explore the early solar system
map the surface of Vesta

appropriate for grades 6-9
keywords: asteroids, solar system, gravity, meteors, citizen science

A product of
CosmoQuest & the SIUE STEM Center
cosmoquest.org
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InVestaGate

explore the early solar system
map the surface of Vesta

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and builds on the AsteroidMappers: Vesta citizen science project.

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Southern Illinois University Edwardsville and
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Instructor’s Guide

About Citizen Science

Citizen science is an engaging way for you and your students to have meaningful experiences in Science, Technology, Engineering, and Mathematics (STEM). Although there are many different types of citizen science projects happening all over the world, most of them can be thought of as

*a collaboration of professional scientists and non-professional volunteers (citizen scientists) engaged in authentic scientific research.*

Citizen scientists are ordinary people of all ages and interests, from weather observers and bird watchers to amateur astronomers and computer programmers! They experience the processes of science first hand as they help scientists to collect, analyze, and sometimes even interpret large amounts of data. They communicate their experiences and their findings to each other and to the public through blogs, forums, social media, and face-to-face meetings and conferences. Citizen science brings many, many opportunities to learn new things and to meet new friends.

Encourage your students to become citizen scientists! They will practice 21st Century Skills--critical thinking, communication, and collaboration--as well as science processes, all while learning amazing new things about the world around them. Exploring Vesta with CosmoQuest's *InVESTAgate* and Asteroid Mappers is a great way to get started. Enjoy!
Instructor’s Guide

Introduction

This unit focuses on the origins, composition, and features of small planetary bodies, particularly asteroids. It also introduces teachers and students to the Vesta Mappers citizen scientist project, which is part of the CosmoQuest online community. CosmoQuest seeks to create and support a vibrant, global community of teachers and learners who explore and share their universe through citizen science. The popular and successful citizen science projects it contains, (Mercury Mappers, Moon Mappers, and more), use the efforts of volunteers to help researchers analyze the flood of data that confronts them. Through citizen science projects, many unique scientific discoveries have been made, ranging from individual discoveries to those using classifications that depend on the input of everyone who has visited the site.

The arc of this unit is the development of an imaginary mission to the asteroid Vesta. In days one through four, students investigate the differences between planets, dwarf planets, asteroids, comets, and meteoroids. During days five through seven, students are challenged to learn all they can about the asteroid Vesta. In days eight through ten, they develop an engineering plan and experiment with models of technologies in the same way that scientists do to plan actual missions to an asteroid. Through this process, students will explore not only science content but science and engineering practices as well.

The content of the unit was intended for middle school students (grades 7-9), but is easily adapted for high school students. This unit provides links to background information for the teacher on the science of asteroids and the Solar System. The free resource Exploring Meteorite Mysteries (http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm) gives a broad introduction to meteorites, asteroids, impact craters, and Solar System history. Information specifically about the Dawn mission can be found at http://dawn.jpl.nasa.gov/.

The CosmoQuest site includes information on the science goals of Asteroid Mappers (http://cosmoquest.org/x/asteroid-science/) and had a tutorial for the Asteroid Mappers software. It is strongly encouraged that the teacher familiarize himself or herself with the tutorial (http://cosmoquest.org/x/asteroid-mappers-tutorial/) before beginning the lesson with students.

Dawn and CosmoQuest have held a series of Hangouts on Air about the science being done at Vesta and the expected science to be done at Ceres when the spacecraft arrives in 2015. These interviews with asteroid scientists can be watched at any time from: http://www.youtube.com/playlist?list=PLwuQGMPDT-L-qTZsNFCK2so0FFFFf-Sd7

The lessons in this unit follow the Biological Sciences Curriculum Study (BSCS) 5E instructional model. For more information on this inquiry lesson format, see http://www.bscs.org/bscs-5e-instructional-model.
**Beginning the Unit**

*Technology Expectations*

The overarching goal of the unit is to engage students in the authentic scientific research that is conducted through citizen science projects. Because *Vesta Mappers* is web-based, computer access is an implied necessity for this unit. The minimum number of computers is one per student team, bearing in mind that more than three students at a computer may result in student disengagement in the activity. In addition, a Promethean© Board, SMART© Board, or other classroom projection system will facilitate the presentation of the instructional material.

The *Vesta Mappers* project can be found at [http://cosmoquest.org/projects/vesta_mappers/](http://cosmoquest.org/projects/vesta_mappers/)

*Mapping Vesta*

On Day Seven of the unit, you will be guiding your students through the process of marking craters by using the tutorial at the *Vesta Mappers* website. It is strongly recommended that you become familiar with the tutorial and the process of marking craters before you present the information to your students.

*Student Teams*

Before you begin teaching the unit, arrange your class in teams of three to five students. Many of the activities in the unit, like the process of science itself, require collaboration. As you assign the teams, be sure to mix skill and ability levels. Also keep in mind the number of available computers and arrange the teams to allow members easy access to them.

*Student Journals*

A good way to help students integrate their learning during the unit is to ask them to keep an *InVESTAgate!* Journal. The journal can include notes on vocabulary words and concepts, class assignments, and their own personal observations. The journals can also be used as a tool for assessment and a link to language arts skills.

*Standards*

The authors have chosen to use the Next Generation Science Standards, posted at [http://www.nextgenscience.org/](http://www.nextgenscience.org/), as the basis for the lessons in this unit. Efforts were made in Cross-Curricular Links to include standards from the Common Core for math, language arts, and social studies.

*Teaching the Unit*

For each lesson, the “Engage” through “Evaluate” sections are planned to fill one 50-minute class period. You may find it necessary to adjust segments of the lesson to fit the needs of your class, your own teaching style, and the amount of time available. However, it is necessary to present the first four “Es” in the order listed to preserve the process of inquiry that the lesson intends.

*InVESTAgate Introduction*
Many of the lessons offer more than one activity to explore the content. These options are separated by the word “OR” in the plans. You may choose to use more than one option to re-teach difficult concepts or to extend the unit.

The ideas in the “Elaborate” and “Cross-Curricular Links” sections are meant to enrich the lesson and integrate learning in other subject areas. These activities are optional and could be provided as opportunities for homework or extra credit. If they are used as class activities, each would require one additional 50-minute class period.

