PROFESSIONAL DEVELOPMENT

AP® Environmental Science

Introductory Concepts for Understanding Climate

CURRICULUM MODULE

The College Board
New York, NY

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Equity and Access Policy Statement

The College Board strongly encourages educators to make equitable access a guiding principle for their AP programs by giving all willing and academically prepared students the opportunity to participate in AP. We encourage the elimination of barriers that restrict access to AP for students from ethnic, racial, and socioeconomic groups that have been traditionally underserved. Schools should make every effort to ensure their AP classes reflect the diversity of their student population. The College Board also believes that all students should have access to academically challenging course work before they enroll in AP classes, which can prepare them for AP success. It is only through a commitment to equitable preparation and access that true equity and excellence can be achieved.

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Preface

AP® curriculum modules are exemplary instructional units composed of one or more lessons, all of which are focused on a particular curricular topic; each lesson is composed of one or more instructional activities. Topics for curriculum modules are identified because they address one or both of the following needs:

- a weaker area of student performance as evidenced by AP Exam subscores
- curricular topics that present specific instructional or learning challenges

The components in a curriculum module should embody and describe or illustrate the plan/teach/assess/reflect/adjust paradigm:

1. *Plan* the lesson based on educational standards or objectives and considering typical student misconceptions about the topic or deficits in prior knowledge.
2. *Teach* the lesson, which requires active teacher and student engagement in the instructional activities.
3. *Assess* the lesson, using a method of formative assessment.
4. *Reflect* on the effect of the lesson on the desired student knowledge, skills, or abilities.
5. *Adjust* the lesson as necessary to better address the desired student knowledge, skills, or abilities.

Curriculum modules will provide AP teachers with the following tools to effectively engage students in the selected topic:

- enrichment of content knowledge regarding the topic;
- pedagogical content knowledge that corresponds to the topic;
- identification of prerequisite knowledge or skills for the topic;
- explicit connections to AP learning objectives (found in the AP curriculum framework or the course description);
- cohesive example lessons, including instructional activities, student worksheets or handouts, and/or formative assessments;
- guidance to address student misconceptions about the topic; and
- examples of student work and reflections on their performance.

The lessons in each module are intended to serve as instructional models, providing a framework that AP teachers can then apply to their own instructional planning.

— The College Board

Introduction

Mark Ewoldson
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One of the most critical issues facing today's students—as the citizens and leaders of tomorrow—is global climate change. In order for students to properly evaluate the connections between human societies' activities and climate change, they must have a deep foundational understanding of the mechanisms that regulate our global climate system. A full sequence of lessons to provide that understanding could take several weeks and are beyond the scope of this curriculum module. Instead, this curriculum module will focus on providing students with an introduction to the concepts necessary for a preliminary understanding of climate. These lessons should be followed by further study on climate concepts such as atmospheric convection, pressure, and wind patterns, as well as oceanic-atmospheric interactions that transfer energy.

Lesson 1: Global Seasons and Insolation provides a foundational understanding of how the Earth receives energy. Through two demonstrations and an inquiry-based investigation, students will come to understand how the angle of the incoming solar radiation, due to the Earth's tilt with respect to the plane of the ecliptic, affects the global seasons and insolation at various latitudes.

In Lesson 2: Modification of Incoming Solar Radiation, students will engage in a demonstration, an investigation, and the use of an online simulation and data sets in order to visualize how solar radiation is modified in Earth's atmosphere and on its surface. By engaging in these activities, students should gain a deeper understanding of concepts such as Rayleigh scattering, specific heat, albedo, and greenhouse effect.

Connections to the AP Environmental Science Curriculum

Introductory concepts connected to climate in the AP Environmental Science topic outline are found under section *I. Earth's Systems and Resources, B. The Atmosphere*. The introductory climate activities in this module will provide critical conceptual scaffolding for students, which will support a more durable understanding of introductory climate concepts, which in turn will support subsequent instruction on more complex climate topics.

Connections to the AP Environmental Science Exam

The topic of climate or climate change appears every year on the AP Environmental Science Exam. These concepts are assessed in both the multiple-choice and free-response sections of the exam. Typically, 5 to 10 percent of the multiple-choice questions on the AP Environmental Science Exam are devoted to climate and climate change. Therefore, it is imperative to address these topics thoroughly through demonstrations, inquiry-based investigations, and class discussions.

Instructional Time and Strategies

AP Environmental Science teachers generally address the concepts associated with introductory climate topics at various places in their curriculum. The lessons and supporting activities in this curriculum module can be completed sequentially, in approximately one week of instruction (based on a schedule of 50-minute class periods, five days a week).

Within each lesson are formative assessments that help you determine how well students comprehend the material. Additional activities are suggested both for students who have not mastered the concepts and need further practice and for those who wish to go beyond the included material.

Lesson 1: Global Seasons and Insolation

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Essential Questions

- What causes the various seasons on Earth?
- How does the angle of incoming solar radiation affect the climate of Earth?

Lesson Summary

The sun provides virtually all the energy that heats the surface of our planet. In order to understand climate—specifically global temperatures—students must understand the myriad of factors that play a role in atmospheric temperature regulation. In this lesson, students will investigate, through inquiry-based activities and demonstrations, what causes global seasonal differences and the factors that affect insolation.

