**Space Rocks!**

**A Meteorite Board Game**

***Overview —***

**Ages:** 3rd grade and up

**Duration:** 15 – 45 minutes

Players assume the roles of meteorites and play a board game to learn about meteors, meteoroids, and meteorites. They compete to get to Antarctica, where they have the chance to be found and studied by scientists! The game can be played as a whole group activity, in teams, or by individuals.

***WHAT’S THE POINT?***

Participants will:

* Learn about meteorites and how we discover them.
* Discover that the odds of a meteorite landing on Earth and being discovered are low, and yet hundreds to thousands are found each year!
* Have fun!

***MATERIALS —***

* Space Rocks game board (one per each group of players) (*Note: link to pdf of game board)*
* Game Pieces (use pebbles or game pieces from other games)
* Game Cards (link to pdf) (or powerpoint questions (link to ppt), computer, and projector)
* Copy of Background Information for facilitator
* Dice
* Optional Supporting Videos:
  + History Channel – The Secrets of Meteorites. <http://www.history.com/shows/how-the-earth-was-made/videos/the-secrets-of-meteorites>
  + PBS NOVA – Hunting for Meteorites. <http://www.pbs.org/wgbh/nova/space/matson-meteorite.html>
* Optional Supporting Websites
  + NASA’s Solar System Exploration – Meteors and Meteorites. <https://solarsystem.nasa.gov/asteroids-comets-and-meteors>
  + Killer Asteroids. <http://www.killerasteroids.org>
  + NASA Goddard Scientific Visualization Studio – Asteroids. <http://svs.gsfc.nasa.gov/search/Keyword/Asteroid.html>

***PREPARATION —***

* Print the Space Rocks game board; if possible, laminate or glue to poster board
* Determine whether you will project the questions from a computer or use physical cards. If using cards, print and cut apart the Space Rocks! Game Cards. (Laminating the cards will increase their durability)

***ACTIVITY —***

1. **Welcome and introduce the topic.**Ask participants what they know about meteorites. After participants have shared and compared their thoughts, share some background:

* Impacts cause explosions that blast meteoroids off the surface of their parent body by an impact and eventually land on the surface of another moon or planet.
* Most meteorites come from asteroids, such as the large asteroid Vesta.
* While they are moving through space, these rocks are known as meteoroids.
* While they pass through the Earth’s atmosphere, they create a streak of light called a meteor.
* Most meteoroids are small and burn up in Earth’s atmosphere.
* Many meteorites land in the ocean or other locations where they are never discovered.
* On Earth, we have found meteorites from the Moon, Mars, and asteroids.

Describe the game: they will be playing individually or in teams to move their rock from a parent body (the Moon, Mars, Vesta, or Bennu) to Earth; their goal is to land their rock on Antarctica where it has a larger chance of being discovered.

1. **Set up the game.** Place the game board in the center of each group of players and place the cards (question-side down) nearby. If more than 4 participants are playing, either conduct multiple games or invite them to play as teams. Invite each player or team to select their “meteoroid” game piece to move about the game board, starting from one of the four corners (parent bodies): Moon, Mars, Vesta, or Bennu.
2. **Rules of the game.**Make sure that everyone understands the game and their role in it before proceeding to play. Reassure them that they can ask for your help in the process, if needed, as the game is played.
   * The players or teams will move from their parent body (Moon, Mars, Vesta, or Bennu) in toward the Earth. The first player or team to land in Antarctica and correctly answer a final question wins.
   * Whether they can move forward depends on both what they roll on the dice and whether they can answer a card question correctly. If they don’t roll the correct number or answer the question correctly, they need to stay in the same spot until it’s their turn again.
   * If a group is playing together as a single team, then all can help to answer the questions.
   * More information about the correct answers is available on a cheat sheet that the facilitator can use to explain the answers, or that the players can review after the game.
3. **Game Instructions.**
   * Roll a die to determine which player or team will go first. The player or team with the highest number will begin the game. Play always passes to the player on the left. The rules for their play depends on which zone their piece is in.

Leaving the Parent Body (Moon, Mars, Vesta, or Bennu)

* + The first player or team rolls a die. If they roll an odd number, their turn ends. If the player rolls an even number, then an impact has occurred, which may blow your rock into space to become a meteoroid. Another player picks a card and reads the question aloud for the active player to answer. If they answer correctly, they can move forward to the Meteoroid Zone before their turn ends.
  + The die passes to the player or team on the left; again, they need to roll an even number and then answer a card question correctly to move forward to the next zone. If player answers the question incorrectly, they will remain in their current position and pass the die.
  + Continue passing the die to the left.