**Ending the Unit**

The posttest provided may be too extensive for the purposes of your classroom. Feel free to use the test as a question bank and choose just those items appropriate for your students.
<table>
<thead>
<tr>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction: Solar System Formation (accretion)</td>
<td>The Role of Gravity</td>
<td>It’s Not a Planet?</td>
<td>Asteroids, Comets, and Meteoroids</td>
<td>Observing Asteroids</td>
<td>Asteroid Cratering</td>
<td>Asteroid Mappers</td>
</tr>
</tbody>
</table>

**Standards**
- ESS1.A, B; PS3B; CCC 3, 7; SEP 7; WHST.6-8.1,10

**Engage**
- Show picture of Vesta; Students write what they think it is; discuss findings
- Engage Gravity misconception cards
- Engage Classification activity involving random objects
- Engage Comet demonstration
- Engage Asteroid Eros - measuring asteroid features
- Engage: Show NASA videos of impact and cratering of meteors
- Engage Overview of Asteroid Mappers site on CQ

**Explore**
- Active Accretion OR Building Blocks of Planets activities
- Explore Galileo experiment
- Explore Ceres/Pluto Dwarf Planet Activity
- Explore Modeling Vesta OR Searching for Meteorites
- Explore Looking at Asteroids OR Impact Craters
- Explore Students complete tutorial and map crater images on Vesta

**Explain**
- Administer pretest Planetary bodies build through accretion
- Explain Gravity affects formation of planetary bodies
- Explain Classification of planetary bodies
- Explain Differences between comets, meteorites, and asteroids
- Explain Meteorites and asteroids are evaluated using brightness
- Explain Craters are formed when energy transfers from a moving mass to a planetary body
- Explain Teacher led discussion of findings and interpretation

**Elaborate**
- Solar system trading cards OR Solar system timeline
- Elaborate Follow the Falling Meteorite
- Elaborate Research the history of classification of Ceres and Pluto
- Elaborate Interactive meteorite website
- Elaborate Interactive asteroid games OR Vesta flip book
- Elaborate Crater Hunters
- Elaborate DAWN: Vegetable light curves

**Evaluate**
- Pre-test Teacher assesses journal entries
- Evaluate Assess worksheets and journal entries
- Evaluate Venn diagram of planet, asteroid and comet
- Evaluate Vocabulary Quiz
- Evaluate Concept Quiz
- Evaluate Complete data table and questions
- Evaluate Explain crater formation; support with facts from journals

**Cross-Curricular Activities**
- ELA: Argument for their ideas in engage activity
- Cross-Curricular Activities ELA: Research Galileo and Newton’s ideas of gravity
- Cross-Curricular Activities ELA: Analysis of text in activity worksheets
- Cross-Curricular Activities Art: Artistic display for the 3D model of Vesta
- Cross-Curricular Activities Math: Challenge questions for Asteroid Eros
- Cross-Curricular Activities Geography: Students research locations of crater on Earth
- Cross-Curricular Activities Social Studies/ELA: Research and present the life of Kenneth Edgeworth or Gerard Kuiper

*Standards*
- ESS1.A, B; PS1.A, B; CCC 3, 7; SEP 4; MP6; WHST.6-8.7
- Standards ESS1.A, B; CCC 6; RST.6-8.1, 7; WHST 6-8.9
- Standards ESS1.A, B; PS2.A; CCC 3, 4; SEP 2-5; RST.6-8.3; MP 2, 4, 6
- Standards ESS1.B; PS4.B; CCC 5; RST.6-8.3; WHST.6-8.2; MP 4, 5, 7
- Standards ESS1.B; PS3.A, B, C; CCC 2, 7; SEP 8; RST.6-8.2, 3; WHST 7
- Standards ESS1.B; CCC 1; SEP 4; RST.6-8.4; WHST.6-8.9
<table>
<thead>
<tr>
<th>Day 8</th>
<th>Day 9</th>
<th>Day 10</th>
<th>Day 11</th>
<th>Day 12</th>
<th>Day 13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expedition Asteroid: Vesta Landing</td>
<td>Expedition Asteroid: Mining Vesta</td>
<td>Expedition Asteroid: We Deliver!</td>
<td>The Universe is Out to Get You…or is it?</td>
<td>Review</td>
<td>Assessment</td>
</tr>
<tr>
<td><strong>Standards</strong></td>
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</tr>
<tr>
<td>ETS1-1, 1-4; SEP 1, 6; CCC 6; MP6, 7; WHST.6-8.2</td>
<td>ESS1.B; ETS1-1,1-4; SEP 1, 6; CCC6; MP6, 7; WHST.6-8.2</td>
<td>ETS 1-2, 3, 4; SEP 1, 5, 6; CCC 6; MP6, 7, 8; WHST.6-8.1, 2</td>
<td>ETS; SEP</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td><strong>Engage</strong></td>
<td><strong>Engage</strong></td>
<td><strong>Engage</strong></td>
<td><strong>Engage</strong></td>
<td><strong>Engage</strong></td>
<td><strong>Engage</strong></td>
</tr>
<tr>
<td>Introduce Vesta Landing</td>
<td>Introduce Mining Vesta</td>
<td>Introduce We Deliver!</td>
<td>TC3 Impact power point</td>
<td>Review game</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Explore</strong></td>
<td><strong>Explore</strong></td>
<td><strong>Explore</strong></td>
<td><strong>Explore</strong></td>
<td><strong>Explore</strong></td>
<td><strong>Explore</strong></td>
</tr>
<tr>
<td>Design and build a lander</td>
<td>Design and build a materials sorter</td>
<td>Redesign lander to deliver a payload</td>
<td>Meteorite Asteroid Connection</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Explain</strong></td>
<td><strong>Explain</strong></td>
<td><strong>Explain</strong></td>
<td><strong>Explain</strong></td>
<td><strong>Explain</strong></td>
<td><strong>Explain</strong></td>
</tr>
<tr>
<td>Engineering and science are more alike than they are different</td>
<td>Asteroids contain resources for space travel</td>
<td>Cost benefit analysis helps determine if mining is worth the impacts</td>
<td>Solar system is mostly empty space; it is rare for asteroids to hit Earth</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Elaborate</strong></td>
<td><strong>Elaborate</strong></td>
<td><strong>Elaborate</strong></td>
<td><strong>Elaborate</strong></td>
<td><strong>Elaborate</strong></td>
<td><strong>Elaborate</strong></td>
</tr>
<tr>
<td>Interactive GRaND asteroid probe website</td>
<td>How would your device work in microgravity?</td>
<td>What are the potential impacts of mining on an asteroid?</td>
<td>Finding impact craters with LANDSAT OR Meteorite Asteroid Connection activity A</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Evaluate</strong></td>
<td><strong>Evaluate</strong></td>
<td><strong>Evaluate</strong></td>
<td><strong>Evaluate</strong></td>
<td><strong>Evaluate</strong></td>
<td><strong>Evaluate</strong></td>
</tr>
<tr>
<td>Vocabulary quiz; assess journals, completed task</td>
<td>Assess journals and task completion</td>
<td>Assess journals and task completion</td>
<td>Assess student worksheets</td>
<td>Assess students during review</td>
<td>Administer post test</td>
</tr>
<tr>
<td><strong>Cross-Curricular Links</strong></td>
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<td><strong>Cross-Curricular Links</strong></td>
<td><strong>Cross-Curricular Links</strong></td>
<td><strong>Cross-Curricular Links</strong></td>
</tr>
<tr>
<td>ELA: improve journaling skills by reporting on engineering design process</td>
<td>Social studies: compare and contrast mining challenges on Earth with those in space</td>
<td>Math: Evaluate data collected in engineering challenge to compare the cost-effectiveness of various mining operations</td>
<td>Current events: Research meteors and asteroids in the news</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

