Topic

4

How do Atmospheres Affect Planetary Temperatures?

Activity A How do Atmospheres Interact with Solar Energy?

Activity B How do Atmospheres Produce their Effect Upon Surface Temperatures?

Activity C Can we Model an Atmosphere's Effect Upon a Planet's Surface Temperature?

Activity D Can Venus and Mars Be Made Habitable?

Topic 4

How do Atmospheres Affect Planetary Temperatures?

Overview

Topic 4 is a synthesis of the skills and knowledge obtained in the first three topics. Students will utilize these abilities to explain the Greenhouse Effect and its influence upon the surface temperature of a planet.

Activity A: The students brainstorm as to why the observed surface temperature of Earth is so different from that observed by their gray body model. Then they do a literature search to obtain information about the atmospheres of Earth, Venus and Mars. They speculate as to which characteristics of the atmospheres may be responsible for the difference between observed and theoretical surface temperatures. Students then use separate samples of carbon dioxide and air to observe interactions of the compound and the mixture with incident light or heat. The activity ends with a definition of the Greenhouse Effect.

Activity B: Students review the characteristics of Greenhouse gases and their interaction with energy by performing a classroom simulation. In this simulation they use play money to represent energy and follow certain protocols as to the interaction of atmospheric gases with electromagnetic energy in order to reinforce their understanding of the roles of various gases.

Activity C: Students use information obtained from their literature search in Activity A to estimate Greenhouse factors for the atmospheres of the three planets, and then use the models to check and refine these values. They use a modified version of the mini-GEEBITT mathematical model to investigate the Greenhouse Effect. The students attempt to produce surface temperatures for Venus, Earth and Mars that are closer to the actual surface temperatures of these planets than they have achieved with earlier models.

Activity D: The students are assigned the task of determining a combination of the four factors - luminosity of the source, distance from the source, albedo of the planet, and the Greenhouse Effect - that would allow them to "terra-form" Venus and Mars. They use mini-GEEBITT to vary each of the four factors for Venus and Mars to find these combinations. They must then explain how these factors could be changed by developing a hypothetical, but logical scenario based upon their final combination.

The topic ends with a summary by the students and an essay addressing the Real World Problem: Culprits of Climate Warming and Cooling.

Science Content

Experiments and observations in the earlier topics have shown students that in general, the presence of an atmosphere around a planet has a warming effect upon the surface of the planet. Earth, Venus and Mars all have average surface temperatures higher than a black body would, if placed at their distances from the sun. For more information about black bodies please visit the site: http://en.wikipedia.org/wiki/Black_body?

Activity A: Students perform a literature search to investigate the characteristics of the atmospheres of Earth, Venus and Mars and hypothesize as to which characteristics may be responsible for the difference between the observed and theoretical surface temperatures of these planets. They perform an experiment to observe the interaction of carbon dioxide gas and light energy and relate this to the observed differences in temperatures.

Activity B: The students perform a series of simulations to review how Greenhouse gases produce this warming effect. Emphasis is placed upon the relatively low concentrations of these gases in the Earth's atmosphere and the magnitude of their effect upon the surface temperature. Students review how Greenhouse gases emit infrared radiation back to a planet's surface, thus increasing its temperature.

Activity C: The students use the results of the experiment in Activity A and their literature search to predict magnitudes of the Greenhouse factors for Earth, Venus and Mars. They then use a modified version of the mini-GEEBITT model to check these predictions and obtain Greenhouse factors for the three planets.

Activity D: The students apply the knowledge they have acquired throughout the module to develop hypothetical, but logical scenarios for terra-forming Venus and Mars. They also evaluate the practicality of their proposed scenario by producing "habitable" temperatures for Venus and Mars with the mini-GEEBITT model.

Science Skills

Measurement and experimental design

Students carry out experiments with a mathematical model to determine the relative effectiveness of the major factors that determine the surface temperature of a planet. They also perform an experiment to investigate the feasibility of Venus or Mars being able to maintain a temperature suitable for the habitability by humans. The significance of these model results is related to the real world.

Data analysis

Students record the temperatures over time of samples of air and carbon dioxide exposed to a light source. They then produce data sets from a series of classroom simulations in order to determine the energy budgets of three sun-planet systems. The results of these simulations are used to describe the effect of the Greenhouse gases on a planet's temperature. Students use a mathematical model to evaluate predicted values for Greenhouse factors for Earth, Venus and Mars that would make their temperatures more comfortable to human beings. These theoretical results are compared to the actual changes that would have to be made to the planets to evaluate feasibility of such changes.

Considering a Real World Problem

Culprits of Climate Warming and Cooling

On Earth, we know both human and natural activities play roles in the climate system. A major challenge facing climate researchers is to identify significant relationships between these factors and explain their influence on climate in ways that are objective and useful to the public and to policymakers.

What are significant factors that influence a planet's climate and in particular Earth? What are important relationships among these factors? Students will use the information presented in the Real World Problem and the knowledge developed in Topics 1-4 to explain their response in an objective, scientific, clear and useful way for the public and policymakers. The culminating essay gives students an opportunity to synthesize their understandings in *What Determines a Planet's Climate?* It also allows them to apply this knowledge to important questions facing climate researchers and the public. How might trends in carbon dioxide, temperature and population over the past century relate to the greenhouse effect and Earth's climate? What if there is a strengthening of the greenhouse effect caused by human activities? How will other factors that affect Earth's climate respond? For example, how might the Earth's albedo change? In turn, would these changes in different albedo factors produce different affects on Earth climate? What makes carbon dioxide such an important greenhouse gas in terms of changes in its atmospheric concentrations and in the 21st century?

Activity A

How do Atmospheres Interact with Solar Energy?

5 class periods

Topic 4 builds upon the understandings that students have acquired in the previous three topics. They should now be aware of how three factors (luminosity of the source of energy, distance from that source, and planetary albedo) can influence average temperature of the surface of a planet. They should also be aware from their comparisons of model and direct observations that these factors alone are not sufficient to determine a planet's average surface temperature. They have preliminary evidence that the atmosphere of a planet plays a role in maintaining the surface temperature of the planet. Planets with atmospheres have higher temperatures than their gray body models predict.