The Meteoroid Zone: Once in the meteoroid zone, a player needs to roll a 5 or a 6 to approach Earth. If they roll 1 -4, their turn ends. If the player rolls a 5 or a 6, then their space rock is approaching Earth. Another player picks a card and reads the question aloud for the active player to answer. If they answer correctly, they can move forward to the Meteor Zone before their turn ends.

The Meteor Zone: Once in the meteor zone, a player needs to roll an odd number to land on Earth. If they roll an even number, their turn ends. If the player rolls an odd number, and answers a question correctly, they can move forward to the Meteorite Zone before their turn ends.

The Meteorite Zone: Once in the meteorite zone, a player needs to roll a 1 to determine whether they landed in Antarctica, where they are more likely to be discovered by scientists. If they roll 2-6, their turn ends. If the player rolls a 1, and answers a question correctly, they land in Antarctica and win.

***CONCLUSION***

Discuss how unlikely it is for a rock to be blown off another object and land somewhere on Earth where it can be found and studied. And yet hundreds or thousands are found each year!

***BACKGROUND INFORMATION***

Additional details and background information about the questions for the game facilitator: this information if geared toward teens and young adults who can facilitate discussion of the questions and answers. It is not necessary for younger game players to review this information.

**What is a meteor/ what is a meteorite / What is a shooting star/ What is a meteoroid?**

Meteoroids are often small particles that orbit our Sun in space, often no bigger than a grain of sand. When meteoroids enter Earth’s atmosphere, they produce brilliant streaks of light that can be seen in our sky. These brief streaks of light (often called “shooting stars”) are meteors. Meteorites are meteoroids that have landed on Earth’s or another planet’s surface.

**Why does a meteor glow? Which object does not have meteors?**

A meteor is the streak of light we see in the sky as a meteoroid passes through our atmosphere; however, most of the meteoroids are very small—the size of a grain of sand. We don’t actually see the meteoroid. Instead, we are seeing the air itself glowing as it is ionized from the heat of the meteoroid speeding through it.

Since meteors are the glowing gases as a meteoroid passes through an atmosphere, objects without an atmosphere (like the Moon) do not have meteors. However, meteors may have occurred on Moon about 3.5 billion years ago, when it was surrounded by a temporary atmosphere.

**How fast does a meteoroid move in our atmosphere?**

Meteoroids are moving incredibly fast (around 50 thousand miles per hour) as they orbit the Sun; our Earth runs into them.

**What are the different types of meteorites? What do most meteorites look like?**

Most meteorites found on Earth are pebble to fist size, but some are larger than a building. Meteorites may look very much like Earth rocks, but some have the appearance of a burned exterior called a fusion crust. They may also have thumbprint-like depressions. This crust forms when the exterior of the meteoroid is melted by friction as it passes through the atmosphere.

Scientists classify meteorites into three groups:  stony meteorites, iron meteorites, and stony iron meteorites. Stony meteorites make up about 95% of the meteorites reaching Earth. Iron meteorites make up about 5% of the meteorites found on Earth; these come from the cores of shattered planetary bodies (often from a shattered asteroid). These have high amounts of iron and nickel. **Stony-iron meteorites** are in between the other two types of meteorites. These are rare — only about 1% of the meteorite finds on Earth are stony iron meteorites.

**What causes meteor showers/ Which is a meteor shower?**

Meteor showers occur when Earth passes through the trail of dust left by a comet along its highly elliptical orbit. The particles enter Earth's atmosphere and most burn up. Some meteor showers, such as the Perseids in August and the Geminids in December, occur annually when Earth's orbit takes it through the debris path left along the comet's orbit. Comet Halley's trails are responsible for the Orionids meteor shower.

**What is an asteroid? Which is not an asteroid? Asteroid features.**

Asteroids are rocky bodies ranging from 620 miles (1000 km) wide down to dozens of meters, which orbit our Sun or another asteroid. Ceres is the largest of the asteroids, and Vesta is the second largest. Bennu is an asteroid that the OSIRIS-REx mission is studying.

Most asteroids are irregularly shaped and all have craters from impacts with other asteroids. However, the largest asteroid, Ceres, has sufficient gravity to become nearly spherical, so it is also classified as a dwarf planet!  Vesta, another large asteroid, has evidence of ancient lava flows on its surface.

Asteroids usually have extensive cratering on the surface. Some asteroids, such as Ceres, have large amounts of ice. Asteroids are too small to have an atmosphere, so they cannot have storms.

