Elementary Institute of Science

Hands on Astronomy Activity 5

Topic: Solar System Formation
Learning Objective: To determine how our Solar System formed via the process of accretion

Alignment with NGSS Grades 3-5

Crosscutting Concepts and Connections to Engineering, Technology, and Applications/Applications of Science Interdependence of Science, Engineering, and Technology

- Science and technology support each other.
- Tools and instruments are used to answer scientific questions, while scientific discoveries lead to development of new technologies.

Materials:

- 8 Dust Cards
- 4 Chondrule Cards
- 2 Meteoroid Cards
- 1 Asteroid Card

Instructor Preparation

Print out the dust, chondrule, meteoroid, and asteroid cards

Detailed Description

- Introduction
    - How did the Solar System form?
    - How do you think planets and asteroids came to be?
- Explanation
    - Scientists think that our solar system was a big cloud of gas and dust in the beginning of its formation. Some event made it begin to spin, and it eventually spun down into a disk of matter swirling around a massive, glowing center, our protosun (i.e. a baby Sun).
    - As material moved around the protosun, dust grains in the disk collided with each other and started sticking together to form larger rocks. These rocks in turn collided with other rocks and either gravity held them together or they broke into smaller pieces, depending on the kind of collision and the relative gravity of the individual rocks. Over the next few million years, these rocks combined into larger and larger bodies and eventually formed the planets and other large

bodies we have today. Evidence of these collisions is seen on the surface of the planetary bodies, including asteroids, in the form of craters left by the impacts.
    - In today's activity, we will actively model one theory that describes how scientists think asteroids and planets formed: Accretion.
- Discussion
    - What force causes these small dust particles to come together?
        - Allow student responses. Many may say 'gravity.' While gravity is the force that holds the dust particles in orbit around the Sun, explain that these small dust particles do not have enough mass for the force of gravity to cause them to come together.
    - What other forces cause things to stick together?
        - Know how socks stick to the inside of the dryer or how a balloon sometimes sticks to the wall? We call this static electricity. In the case of interstellar dust particles, we call the forces electrostatic. Electrostatic forces are the cause of accretion until the particles are massive enough for gravity to cause attraction.
    - Chondrules (spherical drops of once molten or partially molten minerals):
        - are considered the building blocks of the planets.
        - provide very good information on the earliest history of the solar system.
    - Meteoroids:
        - are solid objects traveling around the Sun in a variety of orbits and at various velocities, ranging in size from small pebbles to large boulders.
        - some cluster in streams called meteor showers that are associated with a parent comet.
        - have various compositions and densities, ranging from fragile snowball-like objects to nickel-iron dense rocks.
        - most burn up when they enter Earth's atmosphere.
    - Small Asteroids:
        - are 4.5 billion years old, as old as the solar system.
        - some are made up of chondrules and other material that holds them together.
        - have many variations, due partly to differences in the number, size, shape, and varying mineral content of the chondrules, and where they were formed in the solar system (close to the hot Sun, far from the Sun?).
    - Accretion
        - Scientists think that asteroids formed by accretion of these dust particles in the solar nebula, the disk of gas and dust that rotated in a flattish disk shape around the early Sun. Just as in our game, dust particles accreted

(came together) into larger and larger bodies: chondrules, then small rocks, and then protoplanets and planets.

- Activity
    - The Goal
        - Similar to "tag," the goal is to tag as many students as you can as the game progresses. Learn how dust particles accrete to form chondrules, which accrete into meteoroids, which accrete to form asteroids!
        - When you tag a person, link arms and keep orbiting, gathering dust particles, chondrules, etc., until you are large enough to form an asteroid.
    - Distribute Dust Cards to each student
        - All students will represent dust at the start of the game.
        - Have one student (or teacher/parent) be the Sun. Have that person stand in the middle of a circle of students
            - Dust particles will be orbiting the Sun!
    - Students gather close to the center for directions.
        - The dust particles will jog (not run) in a circular path around the "Sun," which is in the center of the large open area—playground, gym, etc.
            - Counter-clockwise—as all planets and asteroids move about theSun!
        - As they jog, students should keep their arms to their sides until they come close to another student.
    - Spread out so that the ring is large enough for safe orbiting.
        - If one dust particle tags another, they form a pair and can now extend their arms in order to tag other dust particles.
        - Allow this to continue for several minutes and then call time.
    - Explain that the students who are paired up are called chondrules.
        - Exchange the Dust cards for a new "chondrule" card, one for each pair of students.
    - Play a second round. After a few more minutes, calltime.
        - When the chondrules tag the dust particles (one or more) the group will stay together and can try to tag others.
        - At this point, students will notice that there are groups of various sizes; some dust, some chondrules, and some even larger!
        - Student groups of 3 are called meteoroids. Chondrules accreting into a meteoroid exchange as before, including changing the chondrule cards for a new "meteoroid"card.
    - Play a third round
        - Groups of 4 or more kids are called asteroids.

