PLANETS Science Series

Testing The Waters:

Water in the Solar System

Planetary Science for Out-of-School Time

NASA Partner

PLANETS

PLANETS (Planetary Learning that Advances the Nexus of Engineering, Technology, and Science) is a partnership for the development and dissemination of NASA out-of-school time curricular and educator resource modules that integrate planetary science, technology, and engineering, particularly with underrepresented audiences.

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NAU NORTHERN ARIZONA UNIVERSITY
Center for Science Teaching and Learning

EiE

USGS science for a changing world

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Water in the Solar System

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EDUCATOR *GUIDE*

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About the *PLANETS* Science Series

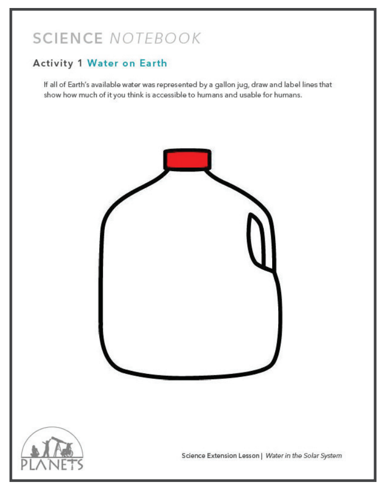
The PLANETS Science Series supports youth exploration in the field of planetary science, by exploring the different reservoirs of water in the solar system and how accessible and usable they are for humans or habitable they are for life. This unit can be done independently, but is designed to complement the PLANETS Engineering Everywhere "Testing the Waters: Engineering a Water Reuse Process" activities, available at the link below:

https://planets-stem.org/water-in-extreme-environments/

This PLANETS Science Series unit has several parts. All of the available materials can be downloaded from the PLANETS website.

Educator Guide

PLANETS Cards



Science Notebook

Learning Objectives

In the PLANETS Science Series: Water in the Solar System, youth will be challenged to answer the following guiding question: Where, and how accessible, usable, and habitable, is water in the solar system?

- » Youth will learn where water is found on Earth and elsewhere in the solar system.
- » Youth will learn about different reservoirs of water on planetary bodies and the factors that affect whether water is usable by humans or habitable for other life.
- » Youth will explore evidence for water in different forms on different planetary bodies.
- » Youth will consider accessibility, usability, and habitability in arguing which planetary body they want to explore.

Connections to Standards

The activities included in this unit support the teaching of multiple standards, including:

Next Generation Science Standards

MS-ESS1-3 Analyze and interpret data to determine scale properties of objects in the solar system.

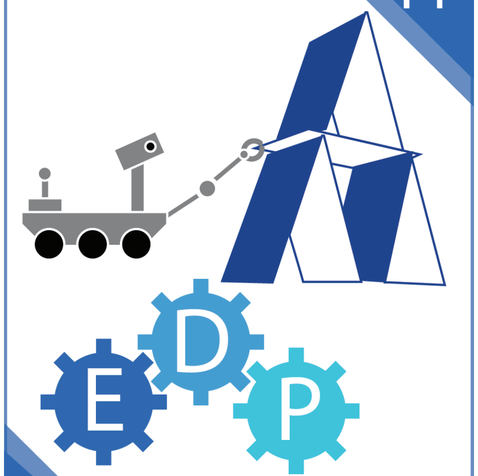
MS-ESS2-2 Describe and graph the amounts of salt water and fresh water in various reservoirs to provide evidence about the distribution of water on Earth.

MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Learning Progression - Prep Activities

These activities introduce youth to engineering, an engineering design process (EDP), and the curricula's definition of technology. A video sets the context for the unit and demonstrates how engineers design process technologies that reuse water in extreme environments.

P1



What is Engineering?
Teamwork & Tower

Purpose

Youth engage in an engineering design challenge using an Engineering Design Process (EDP), criteria, and constraints.

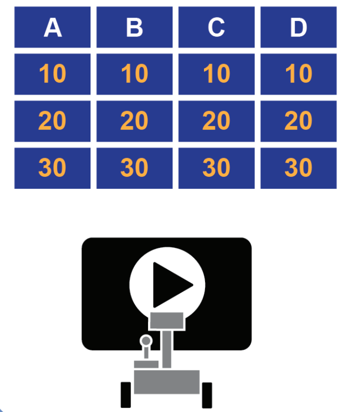
Key Take Away

We are engineers.

Science Reflection

Today we used an EDP to solve problems with criteria and constraints.

P2



What is Technology?
Trivia & Context Video

Purpose

Youth consider the definition of technology as any thing or process humans (engineers) design to solve a problem. The Special Report Video sets the context for the entire unit.

Key Take Away

Processes designed by humans to solve problems are technologies.

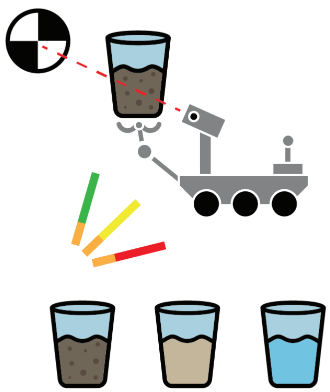
Science Reflection

Today we investigated how engineers design water reuse technologies in places where water is scarce.

Learning Progression - Engineering

In these activities, youth investigate the contaminants, filter materials, and potential uses for filtered greywater for designing their own water reuse process in Activities 4 & 5.

A1



A Grey Area
Water Samples & Quality Tests

Purpose

Youth test the quality of and categorize model water samples using real tools.

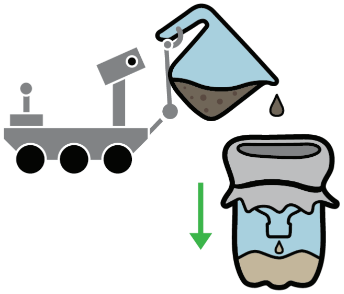
Key Take Away

We can test water quality and categorize it as pure, grey, or waste water.

Science Reflection

Today we investigated common household water contaminants and categorized model sample qualities as pure water, waste water, or grey water based on the contaminants we found.

A2



Investigating Filters
Filter Water Samples

Purpose

Youth explore how different water filter materials reduce contaminants.

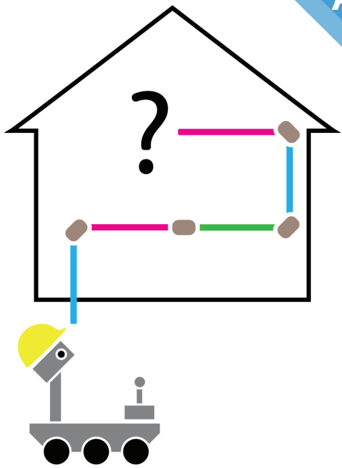
Key Take Away

We can improve water quality with filters.

Science Reflection

Today we investigated different materials to see how well they removed or reduced different water contaminants.

A3



Order Up!
Design a Water Reuse System

Purpose

Youth apply what they learned in Activities 1 & 2 to improve water quality at least one level so it can be reused for a different purpose.

Key Take Away

When water is limited, it can be filtered to remove contaminants/improve quality so it can be reused for different purposes.