Connections to the AP Environmental Science Curriculum

Weather, climate, seasons, and insolation are found in the Course Description under the following headings:

I. Earth Systems and Resources

A. Earth Science Concepts
(Seasons, solar intensity, and latitude)

B. The Atmosphere
(Weather and climate)

Student Learning Outcomes

In this lesson, students will engage in conceptually integrated activities and inquiry-based investigations that foster a deeper understanding of the factors that create and regulate global climate systems. Factors to be investigated include: effect of the Earth's tilt with respect to the plane of the ecliptic, angles of incoming solar radiation with respect to latitude, and daylight length with respect to latitude.

After engaging in this lesson's activities, students will be able to:

- Explain how incoming solar radiation affects the heating of the Earth's surface.
- Discuss how factors such as the angle of incoming solar radiation and latitude affect regional climate.

Student Prerequisite Knowledge

Before beginning this lesson, students should:

- Understand the difference between weather and climate.
- Be able to compare and contrast temperature with heat, understanding that temperature is a numeric value related to an object's kinetic energy (measured as degrees C, F, or K), while heat is the transfer of energy (measured in Joules or calories).

For students who have not mastered this information, additional reading or activities may be helpful. For example:

- Review Climate and Earth's Energy Budget (NASA) http://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php
- Climate (Environmental Literacy Council) http://www.enviroliteracy.org/subcategory.php/8.html

Common Student Misconceptions

One misconception about the seasons held by many students is that the distance between Earth and the sun drives the seasonal cycle, rather than the orientation of the tilt of the Earth with respect to the plane of the ecliptic. Students typically believe that in order for something to become warmer, the object must simply move closer to the heat source. Therefore, they incorrectly reason that the Earth's orbit must move closer to the sun during the summer months, rather than considering how the angle of incoming solar radiation is regulating temperatures. Activity 1 addresses these misconceptions by illustrating how the Earth's orbit does not change during the year.

Teacher Learning Outcomes

Through teaching this lesson, you will improve your skills as a facilitator and help students develop and articulate scientific questions. To do this, you must be familiar with how students should frame scientific claims and support them with evidence. You will engage students in guided inquiry and support students in asking questions that lead to them designing their own experiments and procedures to collect and analyze data in attempts to answer these questions.

Teacher Prerequisite Knowledge

You should know the difference between traditional science investigations and inquiry-based investigations. If you would like to increase your understanding of inquiry-based learning, you might find the following resource helpful: *Inquiry and the* National Science Education Standards: *A Guide for Teaching and Learning*: http://www.nap.edu/openbook.php?isbn=0309064767.

Useful website

You should also have knowledge of the ways that solar energy gets to the surface of Earth and is transformed into thermal energy. If you would like to increase your understanding of climate, consult the resources previously offered in the Student Prerequisite Knowledge section or visit The Habitable Planet resource at http://www.learner.org/courses/envsci/unit/text.php?unit=2&secNum=0.

Useful website

Materials or Resources Needed

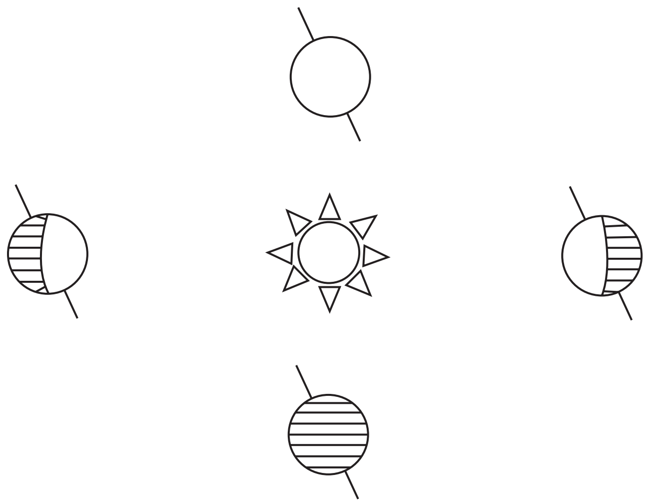
- Globe and standing lamp
- Flashlight and dark surface (e.g., piece of cardboard)
- Cardboard box, protractors, rulers, aluminum foil, tape, thermometers or temperature probes, and desk lamps with 100W incandescent bulbs (or heat lamps)
- Handouts 1 and 2

Activity 1: Seasons and the Earth's Orbit

In this demonstration, students will see that the Earth's tilt with respect to the ecliptic plane is responsible for the seasons.