    - Give a new “asteroid” sign to each of the student groups of 4 or more. As they tag the chondrules or dust particles, they form much larger clusters.
        - The asteroid that forms the largest cluster after the allotted time can be designated “Ceres,” the largest asteroid, while the second can be designated “Vesta.” These are the targets of NASA’s Dawn mission.
    - Repeat the game and see if the results change.
        - Review the explanation and ask students the follow-up questions.
- Conclusion
    - How could dust become a rock?
        - This excellent question arose during classroom trials. One way to think about this is for students to consider the tremendous amount of time involved in solar system formation. Over thousands and thousands of years, billions of dust particles eventually form into tiny grains like sand, then into little pebbles, and so forth.
    - What happened to the student dust particles at the beginning of the game?
    - How did the student chondrules interact with the student dust particles? Was the movement of the two students the same or different?
    - What happened when there were asteroids? Was the movement of the two students after the interaction the same or different? Was the movement of student dust particles the same as that of the student chondrules?
    - What did you notice about the dust particles at the end of the activity?
    - How is the model different than the real thing?
        - In the activity dust (students) moved faster in an attempt to “catch” smaller objects. In reality the dust particles clump together because of electrostatic attractions and do not move faster in order to clump together. Similarly, large clumps were attracted to like and unlike dust grains in order to form planetesimals due to gravity.
    - Why are models and simulations useful?
        - While not completely accurate, physical models are useful to better understand processes that happened in the past that are not observable now.
    - What other questions do you have?

Science Process Skills Used

Observation, interaction

Safety Precautions

- Perform activity in the grass area outdoors

    - Ensure that students do not run

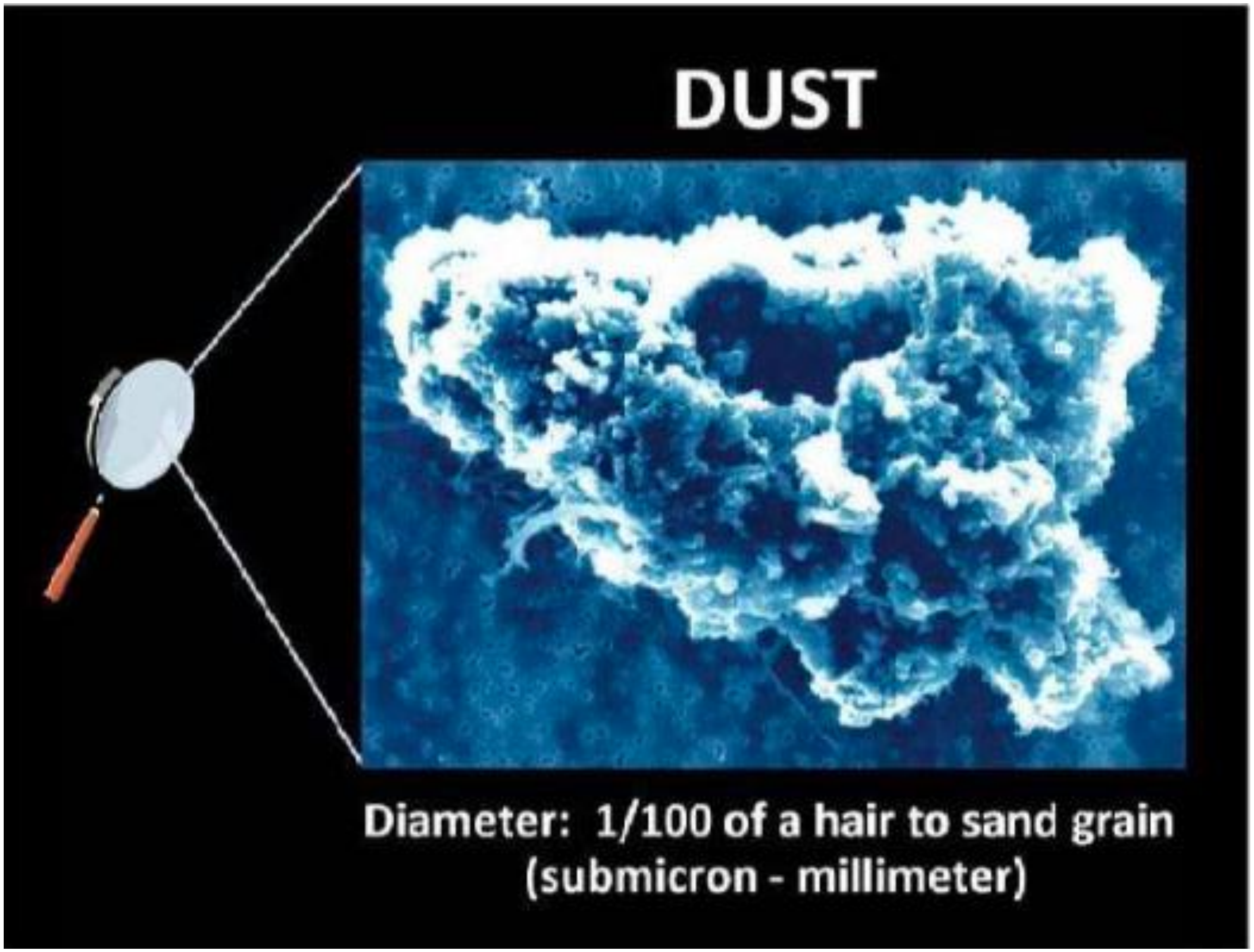
Additional Information for the Instructor