**What are the types of asteroids?**

Asteroids are classified by their composition. Most of the known asteroids (over 75%) are C-type (carbon-rich) asteroids, located in the outer region of the main asteroid belt. These asteroids are usually composed of silicate rocks along with organic compounds and hydrated minerals. Stony or silicate-rich (S-type) asteroids dominate the inner part of the asteroid belt, closest to the Sun. These asteroids are composed of rocky materials and small amounts of metallic iron. M-type (metallic) asteroids are predominantly metallic iron and nickel.

**Where do most meteorites come from?**

Meteorites are ejected from a rocky body by an impact by an asteroid or comet. More than 50,000 meteorites have been found on Earth. Most come from asteroids; in particular, several different types of meteorites appear to be from the asteroid Vesta. A few meteorites originate from the Moon and Mars. Meteorites also fall on other solar system bodies. The Mars Exploration Rover, Opportunity, has discovered six meteorites during its travels on Mars.

**What makes an impact crater?**

Craters are roughly circular, excavated holes made by impact events. When an asteroid or comet strikes the solid surface of a planet or another asteroid, a shock wave spreads out from the impact, creating a crater much bigger than the asteroid or comet. The asteroid or comet is shattered into small pieces and may melt or vaporize.

**How long have asteroids been hitting the planets? Do large or small asteroids hit the Earth more frequently?**

Early in the formation of the solar system (4.5 billion years ago), frequent and large impacts were common for all of the planets and moons. Impacts still occur across our solar system, but at a reduced rate. Scientists estimate that Earth and the other terrestrial planets are struck by, on average, five asteroids less than 2 kilometers (a little over 1 mile) across every million years. Larger impacts also still occur, but are more rare.

**Which is hit by the smallest particles from asteroids and comets?**

The Moon does not have an atmosphere to shield the surface from small particles; Earth, Venus, and Mars have atmospheres that burn up the smallest particles from asteroids and comets.

**BetweeWhicn the Earth, Moon, and Mars, which does an asteroid hit the fastest?**

Asteroids orbit the Sun at high speeds. When asteroids approach a massive planet, the gravity of that planet pulls them faster. Asteroids hit Earth at a faster speed because the Earth’s gravity is greater than the Moon’s or Mars’s. And because Earth is closer to the Sun than Mars and Kepler’s Second Law.

**Where did an impact cause a mass extinction?**

An asteroid or comet caused a mass extinction on Earth about 66 million years ago, extinguishing dinosaurs and most other life.  None of the other planets are known to have any life.

**Which hits the Earth most frequently: asteroids or comets?**

Asteroids hit Earth more frequently. Most asteroids follow orbits between the planets Mars and Jupiter, in planes close to Earth’s (the ecliptic). Comets follow highly elongated orbits around the Sun, which carry them high above and below Earth’s orbit, making them less likely to impact Earth.

**Which asteroid is the OSIRIS REx mission orbiting?**

In 2020, this mission continues to orbit the small asteroid Bennu; it will collect a sample of the asteroid to return to Earth for study.

**On Earth, where and when do meteorites fall?**

Meteorites fall everywhere on Earth, all the time. They are easier to find in areas with less vegetation like deserts. Scientists travel to Antarctica annually to collect meteorites from bases of mountain ranges where glaciers deposit them.

**Names of meteorites:**

Meteorites can be named after the places where they are found. For instance, the largest carbonaceous chondrite ever found on Earth, Allende is named after a village in northern Mexico called Pueblito de Allende, where it fell in 1969. Meteorites found in Northwest Africa start with NWA in their names followed by a specific number for each meteorite. Shergotty is a meteorite that was found in Shergotty, India. Later this was identified as a type of Mars meteorite, and the related group of meteorites were named Shergottites.

**Mars meteorites:**

Are ejected from the surface during an impact on Mars, if they are thrown faster than 3 miles per second. They have gases embedded in the meteorites that match the composition of the Martian atmosphere. By 2019, scientists had identified 224 meteorites from Mars. The oldest Mars meteorites were formed on the surface of Mars over 4 billion years ago, but spend much less time in space before landing on Earth; for instance, Dhofar 019 spent 20 million years in space.

**Lunar meteorites:**

Meteorites from the Moon can also be called Lunaites. These are ejected from the surface during an impact on the Moon (on all sides of the Moon), if they are thrown faster than 1.5 miles per second. Scientists first identified a meteorite as from the Moon in 1981; by 2019, scientists had identified about 400 meteorites from the Moon that had landed on Earth. None of the lunar meteorites was seen falling as a meteor, and none have been found in North America.