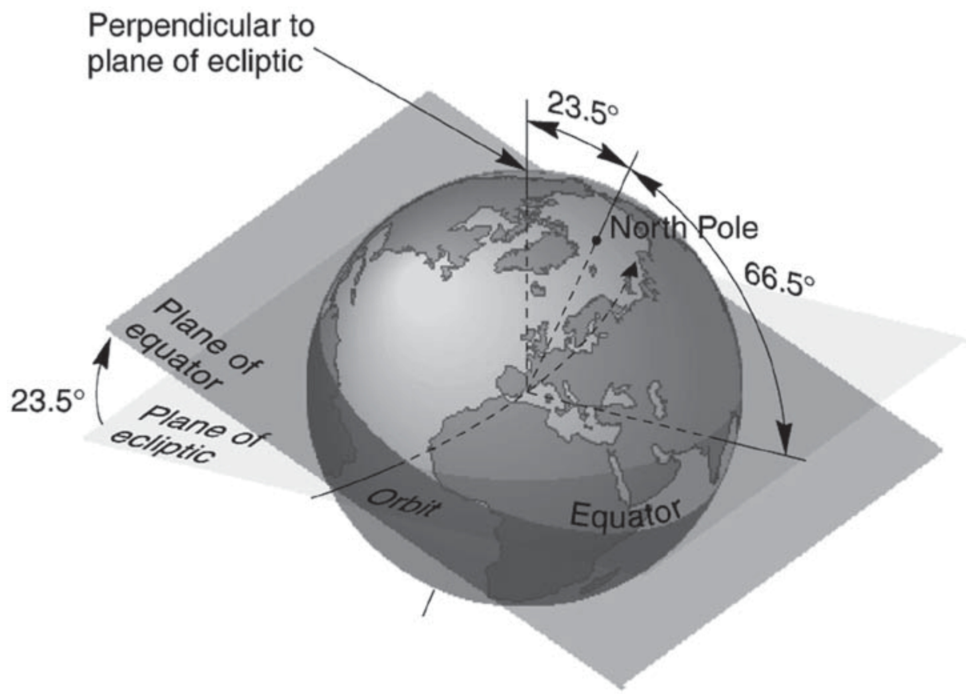
Step 1: Set up a lamp representing the sun that shines in all directions in the middle of the classroom. Use a globe of Earth (on an axis) to replicate what is in Figure 1, where the globe orbits the light at a constant distance from the "sun" and remains at a constant level above the floor.

Figure 1: Rotation Map



Use this demonstration to show students how the 23.5° tilt of the Earth from the plane of the ecliptic (the plane of Earth's orbit) causes seasonal differences in solar-radiation intensity and length of daylight. Students may also need to see a diagram to visualize the actual tilt of the Earth with respect to the plane of the ecliptic, as shown in the figure below.

Figure 2: Tilt Diagram



Students should be able to reason that the summer season would occur in the northern hemisphere during the part of the Earth's orbit when the northern hemisphere is oriented more toward the sun. It is important that students be able to articulate that during this period in the northern hemisphere the sun will rise higher in the sky, be above the horizon for a longer period of time, and shine more directly on the surface of Earth.

Step 2: Have students talk through what is happening in the southern hemisphere with respect to solar intensity and daylight length during this same part of the Earth's orbit.

To increase student understanding, incorporate these guiding questions into the demonstration and class discussion:

- What would happen if Earth had a tilt of only 5°? Or a tilt of 45°?
- When it is winter at the North Pole, is the Earth tilted toward or away from the sun? What does this mean for light intensity, daylight period, and regional temperatures during this time?
- When it is winter at the South Pole, is the Earth tilted toward or away from the sun? What does this mean for light intensity, daylight period, and regional temperatures during this time?

Activity 2: Angle of Incidence

This activity is designed to demonstrate how the angle of sunlight affects its ability to heat the surface of the Earth.

Step 1: Turn off the lights in the classroom and shine a flashlight at different angles toward a dark surface (see Figure 3), causing the light hitting the board to go from circular to very oblong (see Figure 4).

Figure 3: Flashlight Demo

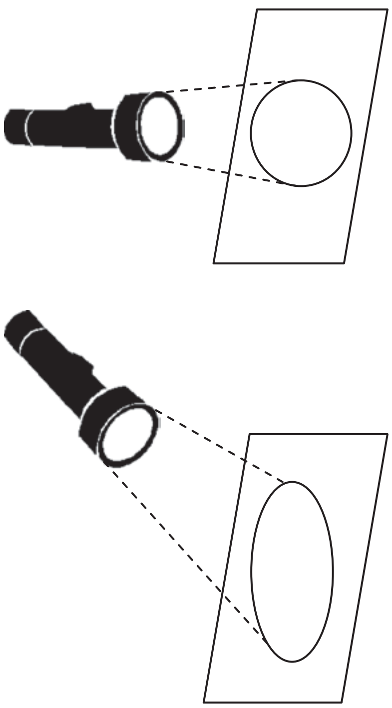
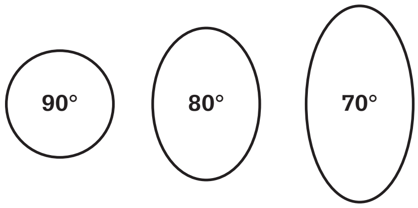


Figure 4: Angle Examples



Step 2: Use a globe to show students that when the flashlight is shone perpendicular to the equator, the light is circular, but when the flashlight is lifted toward the poles, the light hitting the globe elongates even more than seen on the board.

In order to maximize student understanding during this demonstration, incorporate these guiding questions into the activity:

- How does the angle of the incoming solar radiation (insolation) relate to the temperature on Earth's surface?
- On December 21, why is the Arctic Circle (66.5°N) the southernmost latitude where the noonday sun doesn't rise above the horizon?

Activity 3: Insolation

Handout 1

In this inquiry-based investigation, students will measure how the angle of incidence of light input affects the temperature of a surface.

Distribute Handout 1, and inform students that they will be designing an experiment to test the question, "How does the angle of light affect the temperature on a surface?" Have students form small groups and begin the investigation. Guide the groups through creating their experiments as necessary.