Activity A begins with a self-review of the students' current state of knowledge of the surface temperatures of the terrestrial planets of our solar system, and how the observed values differ from those predicted by a gray body model. The discrepancy in temperature is different for different planets. If the assumption is that the atmospheres of these planets are responsible for the discrepancies, then there must be differences among them that account for the range of deviations. Students then perform a literature search using a library and/or the Internet to determine as much as they can about the atmospheres of these planets. They then hypothesize as to what characteristics of the atmosphere may be responsible for this warming effect.

One assumption that will result from this exploration is that the composition of the atmosphere may be the difference that counts. Students perform a physical experiment to test the reaction of samples of carbon dioxide and air to exposure to light. The entire class then comes to a consensus as to which characteristics of an atmosphere are most likely responsible for this warming effect. Students identify the accepted name for this effect, the Greenhouse Effect, and are asked to provide a preliminary definition of their own making.

Learning Objectives

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

- ✓ State that an atmosphere has an overall warming effect upon a planet.
- ✓ Describe major characteristics of the atmospheres of Venus, Earth and Mars.
- ✓ State that the magnitude of that effect depends upon specific characteristics of the atmosphere.
- ✓ Observe and measure the temperature changes of gases exposed to light.
- ✓ Identify this warming effect of the atmosphere as the Greenhouse Effect.
- ✓ Briefly describe how an atmosphere produces the Greenhouse Effect.

Materials

Images of Mercury, Venus, Earth and Mars, access to a library with planetary science references or, preferably, access to the Internet (possibly as a homework assignment).

For each laboratory group:
Three 250 ml volumetric flasks
Three stoppers with holes (to seal the flasks)
One stopper without a hole
Large trough/pan of water
A small, thin square of glass
One short glass tubes to be inserted into one of the stoppers
0.5 meter of flexible tubing to run from the glass tube
2 digital thermometers to be inserted into the other two stoppers
2 100-Watt heat lamps
Three Alka-Seltzer tablets

Engagement

Class Period 1

The teacher can begin this activity by having the students summarize what they know about the factors that affect the surface temperature of a planet. They should be able to refer to their results from the previous three topics. They should bring out the fact that some of the physical models they constructed had plastic coverings and that this produced higher temperatures in these models than in those without coverings. What effect do atmospheres have on planetary surface temperatures? Have students fill out the table on the first page of the Activity A handout, and let them discuss the ramifications of the results among themselves. The table is provided here with the values already included:

Planet	"Gray" Body Temperature		Actual Surface Temperature		Percent Difference	Is An Atmosphere
	K	ºC	K	ºC	(from K)	Present?
Mercury	435	162	440	167	1.2 %	yes, very thin
Venus	229	–44	737	464	68.9 %	yes, very thick
Earth	254	–19	288	15	11.8 %	yes, thick
Mars	210	–63	210	–63	0 %	yes, thin

Table 4.1.

Showing pictures of these planets at this time may help the students come to a consensus. The students should note that planets with the thickest atmospheres seem to have the greatest warming effect. If students have not mentioned it, the teacher can now introduce the term "Greenhouse Effect" as the scientific name for this atmospheric warming of a planet's surface. At this point, no further explanation of the Greenhouse Effect should be attempted. The teacher should have the students hypothesize as to what exactly about the atmosphere is able to produce this warming effect. Students should be able to come up with several possibilities, including the thickness of the atmosphere (or atmospheric pressure), the composition of the atmosphere (component gases, specific gases, or the relative amounts of these gases.) Suggestions may include that a thicker atmosphere traps more heat like the plastic covering on the physical model, or that certain gases do the trapping, and so on.

Procedure

After the students have a variety of hypotheses as to how an atmosphere could produce the observed warming effect, they need to test their hypotheses. Since they are unable to visit each of these planets, they will be required to do a literature search to determine what is currently known about the atmospheres of these planets, and see if any of their hypotheses can be disproved by this information. The students are then asked (either as homework or as class work if the resources are available) to complete table 2 with as much information about the atmospheres of these planets. They should also be asked to consider the various hypotheses that have been proposed and decide if any of them can be eliminated, or if any of them are better explained by the observed values. An example of how a student might complete table 2 is included here for the teacher's use. A more complete table of atmospheric composition is provided on page 73. (*Note 1 bar is approximately 1 atmosphere of pressure, 1 mb = 1 millibar*)

Planet	Mercury	Venus	Earth	Mars
Atmospheric Pressure (bar)	10^{-15}	92	1.014	0.006
Clouds?	none	100%	Yes, but variable amounts	Yes, but very thin
Winds (m/s)	none	0.3 to 1	0 to 100	2 to 30
Oxygen (%)	42	0	20.946	0.13
Nitrogen (%)	trace	3.5	78.084	2.7
Carbon Dioxide (%)	trace	96.5	0.035	95.32
Water (%)	trace	0.002	varies, ≈1	0.021
Other gases (%)	Sodium 29 Hydrogen 22 Helium 6 Potassium 0.5	Sulfur Dioxide 0.015 Argon 0.007 Carbon Monoxide 0.0017	Argon 0.934 Neon 0.0018 Helium 0.00054 Methane 0.00017	Argon 1.6 Carbon Monoxide 0.08 Nitrogen Oxide 0.01

Table 4.2. Values were obtained from NASA's National Space Science Data Center (http://nssdc.gsfc.nasa.gov/).

Class Period 2

At the end of the discussion of the significance of their findings, some students may argue that the amount of atmosphere (atmospheric pressure) is the most important factor in explaining how the Greenhouse Effect occurs. But then how do they explain the different effects on Mercury and Mars? Some students may argue that the composition is more important, noting that Venus has the least mixed atmosphere, and is mostly composed of carbon dioxide. Have students discuss how they might test these hypotheses with physical experiments. Testing effect of the atmospheric pressure would be difficult to do in the school laboratory, but testing the effect of certain gases is not. Propose the experiment that follows in the Student Activities, comparing the heating properties of a sample of air (Earth) with a sample of pure carbon dioxide (approximately Venus).