*Key to Standards:*

ESS - Next Generation Science Standards, Earth and Space Sciences
PS - Next Generation Science Standards, Physical Science
ETS - Next Generation Science Standards, Engineering and Technology
SEP - Next Generation Science Standards, Science and Engineering Practices
CCC - Next Generation Science Standards, Cross Cutting Concepts
MP - Common Core Standards, Mathematics Practices
WHST - Common Core Standards, Writing in History, Science, and Technical Subjects
RST - Common Core Standards, Reading in Science and Technical Subjects

InVESTAgate Unit Overview
Instructor’s Guide

Materials List

The items listed should be standard in most science classrooms or easily obtained. Please check the references in the day’s lesson plans for the quantities suggested and adjust to fit the size of your classroom.

Lesson 1 – Introduction: Solar System Formation
- Vesta journal for each student
- Picture of Vesta
- Active Accretion activity:
  - Student role cards
- Balloon Blocks of Planets activities
  - Balloons
  - Handful of Styrofoam pellets from packing material
  - One 22 cm glass pan
  - 50-100 small steel ball bearings (approx 4.5 mm diameter)
  - 5 medium ball bearings (approx 1 cm diameter)
  - 2 magnetic marbles
  - Round glass or aluminum pie or cake pan
  - Student worksheets

Lesson 2 – The Role of Gravity
- Gravity misconception cards
- Variety of object pairs such as ping pong balls, golf balls, marbles, small Styrofoam balls, paper wads, wooden blocks, brass cubes, feathers, sheets of paper
- Triple beam balance
- Student worksheets

Lesson 3 – It’s Not a Planet?
- Objects to classify (such as button or beads)
- Student worksheets

Lesson 4 – Asteroids, Comets, and Meteoroids
- Dry ice
- Dirt
- Dish liquid
- Quart size baggie
- Searching for Meteorites activity
  - Balloons
  - Flour
  - Small pebbles
  - Water
  - Funnel measuring cup
  - Thin stick or skewer
  - Graph paper,
  - Student worksheets
- Modeling Asteroid Vesta in 3-D activity
  - Two different colors of clay or play dough

InVESTAgate Materials
Lesson 5 – Observing Asteroids

- Metric rulers
- Calculators
- Pictures of asteroids
- Large nail or small piece of metal piping
- Metal file
- White paper
- 8 cm squares of construction paper (one each of red, black, blue, and white)
- Thermometers
- Incandescent light source
- 2 ring stands
- Clamps
- Cardboard
- 50 cm square of non-shiny black paper or cloth
- Student worksheets

Lesson 6 – Asteroid Cratering

- Plaster of Paris
- One large disposable pan or box (if completed as a demo)
- 3-4 small and deep containers such as margarine tubs or loaf pans (for groups)
- Mixing container
- Stirring sticks
- Water
- Projectiles (e.g. pebbles, steel shot, lead fishing sinkers, ball bearings)
- Powdered cocoa, gelatin, or fine sand
- Strainer
- Meter stick
- Student lab and data sheets

Lesson 7 – Expedition Asteroid: Vesta Landing

- Computer access for individual or pairs of students

Lesson 8

- Meter sticks
- Metric rulers or tape measures
- Target (Draw two concentric rings in the center of a standards paper plate)
- Paper cups
- Straws
- Tape
- Rubber bands
- String
- Index cards
- Paper clips
- Other appropriate building materials

InVESTAgate Materials
Lesson 9 – Expedition Asteroid: Mining Vesta
- Paper cups
- Small paper clips
- Plastic beads (5 mm diameter or larger)
- Sand
- Building materials such as index cards, tape, magnet, string, straws, construction paper, rubber bands

Lesson 10 – Expedition Asteroid: We Deliver!
- Meter sticks
- Metric rulers or tape measures
- Target (Draw two concentric rings in the center of a standard paper plate)
- Paper cups
- Straws
- Tape
- Rubber bands
- String
- Index cards
- Paper Clips
- Other appropriate building materials

Lesson 11 – The Universe Is Out to Get You?… or is it?
- TC3 Impact power point
- Meteorite Asteroid Connection, Activity B (Long Road to Earth)
  - 1.2 meter square or larger piece of corrugated cardboard or very stiff poster board
  - 60 cm x 30 cm piece of corrugated cardboard or very stiff poster board
  - Push pins
  - Colored and regular pencils
  - String
  - Scissors
  - Ruler
  - Protractor
  - Clay-dough or similar substance in yellow or white
  - Magazine with colored pictures
  - Tables 1 and 2 from the lesson instructions
  - Razor knife (USE CAUTION with students and sharp objects)
- Meteorite Asteroid Connection, Activity C (Collision Course)
  - Craft or Butcher paper (60 cm x 60 cm) for each group
  - Pencil/pen and colored pencils (optional)
  - Rulers
  - Protractors
  - Table 4

Lesson 12 - Review
- Review game

Lesson 13 - Assessment
- Post-test
Instructor’s Guide

Vocabulary

Accretion (ə-ˈkrē-shan): accumulation under the influence of gravity and some minor forces.