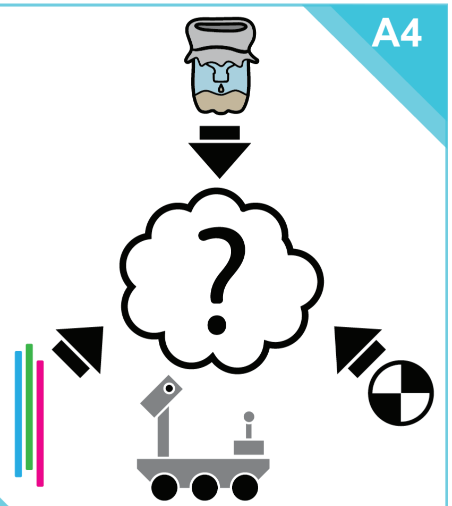
Science Reflection

Today we engineered a process to filter a limited amount of water so it could be reused for different purposes.

Learning Progression - Engineering

In these activities, youth apply what they learned in Activities 1-3 to design, improve, and share their water reuse process.

A4



Create a Process
Plan, Create, Test

Purpose

Youth apply what they learned in prior activities to design and test a water reuse process using filter materials and home piping reconfiguration.

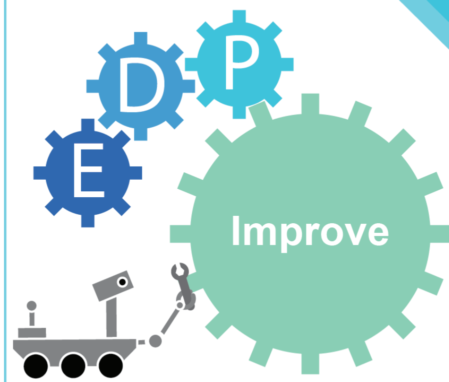
Key Take Away

We can engineer a process to improve water quality so it can be reused for other purposes.

Science Reflection

Today we used data from prior investigations to imagine, create and test a water reuse process for an extreme environment where water is scarce.

A5



Improve
Improve a Process

Purpose

Youth improve their process to better meet the criteria of their extreme environment.

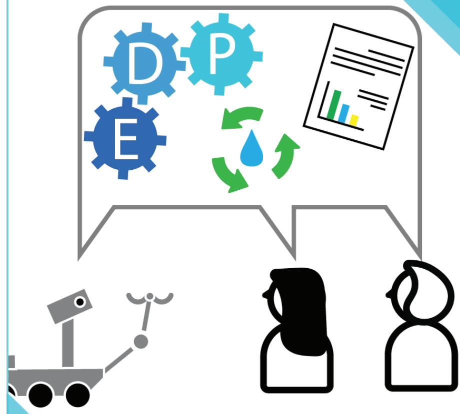
Key Take Away

We can improve technologies we have designed.

Science Reflection

Today we improved our water reuse process. Not getting it the first time helps make technology better.

A6



Engineering Showcase
Communicate Results

Purpose

Youth prepare presentations to communicate their water reuse process to others.

Key Take Away

We can communicate how we designed our water reuse process using an EDP.

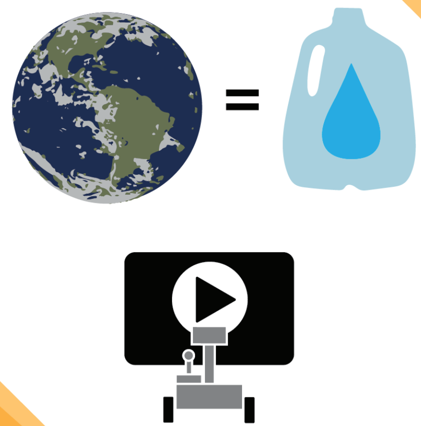
Science Reflection

Today we communicated our water reuse process and how we used an EDP to design it.

Learning Progression - Science

In these activities, youth explore how much, how accessible, and how usable water is on earth and elsewhere in our solar system. Youth also consider if water is potentially habitable on other planetary bodies. Youth also propose a planetary body to explore based on evidence of water.

S1



Earth's Water
Experiment & Videos

Purpose

Youth explore the concept of water availability, accessibility, and usability on earth.

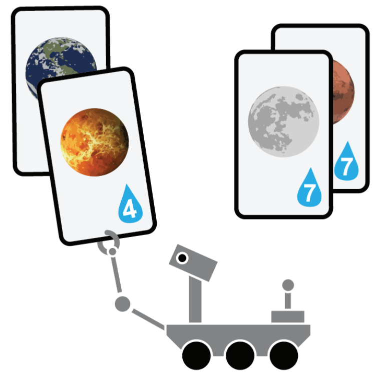
Key Take Away

Water is abundant on earth, however humans can access and use only a tiny fraction of the water. Other organisms can access and use water in ways that humans cannot.

Science Reflection

Today we investigated how various factors can make earth's water reservoirs inaccessible or unusable for humans but other organisms can access and use water in ways humans cannot.

S2



Water in the Solar System
PLANETS cards

Purpose

Youth explore where water is available in the solar system and begin to consider its accessibility and usability.

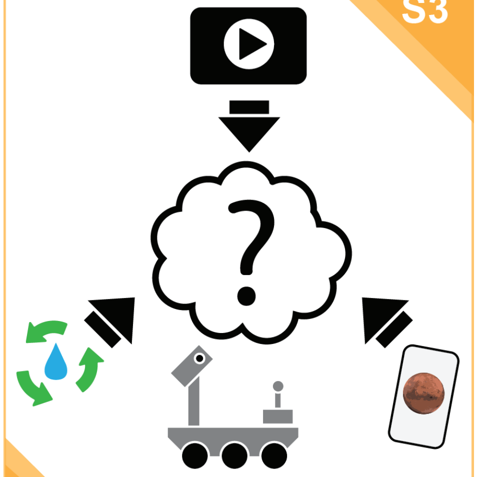
Key Take Away

Water is abundant in the solar system and exists in similar reservoirs and phases as earth.

Science Reflection

Today we learned that water elsewhere in the solar system exists in similar reservoirs to earth and have similar accessibility and usability considerations.

S3



Exploration Potential
Choose a Water Reservoir & Share

Purpose

Youth propose a planetary body to explore based on the availability, accessibility and usability of water and present their choice.

Key Take Away

We can use what we learned about earth's water and evidence of water in the solar system to make an argument about what to explore.

Science Reflection

Today we explored how we can use data about water from elsewhere in the solar system to make recommendations for future exploration.

EDUCATOR *GUIDE*

Unit Overview

In this unit, youth will learn:

- There are physical and chemical properties that determine whether water is usable by humans or habitable for life.
- The Earth has a lot of water that is found in different reservoirs: the surface, the atmosphere, and underground.
- Only a small amount of all the water on Earth is usable to humans.
- There is a lot of water in the solar system, and most of this water is found among the outer planets, farther away from the Sun than the Earth.

In this unit, youth will learn about where water is found in the solar system and whether it is likely it is to be accessible, usable, or habitable. This builds on the concepts of water reuse for extreme environments like interplanetary space and other planetary bodies in the Engineering Everywhere unit, Testing the Waters: Engineering a Water Reuse System. Youth will also explore where and what form water takes in the solar system (e.g., ice vs. liquid water). In the final activity, youth will identify potential water sources in planetary bodies for the potential for primitive life or use by human astronauts or future colonies.

In Activity 1, "Water accessibility and usability on the Earth," youth learn how the amount of available water on earth compares to the amount of usable water on Earth.

Activity 1 Guiding Questions

- How much of Earth's water is usable?
- What is salinity and how does it affect the amount of water we can use?
- Is usable water for humans the same as habitable water for primitive life?

Although the Earth's surface is about 71% covered by water, most of this water is in the oceans, which we cannot use because of its high salinity, or it exists as ice trapped in glaciers and ice caps, or it is located underground. Only a tiny fraction of Earth's is easily accessible and fresh water for human uses.
In Activity 2, "Where can you find water in the solar system?" youth explore the physical properties of planetary bodies in our solar system and the different reservoirs of water on those planetary bodies using a deck of planetary information cards.