Class Period 3

The teacher should separate the students into groups of three or four, and then demonstrate the technique the students should use to produce a sample of pure carbon dioxide using Alka-Seltzer tablets and a water trough. Have the groups complete the handouts for the Experimental Design Proposal, the Methodology for a Controlled Experiment, and then perform the experiment as they have planned it. Be sure the lamps the students use produce a lot of infrared (heat) radiation. Normal incandescent light bulbs will work, and should be placed within 15 cm of the gas filled beakers for best results. (*Please note that this experiment was adapted from Activity C9 of Part II of The Global Warming Project, http://www.letus.northwestern.edu:16080/projects/gw/. This site is an excellent source of materials related to Global Warming.*)

Class Period 4

Each student should graph his or her group's results. They should observe that the container of pure carbon dioxide reaches a higher temperature than the air sample at a faster rate. They should then answer the questions at the end of the activity and the class should come together for a final group discussion.

Consensus

Class Period 5

In their discussion, the students should note that we have not disproved that atmospheric pressure may be a contributing factor to the Greenhouse Effect since they did not perform an experiment to test that hypothesis. They have observed that the composition of the atmosphere *does* play a role in its warming ability. Carbon dioxide is just one example of a gas that can trap heat in the atmosphere. Other gases that have been tested and found to have a similar effect are water vapor and methane. Collectively, these gases are called Greenhouse gases.

Synthesis

Have students compare the amounts of the Greenhouse gases in the various atmospheres. Mercury has only trace amounts of any Greenhouse gases, and a very thin atmosphere. Venus has almost 97% of its thick atmosphere composed of Greenhouse gases, while Earth has only about 1.04% of its atmosphere composed of these gases. Mars, with another thin atmosphere, has about 96% of its atmosphere made of Greenhouse gases. So, while the percent composition of the atmosphere is important, the amount of atmosphere does seem to play a role. Venus, with an atmospheric composition similar to that of Mars, has a much larger Greenhouse Effect. What still needs to be explained is exactly how these Greenhouse gases produce their warming. What is the mechanism behind the Greenhouse Effect?

Characteristics of Four Planetary Atmospheres

Gas	Composition (in % or parts per million (ppm))			
	Earth[1]	Venus	Mars	Mercury
Nitrogen (N_2)	78.08%	3.5%	2.7%	trace
Oxygen (O_2)	20.98%	–	0.13%	42%
Argon (Ar)	0.93%	70 ppm	1.6%	–
Carbon Dioxide (CO_2)	0.035%	96.5%	95.32%	trace
Neon (Ne)	0.0018%	7 ppm	2.5 ppm	trace
Methane (CH_4)	0.0017%	–	–	–
Krypton (Kr)	0.0011%	–	0.3 ppm	trace
Helium (He)	0.0005%	12 ppm	–	6%
Xenon (Xe)	0.00009%	–	0.08 ppm	trace
Hydrogen (H_2)	0.00005%	–	–	22%
Nitric Oxide (N_2O)	0.00005%	–	–	–
Sulfur Dioxide (SO_2)	–	150 ppm	–	–
Carbon Monoxide (CO)	–	17 ppm	0.08%	–
Water (H_2O)	0.1 to 4%	20 ppm	210 ppm	trace
Sodium (Na)	–	–	–	29%
	Other Atmospheric Properties			
Average pressure at the surface	1014 mb	92000 mb	6.1 mb	1×10^{-12} mb
Density at the surface	1.217 kg/m^3	65 kg/m^3	0.20 kg/m^3	NA
Scale height[2]	8.5 km	15.9 km	11.1 km	NA
Mean molecular weight	28.97 g/mole	43.45 g/mole	43.34 g/mole	NA
Surface wind speed[3]	0 to 100 m/s	0.3 to 1 m/s	2 to 30 m/s	NA

Table 4.3. Source: NASA's National Space Science Data Center

Notes:
1. Percentages for Earth's atmosphere are based on a dry atmosphere.
2. Scale height: height interval in which atmospheric pressure drops by a factor of p/e = 0.38 (37%)
3. Wind Speeds: near surface wind speeds in meters/second.

Activity B

How do Atmospheres Produce their Effect Upon Surface Temperatures?

4 class periods

After investigating the warming effect of several planets' atmospheres, the students were left with the question as to how the atmosphere actually produces this effect. They attempted to relate the actual characteristics of the planetary atmospheres to their warming ability, but no concrete conclusions could be made. Further investigation is necessary. Do all of the components of the atmosphere have an equal effect upon the surface temperature? If not, which atmospheric components are most effective in warming a planet? How exactly do they produce this warming effect? Do human activities influence any of these components?

In this activity, students explore the influence of atmospheric gases, in particular greenhouse gases, on planetary temperature. For the purposes of this activity, we isolate the process of how greenhouse gases are exchanged in our atmosphere and interact with energy. Therefore, it does not take into account the range of factors in the planet system that contribute to planetary temperature and energy balance such as surface features and clouds.

Learning Objectives

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

- ✓ Describe the effect of nitrogen and oxygen on incoming and outgoing electromagnetic energy.
- ✓ Describe the effect of carbon dioxide and water vapor on incoming and outgoing electromagnetic energy.
- ✓ Define "greenhouse gas" and state its effect on the surface temperature of a planet.

Relevance

Even though a model may successfully simulate conditions in the real world, it may not be doing so through the same processes as in the real world. Scientists need to understand how their models obtain their results, and be able to interpret these results with respect to the real world processes that are being represented.

Climate models are used both as tools to deepen our understanding of how the climate system works, as well as to make predictions about future climate. One of the most often misunderstood aspects of the climate system is the greenhouse effect; how it works and the relative amounts and warming effects of different gases. These understandings are essential to evaluate how changes in concentrations of atmospheric greenhouse gases will influence this process and in turn, produce a positive or negative forcing on our climate.

