Planet Designer: What's Trending Hot?

Middle School Grades

Lesson Summary

Students create a planet using a computer game and change features of the planet to increase or decrease the planet's temperature. Students will explore some of the same principles scientists use to determine how likely it is for a planet to maintain flowing water.

Prior Knowledge & Skills

- Familiarity with the term "greenhouse effect"
- Familiarity with the Celsius temperature scale
- Ability to use data tables

AAAS Science Benchmarks

The Physical Setting

The Earth

Energy Transformations

Common Themes

Models

NSES Science Standards

- **Science as Inquiry:** Abilities necessary to do scientific inquiry
- **Physical Science:** Transfer of Energy

Teaching Time: Two 50-minute periods

Materials

Each student will need:

- Copy of Student Directions
- Access to a computer with Flash
- Extra paper (tag board or construction paper), 12"x18" recommended

Advanced Planning

Preparation Time: 20 minutes

- Make copies of the student pages
- Prepare a computer room to run the Flash interactive (if Flash is supported) or download the executable file on each computer if Flash is not available. The interactive can be found here: http://lasp.colorado.edu/home/education/k-12/project-spectra/.
- Open the Flash Interactive, "Planet Designer: What's Trending Hot?"

Why Do We Care?

The Mars Atmospheric and Volatile EvolutioN (MAVEN) mission will collect data to help scientists trace Mars' atmospheric history to determine what happened to the flowing water.

Why do we care about water? Every known life form on Earth requires water to survive, and wherever we find water on Earth, we find life. Finding liquid water on another planet is exciting, not because it means life does exist, but that it *could* exist. It's that possibility that motivates missions like MAVEN to keep searching for clues about Mars' early history.

Suggested background reading

MAVEN website:
http://lasp.colorado.edu/maven/

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Activity Dependency "Goldilocks and the Three Planets"

Expendable Cost per Group US$0.30

Engineering Connection (adapted from "Planet Designer: Kelvin Climb for High School")

The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission to Mars will launch in the fall of 2013. Mars likely had a thick atmosphere early in its history and surface temperatures were warm enough for the planet to have sustained liquid water at the surface, but today Mars is a dry, desolate place. MAVEN is equipped with instrumentation engineered to explore Mars' upper atmosphere. MAVEN will measure the amount of atmosphere Mars loses today, so that we can estimate how much atmosphere Mars had in the past. This will help us understand how the Mars climate evolved from warm and wet to cold and dry.

Learning Objectives

After this activity, students should be able to:

- Explain how distance to the Sun, reflectivity, and atmosphere affect planetary temperature
- Explain factors that can contribute to a planet's ability to have liquid water at the surface

Introduction / Motivation (adapted from "Planet Designer: Kelvin Climb for High School")

The MAVEN mission, launching in 2013, will explore the upper atmosphere of Mars. There is quite a bit of evidence that liquid water flowed on the surface of Mars in the past. MAVEN will collect data to help scientists trace Mars' atmospheric history to determine what happened to the flowing water. Today, you will be exploring some of the same principles scientists use to determine how likely it is for a planet to maintain flowing water.

Why do we care about water? Every life form on Earth requires water to survive, and wherever we find water on Earth, we tend to find life. Finding liquid water on another planet is exciting, not because it means life does exist, but that it *could* exist. It's that possibility that motivates missions like MAVEN to keep searching for clues about Mars' early history.

Today, you are going to create your own planet. You'll start with a completely featureless planet. This planet absorbs all of the sunlight (electromagnetic radiation) that hits it. You'll be able to adjust the distance from the Sun and the planet's density and radius to see if or how those things affect a planet's temperature.