Some questions to include during and after this investigation may be:

- What angles did you test? Which angle had the greatest temperature? The lowest temperature?
- What assumptions did you make when designing your experiment?
- Can you identify your major sources of uncertainty for this experiment?

Formative Assessment

Handout 2

Ask students to compare monthly average insolation data for two cities: Qaanaaq, Greenland (near the North Pole), and Quito, Ecuador (near the equator). Distribute Handout 2. Students will analyze differences and similarities in the two cities that arise based on latitude and regional differences. Look for student understanding of how the latitude of the two cities will affect the insolation and daylight length. Students should be able to articulate how these differences affect regional temperatures in the cities. Students should complete the handout individually or in groups, and you should provide feedback about their answers.

Some students may have difficulty seeing the yearly variances in the data set provided for the two cities. In these cases, have students graph the data from the table before trying to answer any of the associated questions. They should include both cities' average insolation measurements on one graph so they are easy to compare. Once students construct a graph of the data in the table, they should more easily see the dramatic variances experienced by Qaanaaq in comparison to Quito.

Reflection of Formative Assessment

These concepts are often a challenge for students as they deal with spatial scales that are sometimes difficult for them to fully comprehend. If some students are still struggling to understand how the tilt of the Earth affects the angle at which solar radiation reaches a location, based on latitude, you may need to repeat the demonstration in Activity 1. This time, direct students' attention on the globe to the cities they examined during the formative assessment, and have them describe the intensity of light that hits these two locations.

Lesson 2: Modification of Incoming Solar Radiation

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Essential Questions

- What happens to solar radiation as it enters Earth's atmosphere?
- Do the differences between the specific heat of water and land affect local climate?
- How does surface albedo affect climate?
- Why does the greenhouse effect regulate the Earth's temperature?

Lesson Summary

This lesson will build upon students' understanding of insolation by addressing how incoming solar radiation is modified by Earth's atmosphere and by its surface. Students will engage in a demonstration to help them visualize the process of Rayleigh scattering that occurs in the atmosphere. Then students will conduct an investigation into the specific-heat capacity of water, sand, and soil. Students should have prior knowledge from an introductory chemistry course about the concept of specific heat of a substance. The investigation will facilitate students' understanding of how specific heat of large bodies of water moderates regional climates. Finally, students will engage in two online activities to address the concepts of albedo and the greenhouse effect. The albedo activity provides instructional flexibility; you may utilize some or all of the supporting worksheets and investigations as instructional time permits. The PhET simulation will further understanding of how the greenhouse effect regulates climate; students will utilize an online simulation where they can manipulate different variables to draw conclusions about greenhouse gases and their interaction with photons and the effect of cloud cover in the atmosphere.

Connections to the AP Environmental Science Curriculum

Weather, climate, albedo, and greenhouse effect are found in the Course Description under the following headings:

I. Earth Systems and Resources

A. Earth Science Concepts
(Seasons, solar intensity, and latitude)

B. The Atmosphere
(Weather and climate)

VII. Global Change

B. Global Warming
(Greenhouse gases and the greenhouse effect)

Student Learning Outcomes

In this lesson, students will engage in demonstrations and inquiry-based investigations that foster a deeper understanding of how incoming solar radiation is modified and what impact that has on climate. Factors to be investigated include: Rayleigh scattering, specific heat, albedo, and greenhouse effect.

Through engaging in this lesson's activities, students will be able to:

- Explain how incoming solar radiation is modified in the Earth's atmosphere.
- Discuss how the factors such as planetary albedo, the angle of incoming solar radiation, and the composition of the Earth's surface determine how much of the sun's energy heats the planet.
- Describe why land-use decisions by humans affect regional climate.
- Understand both the benefits of the naturally occurring greenhouse effect and the impacts of human activities upon the greenhouse effect.

Student Prerequisite Knowledge

Before beginning this lesson, students should:

- Understand the difference between positive and negative feedback loops and their impact on the respective system (or ecosystem).
- Have a basic understanding of specific-heat concepts.
- Be able to compare and contrast temperature with heat, understanding that temperature is a numeric value related to an object's kinetic energy (measured as C, F, or K), while heat is the transfer of energy (measured in Joules or calories).
- Be able to identify the major greenhouse gases that exist in Earth's atmosphere.

Students who have not mastered this information should complete additional reading or activities. The following resources might be helpful:

- Feedback Loops
  http://serc.carleton.edu/introgeo/models/loops.html
- Climate (Environmental Literacy Council)
  http://www.enviroliteracy.org/subcategory.php/8.html

Common Student Misconceptions

Students often think that all incoming solar radiation will reach the Earth's surface. Encourage them to fully think through the many different ways that solar radiation may be modified in Earth's atmosphere and that not all solar radiation will reach Earth's surface. Many students understand that ultraviolet light is an example of electromagnetic radiation but incorrectly reason that infrared is not a form of light as well. As they progress through the activities within this lesson, challenge students to think through how energy is transferred through the atmosphere and the differences and similarities between ultraviolet, visible, and infrared light.