Activity 2 Guiding Questions

- » Where is the most water found in the solar system?
- » What kind of water is available in the solar system and in what planetary bodies?

The majority of water in the solar system is found in the outer solar system among the gaseous planets and their moons. The most water among the rocky planets close to the Sun is found on Earth.

In Activity 3, "Choose a reservoir to explore," groups combine the information they have learned in the previous activities to choose a potential water reservoir to explore, share this selection with the full group, state why they want to explore it (primitive life or human use), and explain their reasoning and the evidence they found to support their choice.

Activity 3 Guiding Questions

- » Is any of the water elsewhere in the solar system potentially habitable for primitive life?
- » Is any of the water elsewhere in the solar system accessible and usable for potential future astronauts or future human colonies?

Most of the liquid water in the solar system outside Earth is found in subsurface reservoirs. This water may be more promising for primitive life than it is for human use, but youth can choose and use their imaginations as long as their claims are supported by information learned and evidence gathered in the unit.

Educator Background

Water in the Solar System

When the solar system formed from interstellar gas and dust, the planets closer to the Sun (Mercury, Venus, Earth, and Mars) had little water because it was so hot. Farther from the Sun, water ice was stable on the surface of planets and moons, so it is much more common in the outer solar system. Some of the water on Earth and Mars possibly came from impacts with comets or icy asteroids from farther out in the solar system where there was more water. Many of the moons in the outer solar system are made partly or mostly of water ice. For example, many large icy moons like Titan, Ganymede, and Triton contain more water than Earth in the form of ice. Also, Saturn's rings are mostly made of water ice. (Note: we often specify "water ice" when talking about frozen water because in the outer solar system it is cold enough for other things, like carbon dioxide, methane, ammonia, and nitrogen to also freeze into solid ice.) Among the planets of the inner solar system (closer to the Sun than the Main Asteroid Belt), Earth has the most water. Mercury and Earth's moon have a very small amount of water ice trapped in cold craters near their poles where the Sun never shines. Venus' surface is hotter than an oven (864 °F, 462 °C), and it has very thick carbon dioxide atmosphere with very small amounts of water vapor. Measurements of the atmosphere show that Venus probably used to have more water, but it has all been lost to space. It was boiled off the surface because of its high temperatures and then blown out of the atmosphere by the solar wind. Mars also lost much of its original water, but still has some water stored as ice beneath the surface and at the poles.

Water is essential to all life as we know it, so it is an important resource to look for elsewhere in the solar system. Scientists propose that water is the best place to look for extraterrestrial life outside our planet. Future astronauts will need to find, generate, and reuse water to survive long duration spaceflights.

Vocabulary

Astronomical Unit (AU): The average distance from the center of the Earth to the center of the Sun (93 million miles, 149.6 million kilometers).

Conductivity: A measure of water's ability to pass electrical current. This ability is directly related to the concentration of ions in the water. These conductive ions often come from dissolved salts.

Extremophile: A microorganism that lives in conditions of extreme temperature, acidity, alkalinity, or chemical concentration.

Habitability: As we know it on earth, a habitable environment is one that has water, a source of carbon for organism metabolism, and a source of energy to fuel that organism metabolism.

Ions: Charged particles. Ions are atoms or molecules with a net electric charge due to the gain or loss of electrons.

Kuiper Belt: A donut-shaped region of icy bodies beyond the orbit of Neptune.

Main Asteroid Belt: A region in the solar system located roughly between the orbits of Mars and Jupiter that is occupied by numerous irregularly shaped bodies called asteroids or minor planets.

pH: pH is a measure of hydrogen ion concentration, which indicates if a solution is acidic or basic. The pH scale measures the relative acidity of a substance. It ranges from 1 to 14 where 7 is neutral, greater than 7 is basic, and less than 7 is acidic.

Salinity: The concentration of dissolved salt in water.

Water availability: The presence or absence of water. How much water is available on

Earth or another planetary body can be measured or estimated.

Water accessibility: A measure of how easily water can be obtained. The more effort or energy it takes to access water depends on its location and its physical state. For example, liquid water at the surface is easily accessible. Water that is frozen or located deep underground is less accessible.

Water usability: A measure of how usable water is by humans for consumption (drinking and cooking), agriculture (growing food), and hygiene (cleaning things and washing away waste). To be usable, water must be relatively pure (not contaminated, dirty, polluted, or too salty), and water must be in liquid form.

Materials List & Preparation

Unit Materials List

Quantity	Item
1 per youth	Science Notebook
2 per group of 3	Clear plastic cups
1 per group of 3	Permanent or wet-erase marker
1 per youth	Pencils
1 deck per group of 3	Planetary cards
1 roll for entire group	Tape
1 per group of 3	Calculators
1 cup for entire group	Table salt (any kind - 3 to 4 tablespoons per group of 3)
1 for entire group	Potato cut into slices (2 per group)
1 per group of 3	Tablespoon
1 per group of 3	Stirring spoon or stick

Preparation for Entire Unit (1-2 hrs)

Read through the entire PLANETS Science Series educator guide to learn more about the science content in this unit. This is intended to help educators become familiar with science concepts related to how water was distributed in the formation of the solar system and thereafter. Educators can decide which concepts and vocabulary are most appropriate for their group.

Activity 1

1. Set-up a device with a projector and internet access, view and test video links:
   - Video on Water Availability, Accessibility, Usability
     https://planets-stem.org/water-in-extreme-environments
   - Optional video on pH:
     https://www.youtube.com/watch?v=I18K2upEHLc
   - Optional Salinity Video
     https://www.youtube.com/watch?v=jzTBR2APU-k
   - Optional video on waste water treatment:
     https://www.youtube.com/watch?v=8isr9nSDCK4
   - Video on Extremophiles
     https://www.youtube.com/watch?v=DVox3i1pcpQ

2. Cut potato(es) into similar sized french fry style slices. Each group of 3 needs 2 slices.

3. Print one Science Notebook for each youth, in color if possible. These will be used in Activities 1-3.

Activity 2

1. Print one set of Planetary Cards, double-sided, in color if possible, for each group of 3. There are several sheets of cards (front and back) that form a deck. Cut the cards with a paper cutter to make individual stacks of 54 cards per deck. These will be used in Activities 2 and 3.

Optional: Consider laminating the self-printed cards or using page protectors to preserve materials for future use.

2. Print out the four Water in the Solar System Chart (pp. 36-39).

Activity 3

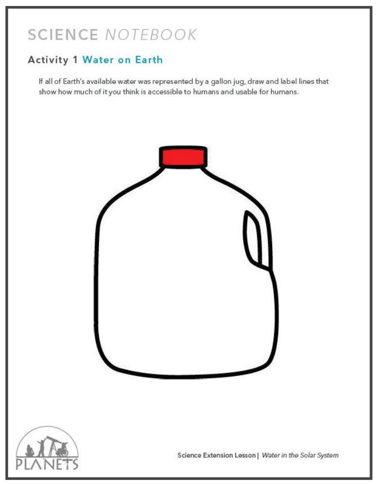
There is no additional preparation for this Activity.

Water on Earth (60 min)

Overview

In this activity, youth will learn that there are different reservoirs of water on Earth: on the surface, in the atmosphere, and underground. Only a small amount of all the water on Earth is usable for humans. Youth will learn about how chemical properties like salinity affect whether available water can be used by humans. Youth learn that much of the water that is not accessible or usable by humans is still habitable and used by other life forms.