If the warming effect of greenhouse gases can be understood, then you also should be able to develop perspectives on whether or not human beings can influence the amounts of these gases in the atmosphere, as well as hypotheses on what effects these gases may have on the earth's climate system. This is an important step toward being able to make well-informed choices about many things that help us sustain healthy and productive lives and contribute to Earth's habitable climate, including the water we drink, the air we breathe, the energy we use and the land we live on.

Materials

Set of play money: $100, $50, $20, $10, $5 and $1 bills
A copy of the Energy Interaction Protocols for the simulations

Engagement

Class Period 1

The instructor can begin the activity by asking: What is the mechanism by which atmospheres affect the surface temperatures of their planets? The students concluded Activity A by proposing several hypotheses as to what properties of the atmosphere are responsible for the observed warming effect. Have them review those hypotheses and suggest possible mechanisms for those hypotheses. Eventually it should become clear to them that they need a better understanding of how the atmosphere and the planet interact with energy. The teacher can then explain the nature of the simulation that the students will carry out during this activity.

Procedure

Before beginning the simulations the instructor needs to ensure that the students have a basic understanding of the Law of Conservation of Energy and the relationship between temperature and energy. A review of Activity B, Topic 2 would be appropriate at this point. The instructor can remind the students of this activity by reviewing some of the questions from that topic. Why does a cold object warm up when placed in a warm room? What will its final temperature be? What must be true about the energy going into the object compared to the energy leaving the object? Why must this be true? Verify that students understand the difference between short-wavelength and long-wavelength electromagnetic radiation and their relationships to heat and energy. Why do objects feel warm? Why do objects feel cool?

Define a simple system consisting of the sun and a featureless planet. Elicit: what are the sources of energy in this system? What happens to this energy after it leaves the source? What happens to the energy when it hits the surface of the planet? What happens to the planet? Why does the planet eventually reach an equilibrium temperature? In the simulations that follow, students will record the energy budget for three different sun-planet-atmosphere systems and interpret the differences in these budgets, ending with an explanation of how greenhouse gases are able to warm a planet.

Class Periods 2 and 3

How do the various gases in the atmosphere interact with high and low frequency electromagnetic waves/energy? Three simulations act as a model for these interactions in the classroom. In the first simulation, one student will play the role of the sun while a second student will play that of the planet's surface. The students will use play money to represent incoming high frequency solar energy (100 dollar bills) and outgoing low frequency infrared energy (20, 10, 5 and 1 dollar bills). At different stages of the activity, other students will be added to represent molecules of oxygen and nitrogen in the atmosphere and then finally carbon dioxide and water vapor as examples of the greenhouse gases. All students will have to follow specific rules as they interact with the energy/play money. Students will observe all three simulations and record their observations on a handout, and answer specific questions about each simulation.

Energy Interaction Protocols for the Simulations

1. The Sun - For the short period of time over which these simulations occur, the sun is assumed to have an unlimited amount of energy that is released at a constant rate. The student representing the sun releases the same amount of energy each turn through out the simulation.

2. The Planet's Surface - The student representing the planets's surface must convert all the incident solar radiation/energy to an equal amount of infrared radiation/energy. Incoming infrared radiation/energy remains as infrared radiation/energy. All incoming energy is held by this player for one turn and then released outwards as infrared radiation during the next turn. The play money that was converted into lower denominations is returned to the teacher.

3. The Atmosphere –
   a. Oxygen and Nitrogen gases do not interact with either solar or infrared radiation/energy. The students representing these gases merely pass the energy on to the next player in that direction in exactly the same form as it was received. The solar radiation/energy is merely passed on to the next player in that direction.

   b. Carbon Dioxide and Water Vapor do interact with infrared radiation/energy. All incoming infrared radiation/energy is held by this player for one turn and then equal amounts are released in all directions as infrared radiation/energy during the next turn.

Emphasized to the students representing oxygen and nitrogen:

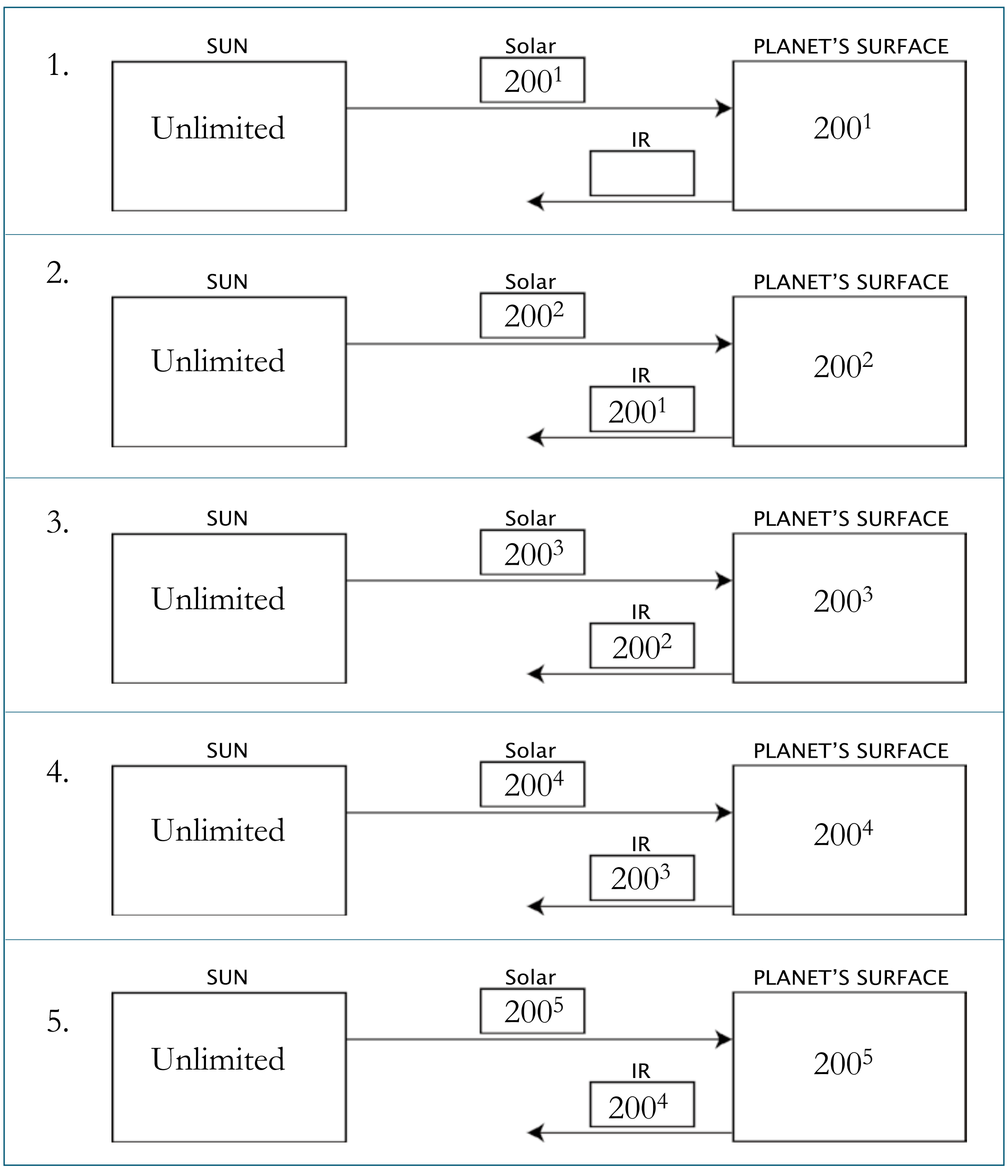
4. Do not interact with any type of energy. Simply watch the transactions as they occur.