Teacher Learning Outcomes

By teaching this lesson, you will improve your skills as a facilitator and help students develop and articulate scientific questions. To do this, instructors must be familiar with how students should frame their scientific claims and support them with evidence. You will engage students in guided inquiry and support students in asking questions that lead to them designing their own experiments and procedures to collect and analyze data in attempts to answer these questions.

Teacher Prerequisite Knowledge

You should know the difference between traditional science investigations and inquiry-based investigations. If you would like to increase your understanding of inquiry-based learning, you might find the following resource helpful: *Inquiry and the* National Science Education Standards: *A Guide for Teaching and Learning:* http://www.nap.edu/openbook.php?isbn=0309064767

Useful website

If you would like to increase your understanding of introductory climate topics, you might find the following resources helpful:

- Rayleigh Scattering
  http://hyperphysics.phy-astr.gsu.edu/hbase/atmos/blusky.html
- Specific Heat Capacity of Water
  http://ga.water.usgs.gov/edu/heat-capacity.html
- Unit 2: Atmosphere in The Habitable Planet (Annenberg)
  http://www.learner.org/courses/envsci/unit/text.php?unit=2&secNum=0

Materials or Resources Needed

- A blue laser and chalk dust; or water, a clear (no markings) glass, milk, and a flashlight
- Light-colored sand, potting soil, thermometer or temperature probe, desk lamp with 100W incandescent bulb (or heat lamp), timer, and three beakers
- Computer with Internet access
- Handouts 3 and 4

Activity 1: Scattering of Light

First, encourage students to brainstorm about what happens to incoming solar radiation once it reaches Earth's atmosphere. Ensure that they understand that not all incoming solar radiation reaches the Earth's surface; some is absorbed into the atmosphere, and some is scattered or reflected.

This demonstration is intended to help students understand how the scattering of light can be seen daily in the atmosphere. Spark their interest by asking, "Why is the sky blue?" Explain that the incoming solar radiation (sunlight) undergoes scattering when it hits nitrogen (78 percent) and oxygen (21 percent) molecules in the atmosphere. Known as Rayleigh scattering, this is more effective at shorter wavelengths; thus, the sky appears blue. (Students may need to be reminded of the visible light spectrum and respective wavelengths.)

There are two ways to demonstrate Rayleigh scattering:

a. Set up and turn on a blue laser pointer such that it points through the classroom (be careful not to point it directly at any student). As you walk along the path of the light, create a chalk-dust cloud in the beam. The blue light scattered by the chalk dust will be seen by different students at different locations.
b. Put a drop of milk into a clear glass filled with water. Shine a flashlight through the water. Rayleigh scattering will cause the solution to take on a bluish tinge.

Follow the demonstration with a whole-group discussion of what happens to solar radiation that reaches the Earth's surface. Students should be able to articulate that this solar radiation may also be reflected or absorbed.

Handout 3

Activity 2: Specific Heat

If equipment availability allows, place students in small working groups for this investigation. Distribute Handout 3, and direct students through Part 1 (calculating specific heat) and Part 2 (designing a model to test specific heat). In discussion with students during and after the investigation, help guide them in understanding how the type of surface material, especially large bodies of water, can influence regional temperatures.

Formative Assessment

For this assessment, students will use their understanding of the heat capacity of water to explain how large bodies of water, such as oceans, can moderate regional temperatures. Distribute Handout 4, and follow along while students compare San Diego and Dallas (two cities found at roughly the same latitude). As students examine monthly temperature variances and provide evidence to support the fact that San Diego will experience fewer dramatic temperature differences throughout the year than Dallas, be sure they understand this is partially due to San Diego's location on the Pacific Ocean, which helps moderate its regional climate. Students should complete the handout individually or in groups. Provide feedback on student answers.

Reflection on Formative Assessment

Understanding specific-heat capacity can be a persistent conceptual challenge for students. If students are still struggling to understand how the heat capacity of water helps moderate regional temperatures after performing the investigation, you may need to conduct an overall review of the concept of specific heat. Begin by having students read the article from the United States Geological Survey found at http://ga.water.usgs.gov/edu/heat-capacity.html. After students have read the article, conduct a whole-class discussion to identify any further student misconceptions about specific heat that need to be addressed.

Activity 3: Albedo Data and Investigations

For this activity, utilize the University of New Hampshire's Student Climate Data website: http://studentclimatedata.unh.edu/albedosequence.shtml#. There you will find the materials and instructions needed to direct students through this activity. To get started, download the entire Albedo Learning Sequence package (see the left-hand tool bar). This activity provides instructional flexibility; you may opt to engage students in some or all of the investigations. While all the activities in this learning sequence support student understanding of albedo, begin with the following introductory activities.

Part 1: Introduction to Albedo

This activity introduces students to the concept of albedo and how it relates to climate. There are supporting worksheets for students with guiding questions about albedo and the connection to positive feedback loops.

Part 2: Seasonal Albedo

This activity engages students in the Carbon Mapper software that stores NASA satellite data on albedo and land cover. Students can use the MODIS data to see global albedo during different seasons.

LESSON 2: Modification of Incoming Solar Radiation

Handout 4

Useful website

Useful website

Formative Assessment

Useful website

Provide students with the most recent graph and map from the National Snow and Ice Data Center that illustrates loss of sea ice extent in the Arctic over the past few decades (see http://nsidc.org/arcticseaicenews/). Have them write a justification for the following statement: *Scientists are concerned about the yearly reduction in Arctic sea ice extent due to its potential to create a positive feedback loop that would increase regional temperatures*. Encourage students to use the data to support their justifications.