In this activity:


SCIENCE *NOTEBOOK*

Activity 1 Water on Earth

If all of Earth's available water was represented by a gallon jug, draw and label lines that show how much of it you think is accessible to humans and usable for humans.

PLANETS

Science Extension Lesson | *Water in the Solar System*

Science Notebook

- » Two videos
- » Materials for salinity experiment. See page 20 for details.

Introduction (5 min)

1. Explain to youth, that in order to understand how available, accessible, usable, and habitable water might be out in the solar system, we first need to understand these parameters for water on Earth.

Learning Goal: Water on Earth (10 min)

1. Ask youth: "How much of the Earth's water is fresh liquid water that we can use?" Ask youth to turn to a partner to discuss, then share.

2. Tell youth that we are going to look at different reservoirs of water on Earth. The word *reservoir* comes from the French "to reserve or save," so it means a place where something is stored – in this case, water.

3. Ask youth: "What are the different reservoirs of water on Earth?" A*ccept all answers (oceans, rivers, lakes, clouds, glaciers, etc.)*. Guide youth to the main categories: on the surface, in the atmosphere, and underground.

4. Ask youth: "Do you think some of the water in these reservoirs would be hard to get to?" *Yes, some water is too deep in the ocean, too deep underground or frozen in glaciers and ice sheets is not easily accessible.*

5. Ask youth: "Do you think there is liquid water on the surface that is too dirty or polluted to drink or use for washing?" *Yes, wouldn't you want to wash your clothes in swamp water or drink out of a polluted river. This water is not usable.*

6. Ask youth: "Why is fresh liquid water important?" *Fresh liquid water is important because that is the form of water that is used by humans.*

7. Ask youth: "How much of Earth's surface is covered by water?" *About 71% of Earth's surface is covered by water.* Remind youth that even though Earth has a lot of available water, not all that water is accessible and usable by humans.

8. In the science notebook on page 3, ask youth to make predictions on the water jug that represents all Earth's water. If all of Earth's water is represented by a gallon of water, then this is the amount of water available on earth. Label the whole jug 'available'.

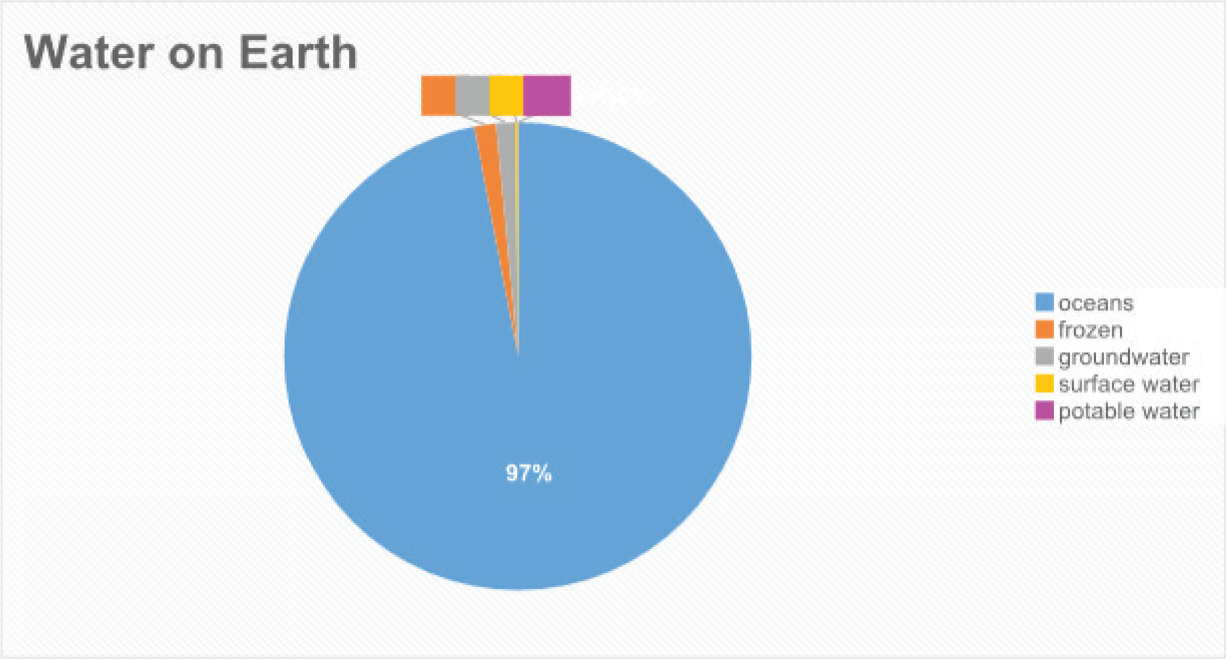
9. Draw and label a line that represents the amount of water that is accessible by humans. Draw and label a line that represents the amount of water that is usable by humans.

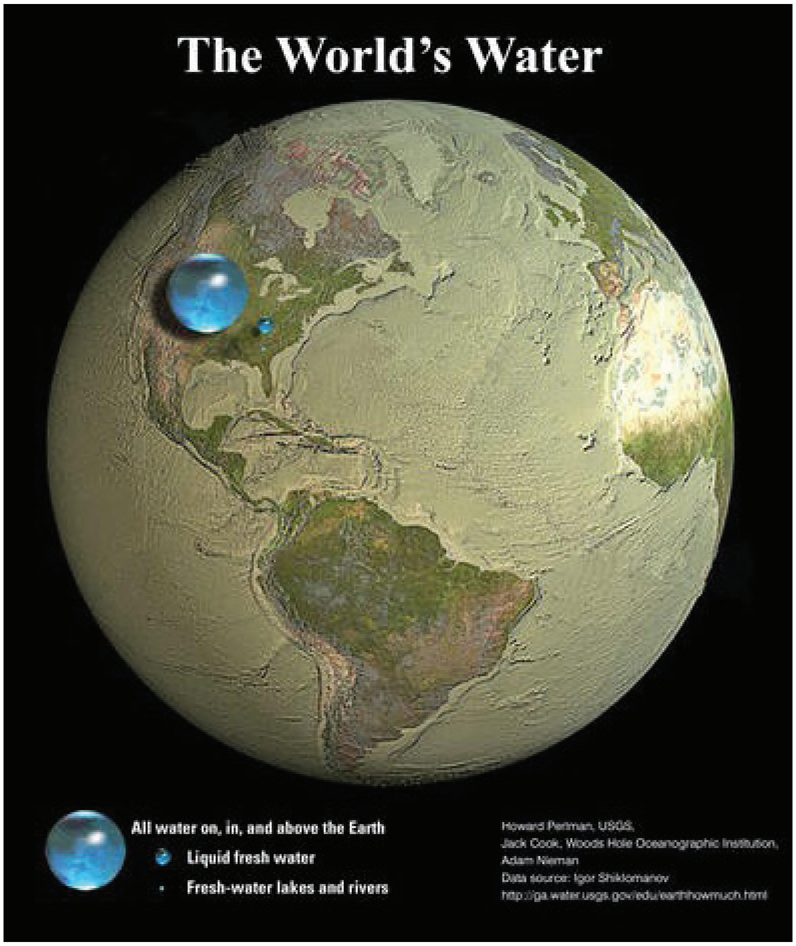
10. Project *Earth's Water: Availability, Accessibility, and Usability*. This video can be found at www.planets-stem.org on the Water in Extreme Environments page in the Science Section. It is also linked here in the electronic version of this guide.

11. Have youth turn to page 4 in their science notebook and draw and label new lines on the *Water Availability on Earth* jug that represent accessibility, and usability.