Emphasized to the students representing carbon dioxide and water vapor:

5. Do not interact with any solar energy, simply watch it go by. Grab any infrared energy that comes your way and hold onto it for one turn, then pass half of it back to the planet's surface and the other half out into space.

Simulation 1: No Atmosphere

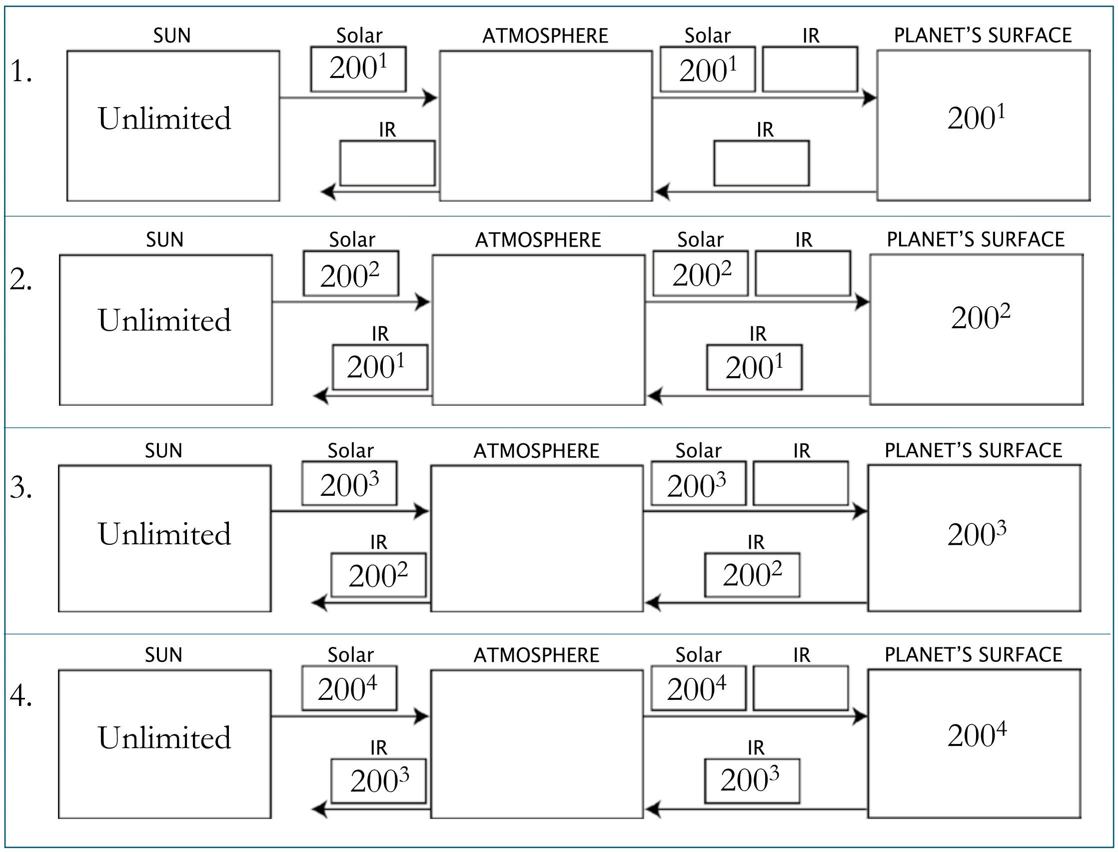
The student acting as the sun sends 2 yellow $100 bills towards the planet. (A total of 200 units reaching the planet). When the student acting as the planet's surface receives these bills, he/she changes them into 10 $20 bills, discarding the $100 bills. (These can be given back to the instructor, who can redistribute them to the various "suns" as needed.) The planet's surface holds on to the $200 in twenties until the next turn, when they will be sent out to space. (A total of 200 units leaving the planet's surface). The students should repeat the simulation for several turns until they realize what the energy relationships are in this simulation. 4 to 5 turns should be sufficient. Questions to ask during the simulation: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What does this do to the temperature of the surface? Have students relate the energy input and output of the planet's surface to the conservation of energy.



Sample Results for Simulation 1.