Analyze (ˈa-nəˌlīz): to study something closely and carefully

Asteroid Belt (as-tuh-roid belt): area between Mars and Jupiter where thousands of asteroids orbit the sun.

Asteroid (as-tuh-roid): one of thousands of small (diameters under 1000 km) solid planetary bodies orbiting the Sun; most orbit the Sun between Mars and Jupiter, but a few come closer as they cross the orbits of Earth and Mars.

Astronomer (ə-ˈsträ-nəˌmər): one who studies the science of celestial bodies and their origins, magnitudes, motions, and compositions.

Astronomical Unit (ə-ˈastrə-ˈnä-mi-kəl, ˈyü-nəl): a unit of length used in astronomy equal to the mean distance of the Earth from the Sun or about 93 million miles (150 million kilometers).

Bleb (blĕb): a small, usually rounded inclusion of one material in another.

Breccia (ˈbreChēa): rock consisting of angular, coarse fragments embedded in a fine-grained matrix.

Carbonaceous chondrite (kahr-buh-ney-shuhs kon-drahyt): a class of primitive meteorites (unchanged since they first solidified about 4.6 billion years ago) that formed in the oxygen rich early solar system. Most of the metal found in them is in the form of silicates, oxides, or sulfides.

Ceres (sîrˈēz): a dwarf planet that orbits within the asteroid belt with a mean distance from the Sun of 2.6 astronomical units (260 million miles) and a diameter of 590 miles (950 km). It also can be considered the largest asteroid in the asteroid belt.

Chondrite (kon-drahyt): stony meteorite containing chondrules embedded in a fine grained matrix of pyroxene, olivine, and metallic nickel-iron.

Chondrule (ˈkændroʊl): a small rounded body of various materials, chiefly olivine of pyroxene, found embedded in a usually fragmented matrix in certain of the stony meteorites.

Comet (ˈkämıt): a small body of ice and dust circling the sun in an elliptical orbit; when it comes near the Sun gases are released that can form a tail or tails, generally pointing away
from the sun.

**Cost benefit analysis** (ˈkóstˈbe-nə-fitˌna-la-səs): an analysis of the cost effectiveness of various alternatives to see whether the benefits outweigh the costs.

**Crater** (ˈkrātər): a hole or depression; most are roughly circular or oval in outline; on Earth most natural craters visible at this point in geologic time are of volcanic origin; on the Moon most craters are of impact origin.

**Density** (ˈden(t)-sə-tē): mass per unit volume; how much material is in a given space.

**Design** (di-ˈzīn): a plan or drawing that shows the look and function of a building or other object before it is built or made

**Differentiation** (dɪˈrɛn əˈshən): the processes that result in the separation of minerals during the cooling of magma.

**Dwarf Planet** (ˈdwôrflˈpla-nət): a spherical celestial body revolving around the Sun, similar to a planet but not large enough to gravitationally clear its orbital region of most or all other celestial bodies.

**Ecliptic Plane** (iˈklip-tikˌplān): the plane defined by the orbit of the Earth around the Sun; most planets orbit in or near the ecliptic plane.

**Ejecta** (iˈjek-tə): material thrown out from and deposited around an impact crater.

**Ellipse** (iˈlips, e-): (elliptical) a closed curve of oval shape.

**EM Spectrum** (EMˌspek-trəm): the entire range of wavelengths or frequencies of electromagnetic radiation ranging from gamma rays to the longest radio waves and including visible light.

**Force** (ˈfôrs): a push or pull upon an object resulting from the object’s interaction with another object; any of various factors that cause a body to change its speed, direction or shape.

**Friable** (ˈfrī-ə-bal): easily crumbled rock fragments.

**Gravity** (ˈgra-va-tē): a force of attraction pulling any two things toward each other, dependent on the mass of the objects.

**Impact** (imˈpakt): the forceful striking of one body, such as a meteorite, against another body such as a moon or planet.

**Impact Crater** (imˈpaktˌkrā-tər): a depression on the surface of a planet, moon, or other solid body in the Solar System formed when a smaller body strikes its surface with

*InVESTAgate Vocabulary*
some force. This is in contrast to volcanic craters which result from explosions or internal collapse.

**Inclusions (ɪn-ˈklʊ-zhənz):** a fragment of another rock enclosed in a rock.

**Interpret (ɪn-ˈtər-prət, -pət):** explain the meaning of

**Investigation (ɪn-ˈves-tər-gāshən):** a detailed inquiry or systematic examination

**Light (ˈlɪt):** electromagnetic radiation across all wavelengths (see also EM spectrum). The wavelengths that can be seen by the human eye are called Visible Light.

**Magnetism (ˈmæg-nəˌtəzəm):** a property possessed by certain bodies, whereby under certain circumstances, they repel or attract one another according to determined laws and ultimately due to the movement of electrons.

**Mass (ˈmɑs):** the amount of matter in a given object.

**Matrix (ˈmæ-triks):** the smaller sized grains in a rock, where the rock consists of large grain fragments surrounded by smaller grains

**Metals (ˈme-təlz):** any of a class of substances that typically are opaque, are good conductors of electricity, and often have a shiny luster like gold.

**Metamorphism (ˈmər-ˌfi-zəm):** the process by which rocks are altered in composition, texture, or internal structure, by extreme heat, pressure, or chemical substances.

**Meteor (ˈmē-tərˌ-ər,-ər):** relatively small body of matter traveling through interplanetary space

**Meteorite (ˈmē-tərˌɪt):** a metallic or stony (silicate) body that had fallen on Earth, Moon or other planetary body from space.

**Meteoroid (ˈmē-tərˌrəlˌd):** a piece of interplanetary matter that is smaller than a kilometer and often only millimeters in size. Most meteoroids that enter the Earth’s atmosphere are so small that they vaporize and never reach the planet’s surface.

**Model (ˈmädˌl):** a preliminary work or construction that serves as a plan for a product; scientific models can be material, visual, mathematical, or computational and are often used in the construction of scientific theories.

