature of the contents. No heat/energy should be lost or gained by the contents. Since the temperature of the thermos' contents has decreased, some energy has been lost by the system. The thermos is not perfect.
- b) Answers may vary here – what is important is how the students justify their answers. Over a short time period (several minutes, for example), the temperature of the contents will not change measurably, so to the short term observer, the system will appear to be in equilibrium. Over the long term, however, it can be assumed that the previously observed heat loss will continue until the contents of the thermos are at room temperature. The long term, decreasing temperature indicates that the system is not in equilibrium.
- c) The short term observer would conclude that input energy = output energy = 0 (due to insulation of the thermos). The long-term observer would conclude that output energy > input energy.

Activity C – Investigation Questions

- 1. How can you ensure that you get adequate representation of all temperatures on Earth to get a reasonable estimate of its average temperature?
- 2. How many temperatures would you like to have in order to determine your average?
- 3. Collect your temperatures in a spreadsheet. Use the spreadsheet to find the average for 5, 10, 15, 20, etc., of your temperatures.
 - a) What happens to the average as you increase your number of samples?

- b) What happens when only temperatures over land are used?
4. The accepted value for the average surface temperature of the Earth is _____. (Ask your instructor for this value). How does your average value compare to this accepted value?

Answer Guide

Questions 1 through 3

The students should understand that in order to get a good average value they should sample the different temperature regimes (high/low latitudes, land/ocean) in proportion to their coverage of the planet. The more samples they use in each regime the closer their average will be to the correct value.

Question 1

- a) The average should vary, but as the number of samples increases, the value of the average should start to approach a specific value.
- b) The temperatures over land should yield a higher average in the summer and a lower average in the winter.

Question 4

15°C or 59°F is a round value for the average surface temperature of Earth. The students should discuss which realization of their averages was closer to the actual value and why. Their explanations should refer to their answers to questions 1 through 3.

Essay: Real World Problem – Preparing for Mars Living in an Arctic Outpost

By the time you complete the activities in this section, you will have identified and prioritized several factors needed to produce a habitable climate. These preliminary ideas can be applied to the Mars Society project to help design and construct the Flashline Research Station.

Do you agree that Haughton Crater is the best Earth location for an experimental Mars human habitat? What geologic and atmospheric conditions exist on Devon Island that may have lead to the decision to construct the facility there?

If you were a researcher on the science and engineering team designing and constructing this facility, what conditions would you have to set to allow humans to adapt to this environment and live in the habitat. Quantify your responses to this question as best as you can.

What materials would you use to construct the habitat in order to compensate for the extreme temperature conditions? How would your design produce habitable conditions for research-

ers to spend long periods of time at the facility? What other mission considerations are there for human habitability?

Assignment: Write a 300 word essay that responds to the questions in this topic's Real World Problem. Justify your response with supportive evidence from the modeling investigations you conducted, as well as what you learned computing the average surface temperature of Earth.

Minimum Expectations for this Essay

- ✓ Student should make a statement agreeing or disagreeing with the selection of Haughton Crater as an experimental Mars habitat on Earth.
- ✓ Student should provide a brief defense (three reasons based on geological or atmospheric criteria) of their agreement or disagreement with this choice.
- ✓ Students should list at least four conditions that would need to be considered in order to make the site habitable for humans over the long term.
- ✓ For each of the conditions described above, students should describe the adaptation that would be required and what kind of materials would be required.
- ✓ For each adaptation above, the student should use the reasoning developed in Topic 2 to explain how this adaptation will help to make the site habitable.
- ✓ Students should give at least two other areas that would need to be considered for a long-term Mars habitation. (Example: The need for several members to have medical knowledge. A number of doctors have had to be “rescued” from Antarctic research stations because their conditions were not treatable at the facilities, or, there was no other doctor available to help them.)