Optional Reference Visuals

	Explanation	Possible Water Reservoirs for Each
Availability	The presence or absence of water. How much water is available on Earth or another planetary body can be measured or estimated.	Subsurface, Surface, and Atmosphere
Accessibility	A measure of how easily water can be obtained. The more effort or energy it takes to access water depends on its location and its physical state.	Surface and Atmosphere (as rain only).
Usability	A measure of how usable water is for human consumption, agriculture, and hygiene.	Shallow subsurface, Surface, and Atmosphere (as rain only).


Water on Earth
97%
oceans
frozen
groundwater
surface water
potable water


The World's Water
All water on, in, and above the Earth
Liquid fresh water
Fresh-water lakes and rivers
Howard Perlman, USGS,
Jack Cook, Woods Hole Oceanographic Institution,
Adam Nieman
Data source: Igor Shiklomanov
http://ga.water.usgs.gov/edu/earthhowmuch.html

Water Usability on Earth – Dissolved contaminants (20 minutes)

1. Ask youth: "What would make water not drinkable?" In Activity 1, we saw how little drinking water there is on the Earth. If they have done the Engineering Everywhere™ Testing the Waters Unit, they learned how to filter water to remove pollutants.

Tip: If youth have completed the Engineering Everywhere™ Testing the Waters Unit, they will have investigated pH and filtering to alter the pH of waste or gray water. Also consider adding acidity to the discussion after showing this video https://www.youtube.com/watch?v=I18K2upEHLc

2. Explain to youth that on planets, the salinity of water is affected by different things that are dissolved in it.

3. Salinity Experiment:
- Split youth into groups of 3 or 4. For every group, you will need:
  - i. 2 clear plastic cups
  - ii. 1 marker
  - iii. 3-4 tablespoons of salt
  - iv. 1 Tablespoon
  - v. 1 Stirring spoon or stick
  - vi. 2 potato slices
- Have a representative in each group label the 2 cups saline water and pure water.
- Have another group member fill the two cups with an equal amount of water.

Tip: This experiment takes 24 hours to show results. Depending on the time structure of your program, you may want to set up this experiment yourself the night before so that you can discuss the results with youth the same day they set up their own investigation.

Tip: In general, the more salt you dissolve, the warmer the water, and the more surface area exposed on the potato, the more dramatic the results will be.

» Have another group member stir in 3-4 tablespoons of salt one at a time to the cup that says saline water.
» Have another group member add a potato slice to each cup.
» Let cups sit out overnight.
» Observe the differences the next day. Note the size and consistency differences. Did the potato slice in the saltwater shrivel? Does it bend or break? Does it feel hard and crisp or limp and soft?

4. Let youth know that potatoes have actually dehydrated from sitting in saltwater. If you drink water that is too salty then it will dehydrate you just like the potato. There is actually less water inside the potato that sat in saltwater. This makes it flimsy and not as crisp.

Tip: If youth have questions about how salinity dehydrated the potato, consider showing this video: https://www.youtube.com/watch?v=jzTBR2APU-k

Tip: If you have access to a microwave or hot water tap, have youth experiment with the difference temperature makes when dissolving the salt. If you have additional time, you can also experiment with stirring or not and/or time how long it takes for the salt to dissolve in hot versus cold water, with stirring or not.

Discussion (5 min)

1. Have a group discussion about salinity using the following guiding questions:
» Do you know what salinity means?
It means the amount of salt dissolved in water.
» Why does the salinity of water matter?
Too much salt in the water makes it unhealthy to drink.
» Does it matter just for humans?
No, it also matters for fish and other aquatic creatures in the water and for plants and animals both in the water and near the water.
» Why can some fish and plants live in salt water?
Fish adapt to live in salty water by peeing out salt, or in fresh water by absorbing salt in their gills, but nothing can live in water that has very high salinity.

Water habitability on Earth – Video and discussion of extremophiles (15 min)

1. Explain that water requirements for human use are different than the water requirements for other life forms. Habitability is the ability of an environment to support life.

2. Have a group discussion about water habitability using the following guiding questions:
   - » What does most life on earth need to survive?
     Most life needs liquid water, relatively neutral pH, moderate temperatures, and an energy source (the sun).
   - » Are these the requirements for all life? *Accept all answers.*
   - » If ocean animals have adapted to salinity, is it possible that life on earth has adapted to other pollutants or extreme environments? *Accept all answers.*
   - » Do you know any examples of life that live in extreme environments without abundant water, high or low acidity, or without sunlight here on earth? *Accept all answers.*

5. Show the following NASA eClips video about extremophiles:
   https://www.youtube.com/watch?v=DVox3i1pcpQ

6. Ask youth: "So now what do you think are the requirements for life on Earth?
   As we know it on earth, a habitable environment is one that has water, a source of carbon for organism metabolism, and a source of energy to fuel that organism's metabolism.

Wrap Up (10 min)

1. Lead a discussion to summarize the availability, accessibility, usability and habitability of water on earth. Use the following questions to guide the discussion:
   - » If most of the Earth's surface is covered in water, why is drinking water limited for human use?
     Because most of it has high salinity (ocean water), and much of the water that is usable is not easily accessible (locked up in ice sheets or underground).
   - » What technologies have humans devised to treat dirty water for human use?
     Filters and sewage treatment plants.
   - » Is there a difference between the usability of water for humans and the

habitability of water for other life forms?

Yes, humans need pure liquid water. Most lifeforms live off water that is not accessible or usable for humans. In fact, if water is habitable and lots of things live in it, then it's contaminated for human use.

» Do you think other planetary bodies that have water might have the same issues?

Sure they do! Let's check it out in the next activity.

Water in the Solar System (55 min)

Overview

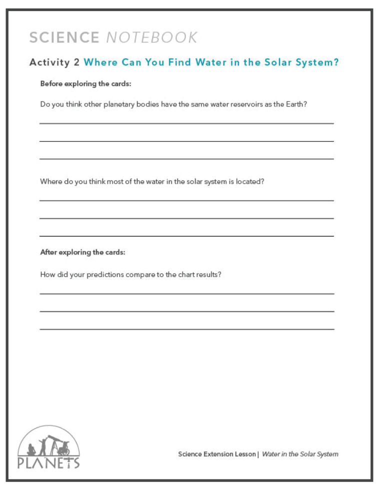
In this activity, youth will get information about different planetary bodies to discover where water can be found in our solar system. Examples from Earth and other planets will be used. The objective of the exercise is for youth to visualize where, and in what types of reservoirs, water is present in our solar system. Then youth will compare and contrast the amount and accessibility of water among the sites.

Youth will learn:

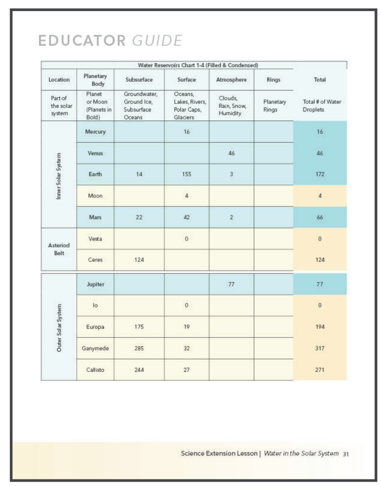
- » Water is abundant in our solar system
- » Water is found in different reservoirs (surface, subsurface, and atmosphere)
- » More water is located in the outer part of the solar system than closer to the Sun

In this activity:

Planetary Cards



Science Notebook



Solar System Charts

Introduction (5 min)

1. Tell youth that in this activity they will get to look at NASA images from other planetary bodies to investigate where water is found in the solar system. These bodies include asteroids, dwarf planets, planets, and moons.