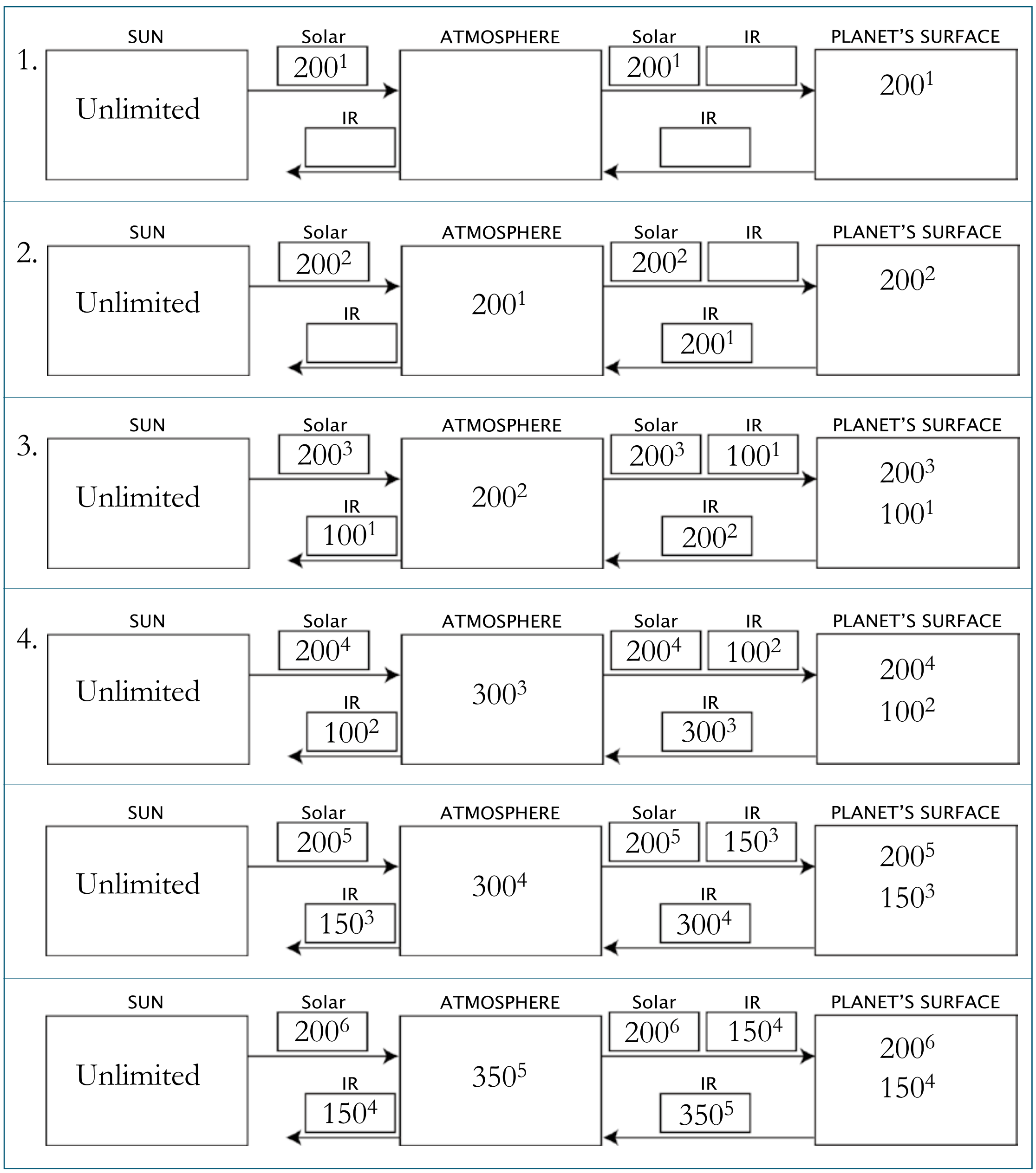
Simulation 2: Atmosphere with only Nitrogen and Oxygen

The students acting as the sun and the earth perform just as they did in the first simulation. One new student is introduced to sit between them. This student represents the nitrogen and oxygen molecules in the atmosphere. He or she observes the transactions between the original two students, but has no effect on the play money passing in either direction. Students should need three or four turns to realize the nature of the energy budget for this system. Repeat the questions from the previous simulation: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What effect do oxygen and nitrogen have on these processes? (Refer to these gases as being transparent to the incoming and outgoing energies/waves.) How does this affect the temperature of the surface?



Sample Results for Simulation 2.

Simulation 3: Atmosphere with Nitrogen, Oxygen, Water Vapor and Carbon Dioxide
Again, the students acting as the sun and the planet's surface perform as they did in the first two simulations. The students portraying Nitrogen and Oxygen molecules continue to behave as they did in the second simulation. A new student is introduced to each system to play the role of water and carbon dioxide molecules in the atmosphere. These students follow these personal instructions: intercept all infrared radiation ($20 bills), hold on to them for one turn, and then on the next turn return half of it to the planet's surface and send the other half off to space. The students may need several more turns to realize the energy budget in this system. They can stop once they realize that the earth's surface is holding more energy on a particular turn than it receives directly from the sun. Ambitious students can be supplied with additional pages for their observations (see table provided at the end of this section) and continue the simulation until there is no further increase in the energy stored in the earth's surface.



Sample Results for Simulation 3.

Repeat the previous questions: How does the total amount of energy arriving at the surface compare to the total amount leaving the surface? What happens to the energy after it arrives at the surface? What effect do the water and carbon dioxide molecules have on these processes? How does this effect differ from that of Nitrogen and Oxygen? Are water and carbon dioxide "transparent"? How does this affect the temperature of the surface? Does this effect surprise you given that there are so few of these molecules relative to the atmosphere as a whole? What do you think will happen if the simulation is carried out for more turns? Will the surface just keep getting warmer and warmer?