Useful website

Students should initially work through this statement on their own, so that you can assess each student's ability to adequately articulate why a reduction in Arctic sea ice would produce a positive feedback loop that could increase regional temperatures. After students have finished writing their justifications, they should form small groups and share their written responses with one another. The groups should use verbal peer critique to discuss and analyze one another's claims, based on the evidence presented, and evaluate individual justifications. Once groups have shared their justification and provided peer critique, lead a class discussion on the justifications for the statement using the following resource from NASA: http://earthobservatory.nasa.gov/IOTD/view.php?id=49440. During this discussion, evaluate individual and group claims made about the statement.

Reflecting on Formative Assessment

Useful website

Students should have a firm understanding of albedo and positive feedback loops. If you find that some students have not yet mastered these concepts, recommend further reading or additional activities. The albedo resource on the Earth System Science Education Alliance (sponsored by NSF, NASA, and NOAA) website provides activities and applets, with varying levels of difficulty, which may be helpful: http://essea.strategies.org/module.php?module_id=99.

Activity 4: Greenhouse Effect

Engage students in a quick think-aloud activity. Inform them that the temperature on the surface of the moon fluctuates from –153°C during the night to 107°C during the day, despite it receiving the same amount of energy per square meter as the Earth's outer atmosphere. In comparison, the global mean temperature on Earth is approximately 15°C. Have students brainstorm about the mechanisms on Earth that prevent the large temperature fluctuations seen on the moon.

Useful website

Direct students to the University of Colorado's PhET interactive simulation on the greenhouse effect: http://phet.colorado.edu/en/simulation/greenhouse. They should proceed through the simulation, manipulating variables to describe the effect of clouds on photons and temperature, to demonstrate how greenhouse gases affect temperature, and to describe the interaction of photons with atmospheric gases.

Additionally, there are many accompanying worksheets on this site that other educators have shared, which you may want to have students use along with this activity.

Summative Assessment

This summative assessment explores student understanding of the concepts associated with Earth Systems and Global Change found in the course outline. The assessment also focuses on other skills, such as graphing data and interpreting data from graphs, which students are often asked to do on the AP Environmental Science Exam. The second part of this assessment also serves as good practice for students on typical document-based questions on the free-response section of the AP Exam.

Handout 5

To begin, distribute Handout 5, and direct students to complete Part 1, graphing the decline of the September Arctic sea ice extent. Students should use the data and their knowledge of albedo to discuss the impact of decreasing sea ice extent on regional climate.

Useful website

In Part 2 of the assessment, students will analyze how human land-use decisions can affect local climate. First, students should respond to question 4, parts (a) and (b), from the free-response questions of the 2007 AP Environmental Science Exam. Use the responses to assess student understanding of how human land-use decisions can influence local temperatures. (The 2007 AP Environmental Science free-response questions can be found at http://apcentral.collegeboard.com/apc/public/repository/ap07_envsci_frq.pdf.)

Then, based on the information from a research article in *Nature*, students provide a rationale to support the scientists' conclusions.

This assessment should be graded for accuracy and returned to students, followed by a class discussion about mistakes or common misconceptions. Ensure that students use appropriate variables on the *x*- and *y*-axes on the graph; these types of mistakes are common for students on the AP Exam. Students should show their work when calculating rate of change in Part 1. The AP Exam often asks students to show their work for calculations, and it is best to practice this during class assessments as well.

References

"Albedo Learning Sequence." Student Climate Data at University of New Hampshire. Accessed November 15, 2012. http://studentclimatedata.unh.edu/albedosequence.shtml.

"Arctic Sea Ice News and Analysis." National Snow & Ice Data Center. Accessed November, 15 2012. http://nsidc.org/arcticseaicenews/.

"Climate." The Environmental Literacy Council. Last modified June 19, 2008. http://www.enviroliteracy.org/subcategory.php/8.html.

"Global Climate Change: Albedo." Earth System Science Education Alliance. May 19, 2009. http://essea.strategies.org/module.php?module_id=99.

"Inquiry and the *National Science Education Standards*: A Guide for Teaching and Learning." National Academy Press. 2000. http://www.nap.edu/openbook.php?isbn=0309064767.

Lindsey, Rebecca. "Climate and Earth's Energy Budget." NASA Earth Observatory. June 14, 2009. http://earthobservatory.nasa.gov/Features/EnergyBalance/page1.php.

Marshall, Curtis H., Roger A. Pielke, and Louis T. Steyaert. 2003. "Crop Freezes and Land-Use Change in Florida". *Nature*. 6 Nov. 2003: 29.

"Specific Heat Capacity of Water." The USGS Water Science School at United States Geological Survey. Accessed November 15, 2012. http://ga.water.usgs.gov/edu/heat-capacity.html.

"Surface Meteorology and Solar Energy (SSE) Data and Information." NASA's Atmospheric Science Data Center. Last modified January 25, 2012. http://eosweb.larc.nasa.gov/PRODOCS/sse/table_sse.html.

"Unit 2: Atmosphere." The Habitable Planet by Annenberg Learner. Accessed November 15, 2012. http://www.learner.org/courses/envsci/unit/text.php?unit=2&secNum=0.