2. Ask youth: "What are the different reservoirs of water that we learned about in Exercise 1?" *Surface, subsurface, atmosphere.* "Do you think other planetary bodies have those same reservoirs?" Tell youth to record their prediction in their science notebook. *In this activity we will find out!*

Getting to know the Planetary cards (15 min)

1. Split youth into groups of 2-4. Give each group a set of Planetary information Cards.

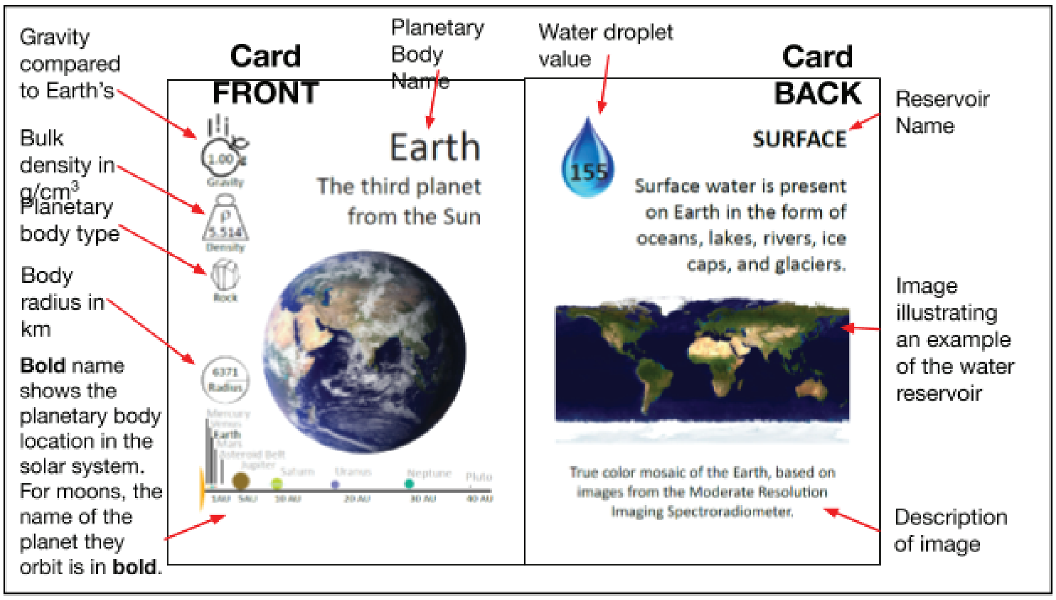
2. Familiarize youth with the card fronts. Tell youth to pick up one of the cards and explain each icon:

- The number in the falling apple icon is the surface gravity of the body compared to Earth (g). The gravity of a body depends on its mass. Have youth find cards for Earth and Mars and look at the gravity numbers. For Earth the gravity value is 1.0 g. For Mars the gravity value is 0.38 g (because Mars has less mass). This means that if you weighed 100 pounds on Earth, you would weigh 38 pounds on Mars.
- The number in the weight icon labeled with a "ρ" is density. The density of an object is a measure of how much material, or mass, is packed into its volume (how big it is) and is measured in units of grams per cubic centimeter. The density of rock ranges from 2.5 to 3.5 grams per cubic centimeter. The density of water is 1.0 gram per cubic centime ter. The density of ice is around 0.92 grams per cubic centimeter, a bit less than water (which is why ice floats on liquid water). The density of planetary bodies helps us deter mine what it's made of.
- The icons for rock, ice, and gas indicate what the body is mostly made of. The inner planets are rocky. The outer planets are mostly gas or a mixture of ice and gas. The moons of outer planets and asteroids are either rocky or mixtures of rock and ice. Ask youth: "Why is the Earth considered a rocky planet?"

Although there is ice on the surface and gas in the atmosphere, most of the Earth is made up of rock.

» The average radius of the planetary body provides a means to compare the sizes of different planetary bodies, or to calculate the total volume of the planetary body.

» Across the bottom of the front of the card, the planets are shown in order of increasing distance from the Sun. We can measure this distance in Astronomical Units, noted as AU. One AU is defined as the average distance from the center of the Earth to the center of the Sun. Have youth look at cards for Earth and for Pluto. Pluto's average distance is almost 40 times the average distance from the Earth to the Sun!



3. Familiarize youth with the card backs. Tell youth to flip their card over and explain each icon:

» On the back side they will see a label indicating the type of water reservoir on that planetary body and a picture showing an example.

» At the top of each card, there is a water droplet and number representing the amount of water that exists in that particular reservoir. The water droplet number is directly related to the volume of water in the reservoir and allows us to compare the amount of water on different planetary bodies across the solar system.

» The image on the back of the card shows an example of the water reservoir, including a description of the image, or a model of what scientists think the reservoir looks like.

4. Next, have youth look at the cards for Mercury, Europa, and Earth. Explain: All the water on Mercury is stored on its surface, so it only has one card for its surface reservoir. The number in the water droplet is (16) indicating there is not much water on Mercury's surface. Compare that with Europa, which has two cards representing the water on its surface (19) and in its subsurface (175).
5. Explain to youth that some moons and planets will have multiple cards, representing multiple water reservoirs. The droplet numbers are cumulative, so to get the total amount of water on a body, add up all the droplet numbers from that body's cards.

6. Tell youth that now they will spend 10 minutes exploring and sorting the cards. Within their small group, ask youth to discuss different ways they might sort the cards, and agree on one way to sort them. Then invite groups to share how they sorted the cards.

Note: The water droplet numbers are mathematically related to scientific estimates of the volume of water on each planetary body. For anyone interested in how, a detailed explanation can be found in the introductory cards in the Planetary Cards deck.

7. Ask: "Did we all sort them the same way?" Then challenge small groups to sort them in another way that no one mentioned. Share again. Guide youth to make these different example categories:

- in order of increasing distance from the sun
- planets vs. moons
- in order of increasing abundance of water
- different reservoirs of water
- planets with their associated moons
- different types of planets
- in order of increasing gravity, density, or radius

8. Ask: "What did we learn from sorting the cards?" *There's a lot of water in the solar system. Earth doesn't have as much water as I thought. Ganymede and some other moons of Jupiter and Saturn have a lot of water.*

Investigating Water in the Solar System (25 min)

1. Now tell youth that we're going to create a chart, so we can better see reservoirs of water in the solar system. Post the 4 printed Water Reservoir Charts in different locations around the room (see the preparation section of this guide, page 22, step 2).

2. Have each group fill out one chart: Ask youth to sort the cards in their decks by planetary body (i.e., with planets and their moons together). Then assign the different planetary bodies evenly among the groups and individual cards evenly among individuals. Alternatively, you can shuffle the deck and deal the cards to youth randomly. In this scenario, the youth will find each one of their reservoirs on the corresponding chart and fill in the water droplet values individually.

3. Allow groups a few moments to get familiar with their planetary bodies.

4. Then, have each group record the water droplet number under each category in one of four *Water in the Solar System* tables. Continue until all cards have been recorded. Many boxes will be left blank. When complete, fold or cut and tape the charts together to make one large long chart and post this where everyone can see. See the blank and completed tables below. As mentioned in Step 2, in the alternative option, youth will visit multiple tables to fill in their water droplet values for each listed reservoir. When everyone has recorded all cards, have youth split into teams to total the water droplet values for each chart.