**Olivine (ˈələˌvən):** a usually greenish mineral that is a complex silicate of magnesium and iron.

**Orbit (ˈər-bət):** the path of an object in space moving about another under gravitational attraction.

*InVESTAgate Vocabulary*
Organic \(\text{ȯr-\,gān-ik}\): compounds of carbon, hydrogen, and oxygen that form complex molecules. (They may or may not be from living organisms.)

Perihelion \(\text{ˌper-ə-\,hēl-yōn}\): the point in the path of a celestial body (as a planet) that is nearest to the Sun

Planet \(\text{ˈplə-\,nət}\): any of the eight large celestial bodies revolving around the Sun and shining by reflected light.

Platy \(\text{ˈplā-tē}\): the texture of a rock that is composed of flat minerals or rock fragments.

Porous \(\text{ˈpȯr-əs}\): contains open or void spaces between solid materials.

Primitive \(\text{ˈpri-mə-tiv}\): of, belonging to, or seeming to come from an early time in the very ancient past

Projectile \(\text{ˈprə-\,jek-təl, -tī-əl}\): object that impacts a surface.

Prospector \(\text{ˈprä-\,spektor}\): one who explores an area for mineral deposits, water, or other resources.

Pyroxene \(\text{ˈpī-\,räk-\,sēn, pə-}\): any group of igneous-rock forming silicate minerals that contain calcium, sodium, magnesium, iron, or aluminum, usually occur in short prismatic crystals or massive form; they vary in color from white to dark green or black

Reflectance \(\text{ˈri-\,flek-tən(t)s}\): the amount of light of a particular color reflected by a surface, divided by the amount of light of the same color that strikes the surface.

Regolith \(\text{ˈre-gə-\,lith}\): loose, unconsolidated rock, mineral, and glass fragments on the Moon and some other planetary bodies; this debris is produced by impacts and blankets the surface.

Retrograde \(\text{ˈre-trə-\,grād}\): a motion in a direction contrary to that of the general motion of similar bodies and especially east to west among the stars; also, having or being a direction of rotation or revolution that is clockwise as viewed from the north pole of the sky or a planet; an orbit that moves in the opposite direction of the Earth’s orbit.

Rim \(\text{ˈrim}\): the border of a land form, such as the curved edge surrounding the top of a crater.

Solar Nebula \(\text{ˈsō-lər, - lər}\ˌ\text{ˈnər-\,byə-lə}\): gravitational accumulation of solid particles and dust around the sun; stars have these nebulae early on in their histories and they are eventually collected into planets, or pushed away by the radiation of the sun.

Sphere \(\text{ˈsfir}\): an object that is round or almost round in all dimensions like a ball.

Static Electricity \(\text{ˈstə-tik,ˌlēk-\,tris-ə-tē, ē-, -tris-tē}\): electricity that consists of

InVESTAgate Vocabulary
isolated motionless charges (as those produced by friction)

**Terrain** (ˈtə-ˈrān also te-\): area of the surface with a distinctive physical or geological character.

**Texture** (ˈteks-chər\): general physical appearance of a rock.

**Trojan asteroid** (ˈtrō-ˈjan\, ˈas-tə- rōid\): an asteroid belonging to one of two groups that orbit the sun at the same distance as Jupiter.

**Unconsolidated** (ˈən-kən-ˈsä-lə-, dāt d\): materials loosely packed but not cemented to each other.

**Unfractured** (ən- ˈfrak-chər, -shər d\): does not contain breaks or cracks.

**Velocity** (və-ˈlä-so-tē, -ˈläs-tē\): rate of motion in a specific direction, measured in distance per time.

**Vesicles** (ˈve-si-kəl s\): bubble-shaped cavities in a volcanic rock formed by expanding gases.

**Vesta** (ˈves-tə\): one of the largest asteroids in the Solar System

**Volatile** (ˈvā-lə-tə s\): chemical elements that enter a gas phase at relatively low temperatures.
Instructor’s Guide

Featured Links

Day One - Solar System Formation
NASA’s Discovery and New Frontiers Programs http://discovery.nasa.gov/
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm

Day Two - The Role of Gravity
Video of gravity demonstrations http://blogs.howstuffworks.com/2011/03/09/how-gravity-works-a-nice-
explation-of-peoples-misconceptions-about-the-force-of-gravity/
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm

Day Three - It’s Not a Planet?

Day Four - Asteroids, Comets, and Meteoroids
Comet model http://www.astro.virginia.edu/dsbk/resources.php
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm
Interactive rock/meteorite identification website http://dawn.jpl.nasa.gov/Meteorite/index.asp

Day Five - Observing Asteroids
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm
Interactive asteroid games http://www.killerasteroids.org/

Day Six – Asteroid Cratering
Impact crater on Comet Tempel 1 http://solarsystem.nasa.gov/deepimpact/gallery/animation.cfm
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm

Day Seven - Mapping
CosmoQuest Vesta Mappers http://cosmoquest.org/

Day Eight - Expedition Asteroid Part 1
GRaND asteroid probe interactive website http://dawn.jpl.nasa.gov/technology/GRaND_inter.asp

Day Eleven - The Universe Is Out to Get You
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm
Finding impact craters with LANDSAT http://craters.gsfc.nasa.gov/index.htm

InVESTAgate Featured Links
Day One - Solar System Formation

Objective:
Students will construct a model to show the process of accretion in solar system formation.

Next Generation Science Standards:
For complete description of each standard, click on the links below.
*ESS1.A: The Universe and Its Stars
*ESS1.B: Earth and the Solar System
*PS3.B: Conservation of Energy and Energy Transfer
*CCC 3: Scale, Proportion, and Quantity
*CCC 7: Stability and Change
*SEP 7: Engaging in Argument from Evidence

Common Core Standards:
*ELA/Literacy WHST.6-8.1: Write arguments focused on discipline content.
*CCSS ELA-Literacy.WHST.6-8.10

Materials:
Journal for each student, picture of Vesta
Active Accretion activity: student role cards
Building Blocks of Planets activities: balloon, handful of Styrofoam pellets from packing material, one 22 cm glass pan, 50-100 small steel ball bearings (approximately 4.5 mm diameter), 5 medium ball bearings (approximately 1 cm diameter), 2 magnetic marbles, round glass or aluminum pie or cake pan, student worksheets

Engage:
Using all the drama and mystery you can muster, tell students you have received an unusual picture in the mail: you don’t know whom it’s from, and the note that came with it says only “Important - Find out all you can.” Display a picture of Vesta, (one where it looks as much like a potato as an asteroid), and ask students to write down what they think it is in their new journals. Lead a class discussion in which students discuss their opinions and evidence with each other and the class as a whole. List their ideas on the board. Point out any ideas that suggest it’s some type of small body in space and say, “I have an activity that can help us explore this idea.”