Once you have explored a completely featureless planet, you'll explore whether different colors affect a planet's temperature. Different colors will reflect sunlight differently. The amount of reflectivity is called albedo, given as a percentage of the light that hits the surface. For example, a planet that has an albedo of 50% reflects half the electromagnetic radiation that hits it and absorbs the other half. An albedo of 100% reflects all of the electromagnetic radiation, and an albedo of zero reflects 0% (absorbs everything). We usually write albedo as a decimal number. *Take a moment to remind students how to convert a percentage into a decimal.*

Then, you will add an atmosphere to your planet. Atmospheric gases absorb different parts of the electromagnetic spectrum. When we look at a spectrum of an atmosphere, we see dips (absorption) from different atoms and molecules. Greenhouse gases in an atmosphere absorb certain infrared wavelengths, heating the surface of a planet. You will add a greenhouse atmosphere to your planet to try to increase the temperature.

Part of your challenge today is to figure out what planetary conditions are necessary for liquid water to exist on the surface of a planet.

Vocabulary / Definitions

Word	Definition
Albedo	The percentage of incident (incoming) light that is reflected from a surface. A perfectly white object would have an albedo of one, indicating that 100% of the light reflects off of the surface. A perfectly black object would have an albedo of zero, indicating that none of the light reflects off of the surface, but all is absorbed.
Astronomical Unit (AU)	The average distance between the Earth and the Sun, or approximately 150,000,000 kilometers (93 million miles)
Celsius (^oC)	A unit of temperature defined by the equation Celsius = 5/9 (Fahrenheit -32) where zero and 100 degrees Celsius are the respective freezing and boiling temperatures of water at one bar (the surface pressure of Earth)
Luminosity	The amount of power radiated by a star (or any object) in the form of light. This can be expressed in watts.
Planetary Surface Pressure	The atmospheric pressure at the surface of a planet

Procedure

Background (adapted from "Planet Designer: Kelvin Climb for High School")

Absorbed light heats a surface, and any object with heat radiates light at wavelengths that depend on its temperature. Objects at room temperature and people, for example, radiate light in the infrared. Much hotter objects (embers, for example) begin to glow in the visible part of the spectrum. In astronomy, a blackbody is an idealized object that absorbs all incident light (albedo of zero) and radiates with perfect efficiency. When visible light shines on a planet, it will heat up and radiate increasing amounts of energy in the infrared. At a certain temperature, the planet reaches an equilibrium, where the amount of visible light absorbed is balanced by the amount of infrared light radiated.

Students will use a computer interactive to explore the blackbody temperature of a planet before considering what contribution greenhouse gases make to the surface temperature. The fundamental rule of a planet's energy budget, simply stated, is, "What goes in must come out." To calculate blackbody temperature, we will use this information:

- The Sun produces a certain amount of energy (luminosity).
- Energy from the Sun travels outward in every direction. Since the Sun is a sphere, the energy travels outward in a sphere. See Image 1.
- The planets travel around the Sun on elliptical orbits with the Sun at one focus. These ellipses are nearly circular, so we will use the average distance to simplify the equations.
- The amount of energy received by an object decreases with distance from the Sun.
- The planets are spherical, but only the hemisphere facing the Sun gets exposed to the energy. We will approximate the area that is directly exposed to be a circle.
- All of the energy that hits a planet is either reflected or absorbed. We know the amount reflected, because we can measure the albedo of the planet. Students will calculate the blackbody temperature of a non-reflective, black planet before moving to this step.
- In equilibrium, the amount of infrared light that the planet radiates must be equal to the amount of visible light that it absorbs.
- The equilibrium temperature of the planet is the temperature the planet must be to balance the equation (what goes in comes out).