Note: Use the original option if you want to keep the planets, moons, and reservoirs together as an orderly cohesive learning unit. Use the alternative option if you have an odd number of groups or want to better distribute actions and timing among youth.

Water Reservoirs Chart 1						
Location	**Planetary Body**	**Subsurface**	**Surface**	**Atmosphere**	**Rings**	**Total**
Part of the solar system	Planet or Moon (Planets in Bold)	Groundwater, Ground Ice, Subsurface Oceans	Oceans, Lakes, Rivers, Polar Caps, Glaciers	Clouds, Rain, Snow, Humidity	Planetary Rings	Total # of Water Droplets
Inner Solar System	**Mercury**					
	Venus					
	Earth					
	Moon					
	Mars					
Asteriod Belt	Vesta					
	Ceres					

Water Reservoirs Chart 2							
Location	**Planetary Body**	**Subsurface**	**Surface**	**Atmosphere**	**Rings**	**Total**
Part of the solar system	Planet or Moon (Planets in Bold)	Groundwater, Ground Ice, Subsurface Oceans	Oceans, Lakes, Rivers, Polar Caps, Glaciers	Clouds, Rain, Snow, Humidity	Planetary Rings	Total # of Water Droplets
Outer Solar System	**Jupiter**					
	Io					
	Europa					
	Ganymede					
	Callisto					

Water Reservoirs Chart 3						
Location	**Planetary Body**	**Subsurface**	**Surface**	**Atmosphere**	**Rings**	**Total**
Part of the solar system	Planet or Moon (Planets in Bold)	Groundwater, Ground Ice, Subsurface Oceans	Oceans, Lakes, Rivers, Polar Caps, Glaciers	Clouds, Rain, Snow, Humidity	Planetary Rings	Total # of Water Droplets
Outer Solar System	**Saturn**					
	(Rings)					
	Mimas					
	Enceladus					
	Tethys					
	Dione					
	Rhea					
	Titan					
	Iapetus					

Water Reservoirs Chart 4						
Location	**Planetary Body**	**Subsurface**	**Surface**	**Atmosphere**	**Rings**	**Total**
Part of the solar system	Planet or Moon (Planets in Bold)	Groundwater, Ground Ice, Subsurface Oceans	Oceans, Lakes, Rivers, Polar Caps, Glaciers	Clouds, Rain, Snow, Humidity	Planetary Rings	Total # of Water Droplets
Outer Solar System	**Uranus**					
	Miranda					
	Ariel					
	Umbriel					
	Titania					
	Oberon					
	Neptune					
	Triton					
Kuiper Belt	Pluto					
	Charon					

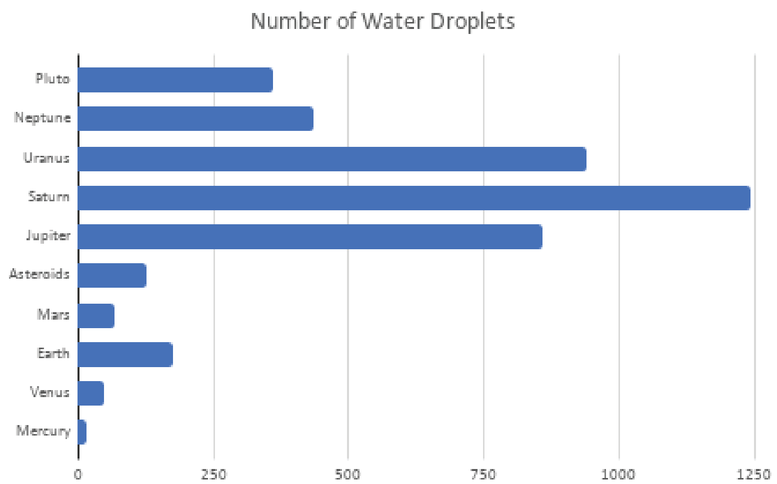
Water Reservoirs Chart 1-4 (Filled & Condensed)						
Location	**Planetary Body**	**Subsurface**	**Surface**	**Atmosphere**	**Rings**	**Total**
Part of the solar system	Planet or Moon (Planets in Bold)	Groundwater, Ground Ice, Subsurface Oceans	Oceans, Lakes, Rivers, Polar Caps, Glaciers	Clouds, Rain, Snow, Humidity	Planetary Rings	Total # of Water Droplets
Inner Solar System	**Mercury**		16			16
	Venus			46		46
	Earth	14	155	3		172
	Moon		4			4
	Mars	22	42	2		66
Asteriod Belt	Vesta		0			0
	Ceres	124				124
Outer Solar System	**Jupiter**			77		77
	Io		0			0
	Europa	175	19			194
	Ganymede	285	32			317
	Callisto	244	27			271

Outer Solar System	**Saturn**			72		72
	(Rings)				91	91
	Mimas	79	9			88
	Enceladus	81	9			90
	Tethys	134	15			149
	Dione	129	14			143
	Rhea	141	16			157
	Titan	255	28			283
	Iapetus	153	17			170
Outer Solar System	**Uranus**	200				200
	Miranda	86	10			95
	Ariel	133	15			148
	Umbriel	138	15			153
	Titania	156	17			173
	Oberon	154	17			171
	Neptune	197				197
	Triton	213	24			237
Kuiper Belt	Pluto	187	21			208
	Charon	137	15			152

5. Once the table is all put together and posted, ask youth to describe any trends that they see.

6. Next, ask youth to add up all the water that is contained within each planet group, for example all the water on Jupiter and all its moons, and all the water on Saturn and all its moons, etc. The chart below shows the answers.

Planetary Body AND Moons	Total # Water Droplets
Mercury	16
Venus	46
Earth	176
Mars	66
Asteroids	124
Jupiter	859
Saturn	1243
Uranus	940
Neptune	434
Pluto	360



7. Have youth generate a bar graph in their science notebooks similar to the one shown above based on the total number of water droplet numbers found in each planetary body group.

Wrap Up (10 min)

1. Give youth a chance to identify patterns in the data in the space provided in the science notebook. Once most have stopped writing, lead a discussion to summarize findings. Use the following questions to guide the discussion:

» Where is water found?
Water is found in many places throughout the solar system.

» Among the planets in the inner solar system (Mercury, Venus, Earth, and Mars), which planet has the most water?
Earth.

» In our solar system, where is the majority of the water?
In the outer solar system, especially in icy moons around Jupiter and Saturn.
» What reservoirs have the most water? Do you see any patterns or differences between moons and planets? The Inner and Outer solar system?
In the outer solar system, planets only have water in the atmosphere, but moons have the most water in the subsurface
» Do you see the any patterns within single planetary systems, for example with the moons of Saturn and Uranus?
In general, the farther the moon is from its planet, the more water it has.
» Did these patterns surprise you? Did they match your predictions?
Accept all answers.
» Tell youth to think about these questions for next time:
i. Now that we know where water is available in the solar system, do you think that it is usable for humans?
ii. Do you think it's habitable for organisms?

Tip: Once youth have completed Activity 2, consider showing this poster to better visualize the water available in our solar system: www.planets-stem.org/water/?

2. Wrap up for the day by congratulating youth on their scientific work. Let youth know that next time, they will choose one of these watery planetary bodies to explore.

Optional PLANETS Card Games (10+ min)

If time permits, let the youth play games with the cards. Encourage them to develop their own games! Reminder: The "front side" of the card has the name of a planetary body along with its picture and physical characteristics. The "back side" of the card has information about a specific water reservoir.