Explore:
Follow the directions for “Active Accretion” from NASA Discovery and New Frontiers (http://discovery.nasa.gov/education/eduClassroom.cfm) programs. This is a game students play in a large area to demonstrate the accretion of particles to form solar system bodies OR
Follow the directions for Exploring Meteorite Mysteries (http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm) Lesson 10, “Building Blocks of Planets,” activities B & C. These two activities use marbles and other objects on a pie pan to model accretion.

Explain:
Administer pretest.
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.
Vocabulary:
Astronomer, chondrule, chondrite, sphere, matrix, solar nebula, accretion, metamorphism, differentiation, organic, static electricity, magnetism
Concepts:
• Planetary bodies build by collecting smaller pieces of unrelated materials such as star dust etc. (accretion)
• Bodies are modified by differentiation and/or metamorphism
Make copies of the diagram from page 16 of “Meteorites: Clues to Solar System History” information pages, (found in the Exploring Meteorite Mysteries materials), so students can tape it into their journals.

Elaborate:
Research and prepare a timeline for the formation of the solar system. OR Copy and trade Solar System Trading Cards at http://amazing-space.stsci.edu/resources/explorations/trading/directions.html

Evaluate:
Teacher assesses journal entries

Cross-Curricular Link:
English Language Arts: Students write arguments to support their ideas during the engage activity. They also begin writing observations, notes, and writing assignments in their Asteroid Journals. These writing activities will continue throughout the unit.
Astronomy Picture of the Day
2011 August 2
Asteroid Vesta Full Frame

Image Credit: NASA, JPL-Caltech, UCLA, MPS, DLR, IDA

Explanation: Why is the northern half of asteroid Vesta more heavily cratered than the south? No one is yet sure. This unexpected mystery has come to light only in the past few weeks since the robotic Dawn mission became the first spacecraft to orbit the second largest object in the asteroid belt between Mars and Jupiter. The northern half of Vesta, seen on the upper left of the above image, appears to show some of the densest cratering in the Solar System, while the southern half is unexpectedly smooth. Also unknown is the origin of grooves that circle the asteroid near its equator, particularly visible on this Vesta rotation movie, and the nature of dark streaks that delineate some of Vesta's craters, for example the crater just above the image center. As Dawn spirals in toward Vesta over the coming months, some answers may emerge, as well as higher resolution and color images. Studying 500-km diameter Vesta is yielding clues about its history and the early years of our Solar System.
Day Two - The Role of Gravity

Objective:
Students will analyze the affect that gravity has on falling objects, and explore the role gravity plays in the formation of solar systems.

Next Generation Science Standards
*ESS1.B: Earth and the Solar System
*PS2.A: Forces and Motion
*CCC 2: Cause and Effect
*CCC 7: Stability and Change
*SEP 4: Analyzing and Interpreting Data

Common Core Standards
CCSS.ELA-Literacy.WHST.6-8.7 Conduct short research projects to answer a question (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.
*CCSS.Math.Practice.MP8 Look for and express regularity in repeated reasoning.

Materials:
Gravity misconception cards, a variety of object pairs such as ping pong balls, golf balls, marbles, small Styrofoam balls, paper wads, wooden blocks, brass cubes, feathers, sheets of paper, triple beam balance, meter stick, student worksheets

Engage:
Today’s lesson builds on the mysterious picture and note from day one. Now that the students have an idea that the picture is a space object, and the object was formed through accretion, they need to learn how gravity affects all objects in the solar system.
Follow the directions for the Gravity Misconceptions activity to help students uncover their own misconceptions about this force.

Explore:
Follow the directions for “Gravity Pulls You Down,” a recreation of Galileo’s gravity experiment.

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.

Vocabulary:
Gravity, mass, force, meteorite, terrain, velocity, impact

Concepts:
• Gravity was a force present in formation of the solar system
• Gravity affects planetary bodies

Elaborate:
Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm Lesson 2, “Follow the Falling Meteorite,” features three activities that introduce triangulation as a method for finding pieces of asteroids that fall to Earth.

Evaluate:
Journal entries and student worksheets from the activity can be used as assessment tools for this lesson.

Cross-Curricular Link:
English Language Arts: Research Galileo and Newton’s ideas of gravity, contrasting and comparing the two theories.
Gravity Misconceptions

Procedure

1. Before class, print the gravity statements below and glue or tape to index cards.
2. Distribute one card to each pair of students.
3. Ask the students to discuss the statement on the card and decide if it is true or false.
4. Tell the students to write a short paragraph explaining their answers in their journals.
5. Collect the cards and continue with the lesson as described in the Day 2 lesson plan.
6. At the end of the activity, discuss each of the statements with the students. Have the students state their original answer and any changes they would like to make now that they have completed the activity.
7. Share the correct answers with the students.
### Gravity Statement Cards

<table>
<thead>
<tr>
<th>A pebble dropped down a hole through the center of the Earth would stop at the center.</th>
<th>The human body can handle increased g-forces in activities such as airplane acrobatics and space training.</th>
<th>Although you cannot feel it, there is a gravitational attraction between you and the person sitting next to you.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity is caused by movement or magnetic fields.</td>
<td>The gravitational force of the Earth on you is larger than the force you exert on the Earth.</td>
<td>Planets with thin atmospheres must have little gravity.</td>
</tr>
<tr>
<td>Gravity keeps the planets in orbit around the Sun.</td>
<td>Some roller coasters include increased g-forces.</td>
<td>Planets far away from the Sun have less gravity.</td>
</tr>
</tbody>
</table>

*InVESTAgate Day 2*
| Gravity is stronger between the most distant objects. | Space shuttle astronauts are weightless because there is no gravity above Earth. | Tides are caused by the rotation of the Earth and the gravitational effects of the Moon and Sun. |
| Being on a space station can cause problems such as bone and muscle loss. | Heavier objects fall faster than lighter objects. | A galaxy 13 billion light years away is gravitationally attracted to you. |
| Without gravity some bugs (bacteria) get tougher. | The Moon has no gravity. | There is no gravity in space. |
| Gravity guides the growth of plants. | | Gravity is a force. |
Gravity Misconceptions Key

1. Gravity is caused by movement or magnetic fields. (False)
   Gravity is related to the masses of objects (not just the Earth!) and the distance between
   objects. It has nothing to do with magnetic fields or movement (in most cases.)