Consensus

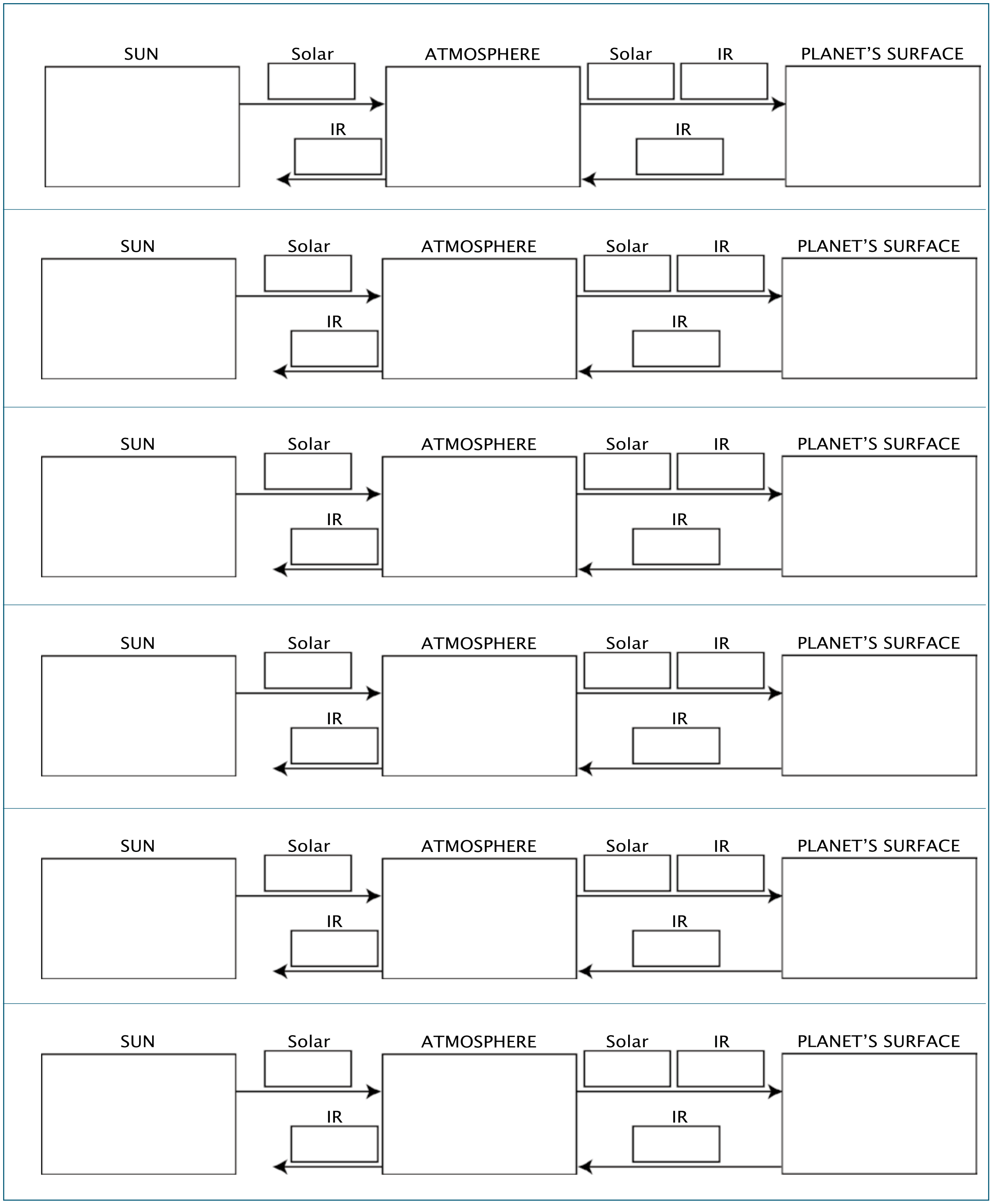
Class Period 4

Have the students summarize the results of the three simulations and relate them to the observations they made in Activity A. Their summaries should include the fact that certain gases in the atmosphere are able to absorb infrared energy/radiation and that these are the gases responsible for the greenhouse effect. They should include the fact that relatively small amounts of these gases can produce a marked greenhouse effect on a planet. Have the students arrive at a definition of the greenhouse effect based upon these summaries that all can agree upon.

Synthesis

We now have a clearer understanding of how greenhouse gases are able to warm the atmosphere of a planet. Ask the students if the greenhouse effect is a benefit or a detriment to a planet? Do we need to be concerned about the greenhouse gases that human civilization contributes to Earth's atmosphere? Is it important to monitor these gases? Which human activities contribute greenhouse gases? What are some important decisions and/or choices that citizens and policy makers must make about human activities that produce greenhouse gases? Do we have sufficient information and scientific knowledge to make these decisions? What do we know and don't know? Why so you think there is such debate about these decisions? There should be a variety of answers from the students, but whatever they conclude, the instructor should ask the question, "How can we be sure?" Based on the observations so far, we cannot be sure. What can we do to improve our understanding of the ramifications of changing amounts of greenhouse gases? We could wait and see what happens, or we could try to predict the influences of these gases with our computer models. Can mathematical models simulate the greenhouse effect?

Optional Extended Turns for Simulation 3



Activity C

Can we Model the Effect of an Atmosphere Upon a Planet's Surface Temperature?

1 class period

After completing Activities A and B, students should have a clear understanding of the Greenhouse Effect. They should be aware that specific gases in a planet's atmosphere are able to absorb the infrared (heat) radiation that is emitted by the planet's surface after it has absorbed incoming solar radiation. These Greenhouse gases are the component of planetary atmospheres that enable them to produce the warming effect that students have identified when they compared theoretical planetary surface temperatures to observed temperatures. In this third activity, students will investigate the ability of computer models to simulate the Greenhouse Effect. They will utilize the information previously obtained about planetary atmospheres to predict Greenhouse factors to be used in a modified version of the *Global Equilibrium Energy Balance Interactive Tinker Toy* – mini-GEEBITT, Version B. They will then use these values to see if it is possible to obtain more realistic surface temperatures for the planets simulated by GEEBITT.

Learning Objectives

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

- ✓ Use the characteristics of a planet's atmosphere to estimate the magnitude of the Greenhouse Factor of that planet.
- ✓ Use a mathematical model to determine the Greenhouse Factor for a planet.
- ✓ Relate the Greenhouse Factors from the models to the actual conditions of the atmospheres of the planets.
- ✓ Summarize the characteristics of the Greenhouse Effect.