Some ideas for games that can be played with the cards include:

Accretion (Easy, 2-5 players) Like the card game war or battle, the objective is to win all the cards. Alternatively, the player who collects most of the water in the solar system could be declared the winner. Shuffle all cards randomly. Deal all cards evenly among all players. In unison, each player reveals the top card of their deck, front up. Using the information on the card fronts, the player with the highest gravity value takes all the cards played and moves them to their deck. If two cards played have equal gravity values, then there is a battle. Battling players place the next card of their deck front down and then another card front up. The owner of the front up card with the higher gravity value wins the battle and adds all cards to their deck.

Build the Solar System (Moderate, 2-5 players) Shuffle all cards randomly. Deal 6 cards to each player, leaving a draw pile. The first card played must be a planet or dwarf planet. Using the solar system location information on the card fronts, the next player must build on this card by playing (1) an adjacent planet - to the right or left, (2) a moon of the planet - below, or (3) another card of the same planet - on top. A planet must be played before a moon of that planet can be played. Asteroids are played as planets (i.e., Jupiter cannot be played next to Mars). A player who can't play draws one card from the pile. If the drawn card plays they may play it, otherwise they are skipped, or are skipped if there are no more cards in the draw pile. The object is to be the first to play all their cards. To play several rounds, one may keep score with the water droplet values - whoever has the least water wins.

Crazy Earths! (Advanced, 2-4 players) Similar to the game Crazy Eights, the object of the game is to be the first player to get rid of all their cards. Shuffle all cards randomly. Deal 6 cards to each player, leaving a draw pile. The top card from the pile is then played to start the game. Players discard by matching "suits" with the top card. Unlike with regular cards, this game uses information that is on both sides of the cards. The "suits" are water reservoir (surface, subsurface, or atmosphere), composition (rock, ice, gas, gas+ice, or rock+ice), and solar system location (Mercury, Venus, Earth, Mars, Asteroid Belt, Jupiter, Saturn, Uranus, Neptune, or Pluto). One can play any Earth card at any time as a wild card. When a player plays an Earth, they declare the "suit" that the next player must play. For example, say "atmosphere" and the next player has to play an atmosphere card; or say "Saturn" and the next player must play a planet or a moon from Saturn's location in the solar system; or say "rock" and the next player must play a planetary body that is a rock type. If a player is unable to match the "suit" of the top card of the discard pile and does not have an Earth, they draw a card from the draw pile. If it plays, they can play it, otherwise their turn is skipped.

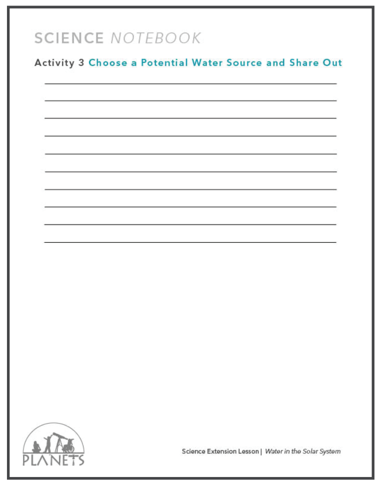
Choose a Potential Water Reservoir to Explore & Share Out (15 min)

Overview

Where can we find accessible and usable water in our solar system that may support life? In this activity, youth will combine what they have learned in the Science Series: Water in the Solar System to propose an extraterrestrial water reservoir to explore for primitive life or human use.

In this activity:

Planetary Cards



Science Notebook

Introduction (5 min)

Tell youth to imagine that NASA is holding a contest for youth that will determine the next object in the solar system for exploration. You and your fellow young people have decided that you want to choose a place that has the potential for life and that humans could possibly visit one day.

Let youth know that today they will need to consider all the data they have collected and content they have learned over the previous activities and use this to choose a water reservoir on one planetary body in the solar system. Let youth know that as they review their data, they should keep in mind that they will need to share their results with the whole group, so they should think about the evidence they use to make their decision and how they will explain their reasoning.

Shuffle one deck of planetary cards and deal out all cards to youth. Alternatively, lay all the cards out on one table and have youth choose at least 3.

Choose a Water Reservoir in the Solar System to Explore (15 min)

1. Explain to youth that they will address each of the following considerations in their science notebook and record evidence for their water source on how available, accessible, usable, and potentially habitable their water reservoir is.
   - How much water is available in this resource? How does the water drop value compare to Earth's water reservoirs?
   - Is the water buried under a layer of rock or ice that would make it difficult to extract, study from afar (remote sensing), or gather samples?
   - In what state of matter does the water in this reservoir occur? Is it already liquid or is it gas (water vapor) or solid (ice)? Is it possible that it could support primitive life or be used by humans as it is?
   - Is the water in this reservoir mixed with another substance like hydrocarbons or carbon dioxide? Does it have salinity? How would this affect potential habitability for life or

Note: Use the original option if you want to keep the planets, moons, and reservoirs together as an orderly cohesive learning unit. Use the alternative option if you have an odd number of groups or want to better distribute actions and timing among youth.

usability for humans?
» What more do you need to know about this planetary body and its water reservoir to help you make your decision?

2. Have the youth record information in the table outlined in the science notebook for up to 3 cards.

3. Ask youth to consider all the information they have learned on water usability and habitability and consider if their water reservoirs are most promising to explore for humans (usability) or primitive life (potential habitability).

4. Tell the youth they will need to choose only one reservoir from their entire group based on evidence (availability, accessibility, usability, habitability) or another condition the youth have deemed more important for consideration than those listed in the table.

5. Tell youth they also need to choose why they are exploring this reservoir, human use, primitive life, or both. Remind youth that human use does not only including drinking, it also includes hygiene (cleaning things, washing clothes, showering, toilets) and irrigating crops.

Prepare for the Presentation (15 min)

1. Ask groups to review the card for their top choice and lines of evidence recorded in their Science Notebooks. Have youth use these to help them prepare a presentation about the water reservoir they selected. Let them know they will share their presentation with the whole group and invited guests, if it is possible to do so at your site.

2. As groups are working, help guide their thinking by asking:
» What evidence did you look at to help you choose your water reservoir?
» Which reservoir will provide the most usable

Note: The presentation is a chance for youth to explain their thinking and reflect on what they learned about water in the solar system throughout the unit. Youth can present and share in a variety of ways, including:

» Invite youth to rank the water sources based on all the available information.

» Ask youth to write a compelling argument to NASA about which planetary water reservoir should be selected.

or habitable water? Why?

Share Out and Discussion (25 min)

1. Ask groups to share which reservoir they determined to be the most accessible, usable and/or habitable water in the solar system. As each group shares, ask them to refer to their card and Science Notebook and provide examples of evidence that led to their recommendation and to explain their thinking. After each group presents, ask questions like:
   - » What surprised you about working with the information?
   - » What is one thing you will remember about the planetary bodies in the solar system?

2. After all groups have shared, ask:
   - » Is there a common type of reservoir in the solar system that multiple groups identified as promising?

Wrap Up (5 min)

Lead a discussion about what else we should consider when choosing a new location to explore in the solar system besides the availability and usability of water. Consider one planetary body that the whole group identified as a popular choice for a water reservoir. Use the following questions to guide the discussion.

1. Discuss other potential habitability issues that might affect the possibility of life on other planetary bodies like gravity, weather, extreme temperatures, radiation, etc. Ask:
   - » How would this change your answer?

2. Discuss: how does the limited information we have about water reservoirs on planetary bodies negatively impact our attempts to explore these places for the possibility of life? *It's important to acknowledge your data gaps in science so that you don't make a costly wrong decision*

3. Congratulate youth on their excellent scientific work. Let them know that identifying places to explore based on evidence is important so that we don't waste precious time and resources.