2. The Moon has no gravity. (False)
   The Moon is an object with mass, and thus it must have gravity! The gravity on the
   surface of the Moon is 1/6th that of the gravity on the surface of the Earth.

3. Planets with thin atmospheres must have little gravity. (False)
   The atmosphere has no effect on the gravity of a planet. Although smaller planets tend to
   lose their atmosphere faster due to lower gravity, there are many other factors that come
   into play.

4. Planets far away from the Sun have less gravity. (False)
   Planets further from the Sun feel less gravity from the Sun than planets closer in, but their
   own gravity only depends on their mass and size.

5. Gravity is stronger between the most distant objects. (False)
   Gravity is weaker between objects as they move away from each other!

6. Space shuttle astronauts are weightless because there is no gravity above Earth. (False)
   There is gravity in space! In fact, the gravity felt by astronauts in low-Earth orbit is only
   slightly less than the gravity felt on Earth. Astronauts (and all of their stuff) appear
   weightless because they and the spacecraft are actually falling to Earth with the same
   speed and acceleration.

7. There is no gravity in space. (False.)
   Gravity is everywhere! Massive objects exert gravitational forces on each other across
   unimaginable distances.

8. A pebble dropped down a hole through the center of the Earth would stop at the center.
   (False)
   Ignoring air resistance and rotation, a pebble dropped through the center of the Earth
   would fall faster and faster until it reached the center, at which point it would start
   moving slower until it reached the other side where it would stop and reverse its motion,
   theoretically moving back and forth forever. In this way, it is like a pendulum. This is
   because the pebble is only acted upon by the mass of the Earth interior to its present
   radius, and the acceleration due to gravity depends on that mass and the distance to the
   center.

9. The gravitational force of the Earth on you is larger than the force you exert on the Earth.
   (False)
   According to Newton’s third law of motion, when one object exerts a force on another,
   the other exerts an equal but opposite force on the first object. So, you exert an equal
   amount of force on the Earth as it exerts on you!

10. Heavier objects fall faster than lighter objects. (False)
    In the absence of air resistance, all objects fall with the same acceleration towards a
    planet’s surface, thus hit at the same time. This was demonstrated on the airless Moon by
    Apollo 15 commander David Scott when he dropped a hammer and a feather from the
    same height and they hit the surface at the same time.

11. A galaxy 13 billion light years away is gravitationally attracted to you. (True)
    Gravity gets much weaker with distance, but, theoretically, the gravitational force
    between two objects never goes to zero. So, there is a teeny, tiny amount of gravitational
attraction between you and everything in the Universe, no matter how distant (ignoring the extreme effects of dark energy).

12. Although you cannot feel it, there is a gravitational attraction between you and the person sitting next to you. (True)
   Just as gravity never goes to zero over large distances, there is always a gravitational attraction between any two objects with mass. It is too weak to feel, but there is a gravitational force between you and every object around you!

13. Gravity keeps the planets in orbit around the Sun. (True)
   Gravity is responsible for most large structures in the Universe. Without gravity, the planets would careen out of orbit in a straight line out of the Solar System.

14. Without gravity some bugs (bacteria) get tougher. (True)
   Studies done on the bacteria salmonella show that it can get up to three times more harmful when in a “weightless” environment such as a space station. Why? Scientists aren’t sure, but the lack of gravitational effects changed how the genes and proteins acted in the bacteria, making test subjects (mice) sick faster and with less exposure than their Earth-bound counterparts.

15. Tides are caused by the rotation of the Earth and the gravitational effects of the Moon and Sun. (True)
   The Moon has a slightly stronger gravitational force on the side of the Earth facing it than the sides of the Earth away from it. This causes the oceans to swell up in some areas, and sink down in others as the Moon pulls on it. Because of Earth’s constant rotation and the Moon’s orbit around the Earth, the tides aren’t perfectly aligned with the position of the Moon.

16. The human body can handle increased g-forces in activities such as airplane acrobatics, space training, and drag races. (True)
   The effects of gravity can be simulated by acceleration in any direction. In such cases, we call these g-forces. Humans going into space regularly deal with g-forces of 3 or 4 times Earth’s gravity, and astronaut Gus Grissom was able to withstand g-forces of up to 16 times Earth gravity in simulators in the 1960s.

17. Some roller coasters include increased g-forces. (True)
   This has the same explanation as for #16. Roller coasters are exciting particularly because they subject visitors to g-forces they wouldn’t otherwise feel in their every day lives.

18. Gravity guides the growth of plants. (True)
   Plants sense gravity so that their roots can grow into the ground and the shoots grow up towards the surface. Gravity is sensed by the presence of special cells in the root tips with small, pebble-like structures called “statoliths.” These help the plant “know” which way is down.

19. Being on a space station can cause problems such as bone and muscle loss. (True)
   The human body evolved to exist on the surface of planet Earth. When in a “weightless” environment such as a space station, the body will lose muscle and bone mass that are no longer needed for walking or standing upright in a normal gravity environment. Astronauts need to train for many hours on special workout equipment to keep up their muscle mass for an easy transition to life back on Earth.

20. Gravity is a force. (True)
   A force is an influence that causes an object to change in some way. Gravity is the force that acts on the property of mass.
Teacher Page

Gravity Pulls You Down
Adapted from "Gravity Gets You Down" by Mary C. Cahill

Objective:
• To determine if objects of different masses fall at the same acceleration.
• To explore the concept of gravity.