Handout 1

Insolation Investigation

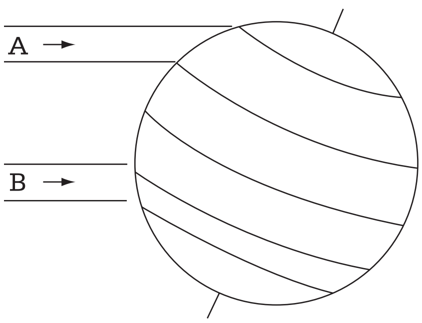
Experimental Question: *How does the angle of light affect the temperature on a surface?*

Introduction: The sun's angle of incidence to the Earth's surface varies according to time of day and position of the Earth relative to the sun. In this investigation, you will model that relationship by shining a light on surfaces that are at varying angles to the light source and measuring the temperatures of each point.

Background: One of the factors affecting an area's climate is insolation: the amount of solar radiation (energy) received on Earth's surface. The equator always receives 12 hours of solar radiation a day; for the rest of the planet, the amount is determined by the position of Earth relative to the sun (i.e., what time of the year it is). The angle of incidence of solar radiation influences the amount of heat absorbed by the planet, with a 90° angle having the highest insolation.

Insolation measures the amount of the sun's energy the surface of Earth receives per unit area. In terms of global climate, the absorbed energy causes an increase in surface temperature. When the sun is not directly overhead and the sun's rays hit the planet at an angle, the energy is distributed over a larger surface area, thus reducing the intensity of insolation.

Angle of Insolation



Materials (per group):

- Protractor
- Ruler
- Aluminum foil
- Pieces of cardboard
- Tape
- Temperature probe or thermometer
- Desk lamp with 100W incandescent bulb (heat lamp)

Procedure: Design an experiment to answer the question, "How does the angle of light affect the temperature on a surface?"

Recording Data: Create a data table to accurately reflect the measurements you took during your investigation.

Analysis:

1. Discuss any trends you observed during your experiment with respect to temperature and angle of light.
2. Describe how the Earth's tilt causes seasons and differences in insolation. Use drawings to help with your explanation.

Handout 2

Comparing Insolation

The following table provides measurements of insolation recorded for a city in Greenland (near the North Pole) and a city in Ecuador (near the equator). Consult the table and use the data to support your answers to the questions below.

Average Insolation (kWh/m²/day)												
Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Qaanaaq, Greenland	0	0.02	0.48	1.78	3.75	5.15	4.91	2.95	1.16	0.12	0	0
Quito, Ecuador	3.67	3.63	3.78	3.71	3.72	3.81	3.89	3.99	3.96	3.95	3.91	3.67

NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002.

Analysis:

1. In Qaanaaq, Greenland, which three months of the year recorded an average insolation of zero? Explain why there is no insolation recorded during these months.
2. Calculate the difference between the minimum and maximum average insolation measurements for both cities for the year. Describe what could account for the statistical difference in variance throughout the year for these two cities.
3. According to the table, the average insolation recorded in May for the two cities is roughly the same. However, the average temperature in May in Quito, Ecuador, is 18°C and in Qaanaaq, Greenland, it is –11°C. Discuss some possible reasons for the dramatic difference in temperature.

Handout 3

Specific-Heat Investigation

Experimental Questions: *What is the specific heat of sand compared that of water? What happens when you compare the specific heat of different soil types?*

Introduction: You should remember from chemistry that the equation for specific heat is $Q = cm\Delta T$, where Q is the amount of energy added, c is the specific heat, m is the mass, and ΔT is the change in temperature. In this investigation, you will be comparing the specific heat of water with that of sand. Because the water and the sand will be heated with the same heat lamp and at the same distance, they will have the same input of heat (Q). When you solve for c_s: $c_s m_s \Delta T_s = Q = c_w m_w \Delta T_w$ therefore, $c_s = (c_w m_w \Delta T_w) / (m_s \Delta T_s)$ where $c_w = 4186$ J/kg°C.

Materials:

- Desk lamp with 100W incandescent bulb (heat lamp)
- Three beakers
- Water
- White sand
- Potting soil
- Thermometer or temperature probe
- Timer
- Computer (optional)

Part 1

Procedure:

1. Put water in one beaker and an equal amount of sand in a second beaker. The mass of the sand and water should be equal. Record the mass:
   m = ______________ kg.
2. Stir the water and take the temperature of both substances, making sure to only put the bulb of the thermometer into the material. Initial temperatures of sand and water samples:
   T_{sand} = ______________ °C
   T_{water} = ______________ °C
3. Position the heat lamp no more than 20 cm directly above both beakers and turn the lamp on. Take the temperature **every minute** for 15 minutes.
4. Turn off the lamp and continue taking the temperature for another 15 minutes (temperature samples 16–30).

Recording Data: Use the tables below to record the temperatures taken in Steps 3 and 4.