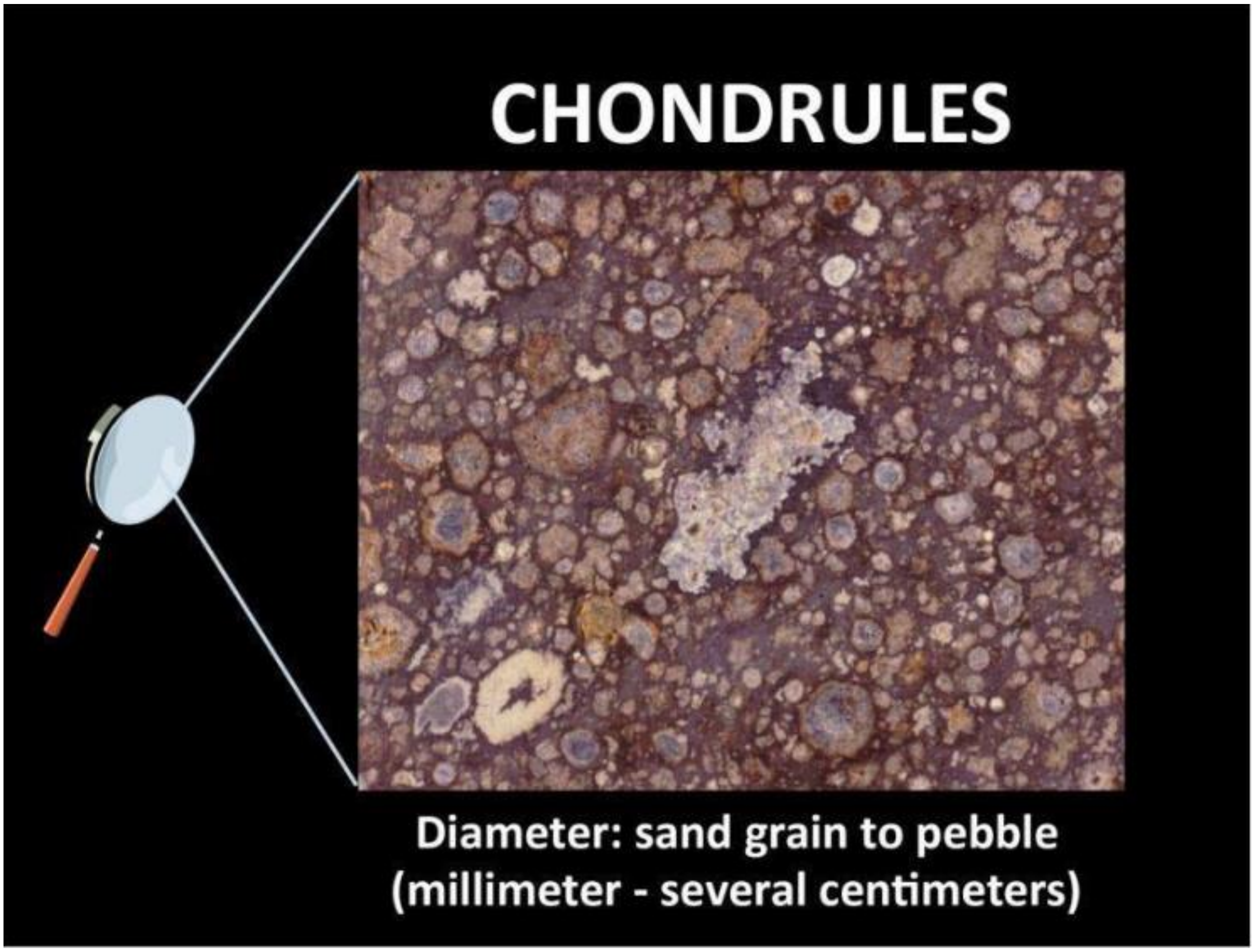
- Modern Solar System Origin Theory
    - General Idea
        - The current Condensation Theory of Solar System Formation (often called the modern theory, the Condensation Theory of Solar System Formation was built on the oldest of evolutionary models, the Nebular Contraction Theory) was the brainchild of French philosopher Rene Descartes, who lived in the 17th century. In the 18th century, Pierre Simon de Laplace revised this theory. Both of these early astronomers based their theories on a disk-shaped solar nebula that formed when a large cloud of interstellar gas contracted and flattened under the influence of its own gravity. In the modern theory, interstellar dust is composed of microscopic grain particles that:
            - are thin, flat flakes or needles about 10-5m across;
            - are composed of silicates, carbon, aluminum, magnesium, iron, oxygen, and ices;
            - have a density of 10-6 interstellar dust particle
        - In Active Accretion, these interstellar dust grains are simply referred to as 'dust.' There is some evidence that interstellar dust forms from interstellar gas. Interstellar gas, the matter ejected from the cool outer layers of old stars, is 90 percent molecular hydrogen (H2) and 9 percent helium (He). The remaining 1 percent is a mixture of heavier elements, including carbon, oxygen, silicon, magnesium and iron. The interstellar dust from which the planets and asteroids formed was that mixture of heavier elements. The hydrogen and helium from the nebula was involved in the formation of our infant Sun and are its major components today.
        - According to the Condensation Theory, the formation of planets in our solar system involved three steps, with the differentiation between planet and asteroid formation being a part of the second step.
    - Accretion Steps
        - Step 1: Planetesimals form by sticky collision accretion
            - During this phase of formation, dust grains formed condensation nuclei around which matter began to accumulate. This vital step accelerated the critical process of forming the first small clumps of matter, which then start to collide with each other at low velocities. The particles eventually stick together through