Image 1

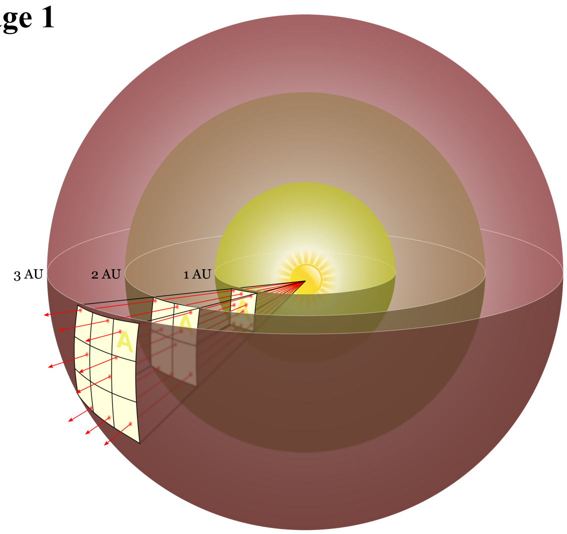

Image 1: The luminosity of Sun is constant, and distributed uniformly in every direction. Light spreads out proportionally over the distance squared, so that at 2 AU, the amount of light an object receives is a quarter of the amount received at 1 AU.

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Students should walk away with the understanding that a weak greenhouse effect on a planet leads to lower temperatures, and conversely, that a strong greenhouse effect leads to higher temperatures. A student's planet might support liquid water on the surface if the distance from the Sun, atmospheric thickness, and surface temperature are adequate. Any one of these factors could influence whether or not a student is able to create a planet with liquid water on the surface. The interactive may show the planet with liquid or frozen water as a possible scenario for the input conditions. Note that because a planet *could* have water on the surface does not necessarily mean that it does! You may want to discuss this subtlety with students, and explain that the interactive shows only one possible scenario.

A real planet is more complicated. Certain areas might be more reflective (clouds, oceans, ice etc.), and the albedo can vary over days (cloud patterns), seasons (winter snowfall), or geologic time scales (ice ages). A real planet has surface interactions with the atmosphere that might make a predicted temperature higher or lower than this calculation could possibly give. On Earth, for example, if the temperature increases, the amount of snow and ice will decrease in some areas, but the amount of cloud coverage would presumably increase. Both things will change our planetary albedo, which factors into the final surface temperature—and that's just one possible change. This is called a feedback effect—when one small change gives rise to other changes in a system. To factor in all of the potential changes, huge supercomputers running almost non-stop are used to predict climate change outcomes.

Table 1: Planetary Parameters

	Venus	**Earth**	**Mars**
Mass (Earth Masses)	0.815	1	0.107
Density (kg/m^3)	5250	5520	3930
Radius (Earth Radius)	0.95	1	0.53
Distance from Sun (AU)	0.723	1	1.524
Albedo	0.75	0.29	0.16
Greenhouse Strength	Very Strong	Moderate	Weak
Atmospheric Thickness	Thick	Moderate	Thin
Average Surface Temperature (deg. Celsius)	470	15	-50

With the Students

1. Take students to the computer room, and instruct them on how to begin building planets.
2. Walk around the room clarifying any questions students may have.

Assessment

Pre-Activity Assessment
Ask: What do you know about the phases of water? What conditions are necessary on Earth for liquid water to exist?

Post-Activity Assessment
Student Presentation: Have students share their planet drawings with the class and allow time for a gallery walk of the drawings and findings. Record student ideas about planets on the board, or use a corkboard display showing what students learned about planet temperature (including vocabulary terms).

Activity Extensions
NASA's Astro-Ventures "Design a Planet" interactive allows students to explore factors that contribute to a habitable planet. It is available here: http://astroventure.arc.nasa.gov/.

References
Baker, Victor R. 2001. Water and the Martian landscape. *Nature* 412:228-236.

Jakosky, Bruce M. and Roger J. Phillips. 2001. Mars' volatile and climate history. *Nature* 412:237-244.

Stevenson, David J. 2001. Mars' core and magnetism. *Nature* 412:214-219.

Curry, J. and P. Webster. 1999. *Thermodynamics of Atmospheres and Oceans*. Waltham, Mass.: Academic Press.

Bennett, J. et al. 2010. *Cosmic Perspective*. Boston: Addison-Wesley Publishing Company, Inc. 297-300, 494.

Contributors
Erin Wood
Grant Euler
David Mitchell
Jim Kellogg
David Brain