Temperature (˚C)		
Time	Water	Sand
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Temperature (˚C)		
Time	Water	Sand
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		

Temperature (˚C)		
Time	Water	Sand
21		
22		
23		
24		
25		
26		
27		
28		
29		
30		

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Insolation ($kWh/m^2/day$)	2.85	3.56	4.78	6.07	6.80	7.20	6.99	6.32	5.27	4.12	3.14	2.64
Average Monthly Temperature High (°C)												
Average Monthly Temperature High (°C)												

Analysis:

1. Create a graph that appropriately illustrates the measurements you recorded in the data table.
2. Calculate the specific heat of sand. How does this compare with water?
3. Compare your calculated values for specific heat with the actual values. Explain why there is a range of values for the specific heat of sand.
4. Based on your findings of specific-heat properties, discuss why large bodies of water (such as an ocean) are better moderators of temperature than soils (such as sand).

Part 2

Procedure:

Repeat the experiment, this time testing the specific heat of three soil products: dry sand, wet sand, and potting soil.

Recording Data: Create your own data table to record the measurements taken during your investigation. Be sure to include appropriate headings and a title for the table.

Analysis:

1. Create a graph that appropriately illustrates the measurements you recorded in the data table.
2. Describe how the specific heat for the wet sand compared with the dry sand. Discuss any possible reasons for the variances in temperature between the two samples.
3. Explain any temperature differences you observed for the dry sand in comparison with the potting soil.
4. How can the specific heat of substances such as water and various soils be a factor in influencing regional climates?

Handout 4

How Large Bodies of Water Moderate Regional Temperatures

Procedure:

1. Look up the latitudes of San Diego, California, and Dallas, Texas. Record their respective latitudes below.
2. Research the average monthly temperature highs and lows for both cities, and record the information in the data tables provided.
3. Graph the monthly temperature highs and lows in the graphs provided. Be sure to provide appropriate *x*- and *y*-axes and a key (if necessary).
4. Answer the analysis questions.

Recording Data:

San Diego, CA (____________ Latitude)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Insolation (kWh/m^2/day)	2.50	3.23	4.19	5.26	5.61	6.24	6.54	5.79	4.94	3.84	2.70	2.25
Average Monthly Temperature High (°C)												
Average Monthly Temperature Low (°C)												

Insolation data provided by NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002.

Dallas, TX (____________ Latitude)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Insolation (kWh/m^2/day)	2.50	3.23	4.19	5.26	5.61	6.24	6.54	5.79	4.94	3.84	2.70	2.25
Average Monthly Temperature High (°C)												
Average Monthly Temperature Low (°C)												

Insolation data provided by NASA Langley Research Center Atmospheric Science Data Center; New et al. 2002.

Graphical Analysis: Monthly Averages for High and Low Temperature Measurements

San Diego, CA: Monthly Averages for High and Low Temperature Measurements

Dallas, TX: Monthly Averages for High and Low Temperature Measurements

Analysis:

1. For both cities, calculate the following:

    a. The difference between the month with the highest average temperature and ~~that~~ with the lowest average temperature.

    b. The temperature difference for the month that illustrates the largest change between the average high and low temperature.

2. Utilizing your calculations from question 1, along with the graphs you created above, describe which city experiences the most dramatic climatic variances throughout the year.

3. Discuss why the city you identified in question 2, based on its geographic location, would experience fewer temperature variances throughout the year.

Handout 5

Introduction to Climate Systems

Part 1: Graphing the Decline in Arctic Ice

According to NASA and the National Snow and Ice Data Center (NSIDC), September Arctic sea ice extent has been declining at a rate of 11.5 percent per decade (relative to the 1979 and 2000 averages).

Table 1.1 Average September Arctic Sea Ice Extent (NASA/NSIDC satellite data)

Year	Extent (million sq. km)	Year	Extent (million sq. km)
1980	7.8	1996	7.9
1982	7.4	1998	6.6
1984	7.2	2000	6.3
1986	7.5	2002	6.0
1988	7.5	2004	6.0
1990	6.2	2006	5.9
1992	7.5	2008	4.7
1994	7.2	2010	4.9

1. Graph the decline of the September Arctic sea ice extent since 1980. Be sure to include an appropriate title and an *x*-axis and *y*-axis. (Note: Plot your graph so that it includes space for a point in the year 2020. See question 3 below.)

2. Use the graph to calculate the rate of change between the following decades (show your work):

   a. 1980–1990 = __________
   b. 1990–2000 = __________
   c. 2000–2010 = __________

3. Based on your calculations in question 2, plot a prediction for what September Arctic sea ice extent will be in 2020. Write a justification for the data claim you have made about what sea ice extent will be in 2020.

4. Discuss how reducing Arctic sea ice extent is an example of a positive feedback loop.

Part 2: Land Use and Local Climate

1. Some scientists estimate that by 2025 more than 60 percent of the global human population will live in urban areas. Urban residents experience a variety of problems related to the physical environment.

   a. Describe how the temperatures of urban areas like Atlanta, Philadelphia, and Chicago differ from those of surrounding rural areas.
   b. Identify and describe *two* differences between urban and surrounding rural areas that contribute to the temperature differences between them.

2. In 2003, scientists in Florida indicated that citrus crops were experiencing more extreme frosts than in years past despite little change in the average monthly temperatures during that time of year. Scientists indicated this was most likely due to the state's decision to drain local wetlands in the area. Discuss why it is a realistic assumption from the scientists that draining local wetlands increased regional frost damage for the citrus crops. (Case study information modified from *Nature*, 2003.)

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Note: Contributors' biographical information was current at the time of publication.

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