electrostatic forces, forming larger aggregates of similar types of constituents. Over a period of a few million years, further collisions make more compact aggregates and form clumps a few hundred kilometers across. At the end of this first stage, the solar system contained millions of planetesimals—objects the size of small moons, having gravitational fields just strong enough to affect their neighbors.

- Step 2: Planetary embryos/cores form by gravitational accretion
    - The loose, granular structure of planetesimals formed in Step 1 made it possible for them to continue to form more massive bodies through collisional coagulation of "nebular dust balls" and prevent these small objects from bouncing off by absorbing the object's energy during collision.
    - The more mass the planetesimals accumulated, the greater their gravitational attraction would be for surrounding objects of all sizes—from dust grains to small planetesimals—until kilometer-sized planetesimals would collide with objects made up of several planetesimals. The result would be that these large planetesimals that were loose aggregates with differing compositions. This gravitational accretion led to protoplanet formation.
    - As the protoplanets grew, their strong gravitational fields began to produce many high-speed collisions between planetesimals and protoplanets. These collisions led to fragmentation, as small objects broke into still smaller chunks, most of which were then swept up by the protoplanets, as they grew increasingly large. A relatively small number of 10-km to 100-km fragments escaped capture to become the asteroids and/or comets.
- Step 3: Planetary development
    - When the early asteroids were fully formed, the gas and dust continued to form planetesimals. The system of embryos in the inner solar system becomes unstable and the embryos started to collide with each other, forming the terrestrial planets over a period of 107 to 108 years. The largest accumulations of planetesimals became the planets and their principal moons.
    - In the third phase of planetary development, the four largest protoplanets swept up large amounts of gas from the solar nebula to form what would ultimately become the Jovian planets (gas

giants). The smaller, inner protoplanets never reached that point, and as a result their masses remained relatively low.


DUST
Diameter: 1/100 of a hair to sand grain
(submicron - millimeter)


CHONDRULES
Diameter: sand grain to pebble
(millimeter - several centimeters)

Meteoroid

Diameter: pebble to boulder
(centimeter - tens of meters across)

ASTEROID

Diameter: boulder to the state of Arizona
(Asteroid Eros is 13 x 13 x 33 km)