Materials

Results from Activity A
Computers loaded with Microsoft Excel software. A maximum of 2-3 students per computer is suggested.
Spreadsheet *Global Equilibrium Energy Balance Interactive Tinker Toy* – Mini-GEEBITT, Version B, found at the web site http://icp.giss.nasa.gov/education

Engagement

One way to begin this activity is to have the students review what they know about the Greenhouse Effect and Greenhouse gases. A possible springboard for this discussion is to ask students to briefly write down what they think Earth would be like if there were no Greenhouse gases in its atmosphere. The students should also include an explanation of the mechanism by which the Greenhouse gases produce their warming effect. After they present their descriptions, ask them "What would the Earth be like if the amount of Greenhouse gases in its atmosphere were to be doubled?" Give them a few minutes to think about their responses, and then let them discuss the possibilities. After the discussion, remind students that global warming and the contributions of Greenhouse gases are major topics of debate within the scientific community. How can we really "know" what might happen? How can we plan for the future? Do we just have to wait and see? With their prior experience in Topics 2 and 3, at least some of the students should be able to suggest the use of computer models to make these predictions. Rather than waiting for the actual amount of Greenhouse gases in the atmosphere to double, we can try to simulate this doubling in a computer model.

Procedure

This activity is best conducted in a computer lab. After the preliminary discussion, divide the class into groups of two to three students. Have the students open their handbooks to the instructions for Activity C. Review how to start Excel on their computers, and how to load mini-GEEBITT, version B. Let the students work through the activity until they have completed table 1 and the questions following it. Have the class discuss the factors they obtained for Earth and their predictions for the other planets. Ask the students why are the values for Earth the same, but the predictions for the factors of the other planets different? Then allow the groups to work through the rest of Activity C, completing tables 2 and 3 and answering all questions.

Consensus

Students should summarize their findings by listing their predicted and best values for the Greenhouse factors for Mercury, Venus and Mars in a table on the board. Ask students how they would rate the effectiveness of mini-GEEBITT, version B for modeling planets. Is the model complete? Are the results reliable? What considerations should be made when using this model?

Synthesis

Return to the original question of the activity, what would the earth be like if the amount of Greenhouse gases in the atmosphere doubled? Ask students how they might answer this question now. How does this answer compare with their original one? Is GEEBITT a useful tool for studying planetary climates? What other questions might be answered through the use of this model?

Activity D

Can Venus and Mars Be Made Habitable?

2 class periods

Activity D may serve as an evaluation tool for Topic 4. Students use the GEEBITT model to determine if the present conditions on Venus and Mars could be modified to produce surface temperatures that would make them habitable by humans. They will have to make use of their understanding of the four factors that determine the average surface temperature of a planet and how these factors can be changed in order to decide how they might change Venus and Mars. They will have to use the GEEBITT computer model to test their hypotheses and see if habitable surface temperatures are possible. They will then have to defend their hypotheses by suggesting ways in which these changes could be implemented in reality, defending the practicality of their proposed method of terraforming. As the students develop their proposals, the teacher will be able to see how individual students grasp the concepts discussed in this module. The final presentations by student groups and the question and answer period that follows each presentation will give the students one more opportunity to display the level of their understanding of these ideas. By the end of this activity, the teacher should be able to evaluate all students' level of understanding of this topic.

Learning Objectives

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

- ✓ Demonstrate the ability to manipulate GEEBITT.
- ✓ Use GEEBITT to determine if there is a combination of the four major factors that can produce habitable average surface temperatures for Venus and/or Mars.
- ✓ Debate the possibility of terraforming Mars and Venus.
- ✓ Relate the knowledge obtained from this module to the quality of humanity's future on Earth.

Materials

Computers loaded with Microsoft Excel software. A computer for each student is preferred, but a maximum of 4 students per computer will work.
Spreadsheet climate model: mini-GEEBITT, Version B found at the web site http://icp.giss.nasa.gov/education

Engagement

Class Period 1

Global warming is a topic of concern among scientists as well as the general public. There is great discussion of whether or not it is occurring, and to what extent. How much of this is due to natural fluctuations in the Earth's climate and how much is due to contributions by humanity? Is there anything we can do to alleviate the extent of the warming? What will the future bring? As students have seen, most of these questions can best be answered through the use of computer models. No one wants to, or is able to, experiment directly on Earth. Imagine a future in which Greenhouse gases run rampant on Earth, turning it into another Venus. Can this be prevented? One away to answer this is to try and come up with methods for terraforming present day Venus and Mars, making these planets more Earth-like so that they have average temperatures that would be habitable for human beings. Before considering the economic impact of attempting such a transformation, is it even theoretically possible? Are there combinations of planetary habitability factors that could terraform Venus or Mars?

Procedure

As with Activity C, this activity is best conducted in a computer lab. After the preliminary discussion described above, divide the class into groups of two to three students. Have the students open their handbooks to the instructions for Activity D. Have students summarize the four factors that affect planetary average surface temperature and describe the nature of these effects. Have the students open mini-GEEBITT, version B. Explain that they are to try and come up values for combinations of these factors that will produce habitable average surface temperatures for Venus and for Mars. Record these values (if there are such combinations) in table 1. Remind the students that they will have to present their findings when everyone has completed their work, and that they must relate the changes in the model to actual changes that could be made to the planets. Are these changes "practical?" Allow students to work on the activity for the rest of the period and to prepare their presentations.

Consensus

Class Period 2

On the second day, each team should present their findings and their conclusions. They should provide possible means of carrying out these changes to the planet. After each presentation, the other students should ask questions of the group and test their understanding of the material. As a summary of the activity, have students discuss the practicality of terraforming Venus and Mars? How viable is this idea? What implications does this have for Earth's future if the amount of Greenhouse gases in our atmosphere continues to increase? How easy will it be to reverse the effects of added Greenhouse gases? What should humanity be doing now in order to ensure continued habitability on Earth?

Synthesis

Even if we are able to terraform Venus and or Mars at some future time, it may be more economical to look for planets in other solar systems that may provide the conditions necessary for habitability by humans. Recently astronomers have identified over 50 neighboring stars that have planetary companions. The identified companions are very massive and probably would not be suitable for humans. There may be other, yet unidentified planets around these stars, that may or may not be habitable. Ask the students if they could suggest a method for identifying stars that may have habitable planets in orbits around them.

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