Concepts:
1. Without air resistance, all objects would fall with the same acceleration regardless of mass.
2. Gravity is the force that causes objects to fall.
3. Air resistance, a type of friction, works against gravity to decrease the acceleration of a falling object.
4. Note that, excluding air resistance, each object falls with the same acceleration or rate change of speed as it falls. This is not to say that they travel at the same speed or velocity. However, objects dropped at the same height with no initial velocity will have the same final velocity as they hit the ground.

Materials:
• A variety of object pairs, such as balls of different sizes and weights. Objects may include: a ping pong ball, golf ball, marble, small Styrofoam ball, paper wad (size of a golf ball, wooden block, brass cube).
• Objects, such as a feather or sheet of paper, that encounter more resistance
• Triple beam balance
• Meter stick

Procedure:
1. Ask your students if they predict that a heavier or larger object, if dropped from a height, will fall to Earth faster than a smaller or lighter object. Tell them that Galileo Galilei (1564-1642) performed a famous experiment that they are going to replicate in order to confirm or refute their prediction.
2. Give each lab group a variety of objects to experiment with.
3. Instruct lab groups to discuss their predictions and write them on their lab sheets. Remind them that they should only test one variable at a time, such as mass or height. They should drop each object, not throw them, so that the initial speed of each fall is zero at the starting height.
4. Have students experiment with object pairs by, first, measuring and recording their mass, and then dropping them while standing on a desk, chair or stepstool. Some students in the group should observe carefully to see whether one object reached the floor before another or both objects reached the floor at the same time. Students should carefully record their
results on their charts. (Students should find that balls of different sizes and weights fall at the same rate of speed.)

5. Have students drop a piece of paper or feather and a ball from the same height. They should discover that the feather or sheet of paper will fall more slowly than the ball. Suggest that they bunch the sheet of paper up into a ball and drop it and the ball from the same height. They should discover that they fall at the same rate of speed. If they drop a flat piece of paper and bunched piece of paper from the same height, the sheet should fall more slowly.

6. Ask students to discuss the possible reasons for these results. They should conclude that air resistance, a type of friction, is slowing down the piece of paper and feather.

7. Ask students what they think would happen if they performed the same experiment in a vacuum tube, which has no air, or on the surface of the Moon. (The feather would fall at the same rate of speed as a brick or ball.)

8. Have students complete their lab worksheets.

9. Show students the video of astronauts experimenting on the Moon (http://www.youtube.com/watch?v=5C5_dOEyAfk) OR the video which shows the Moon experiment as well as an experiment in a vacuum and student demonstration (http://blogs.howstuffworks.com/2011/03/09/how-gravity-works-a-nice-explanation-of-peoples-misconceptions-about-the-force-of-gravity/).

Elaborate:
Discussion Questions

1. Describe how the human body has adapted to the force of gravity on Earth over time. How might it have evolved if gravity had not been present?

2. Compare and contrast the force of gravity on Earth with one of the other planets in our Solar System. Which planet has a stronger gravitational force? What would be the effects on astronauts’ bodies when visiting this planet for an extended period of time?

3. Describe the gravity experiments conducted by Galileo, Newton, and Cavendish. How were these experiments similar? How did these scientists build on each other's research and observations to make their own discoveries?

4. A roller coaster is usually designed to give its riders the sense of defying the force of gravity. Sometimes the back car is moving slightly faster than the others because of the acceleration of gravity. Other times the first car is going slightly faster. Keeping that in mind, which seat in the roller coaster is the scariest? How might a roller coaster designer make a coaster that gives the greatest sensation to the passengers?
Lab Sheet: Gravity Pulls You Down

Objective: To see if objects of different sizes and masses fall at the same rate.

Materials: Triple beam balance, meter stick, 10 objects supplied by your teacher

Procedure:
1. Using a triple beam balance, find the mass of each object at your lab station and record the mass on your data table.
2. Choose a light and heavy object and predict which one will reach the floor first when dropped from the same height. Record your prediction.
3. Have one team member stand on a chair or stool holding the light object in one hand and the heavy object in the other. Measure the height from the floor to the objects.
4. Release both objects at the same time and observe when each object hits the floor. (Two team members may have to sit on the floor to make an accurate observation).
5. Record the result and repeat 2 more times.
6. Choose two other objects and repeat steps #2-5.
7. Were your predictions correct?
8. Drop a piece of paper and ball from the same height. Predict which will hit the floor first. Record result.
9. Bunch the sheet of paper into a ball and drop the paper and a ball. Record the result.

Questions:
1. Explain in a paragraph what happened for each pair of objects that you dropped.

2. Were your predictions correct?

3. Explain why you think that you got the result that you did?
4. Describe what happened when you dropped the sheet of paper and ball. What happened when you bunched the paper and repeated the experiment? Explain.

5. What force(s) were acting on the objects? ________________________________
**Mass of Objects**

List objects and mass.
1. __________
2. __________
3. __________
4. __________
5. __________
6. __________
7. __________
8. __________
9. __________
10. __________

**First Pair Data Table**

<table>
<thead>
<tr>
<th>Objects</th>
<th>Mass (grams)</th>
<th>Prediction</th>
<th>Which Landed First Trials</th>
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</thead>
<tbody>
<tr>
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<td>#1</td>
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**Second Pair Data Table**

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### Third Pair Data Table

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### Fourth Pair Data Table

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<td>#1</td>
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<td>2</td>
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</tr>
</tbody>
</table>
Objective:
Students will classify various objects in the Solar System as planets, dwarf planets, or asteroids.

Next Generation Science Standards
*ESS1.B: Earth and the Solar System
*CCC 6 Structure and Function
SEP 1 Asking Questions and Defining Problems

Common Core Standards
*CCSS.ELA-Literacy.RST.6-8.1 Cite specific textual evidence to support analysis of science and technical texts.
*CCSS.ELA-Literacy.RST.6-8.7 Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
CCSS.ELA-Literacy.WHST.6-8.9 Draw evidence from informational texts to support analysis reflection, and research.

Materials:
Objects to classify, (such as buttons or beads), student worksheets

Engage:
1. Remind students of what they have learned so far:
   • Everything in the Solar System was formed by collisions of grains that were then held together by the forces of gravity.
   • More collisions built larger and larger bodies in orbit around the Sun.
   • Gravity is the attractive force between any two objects.
   • The more mass an object has, the greater its gravity.
2. Bring up the picture of Vesta and the “mysterious note” from day one. Remind them that they haven’t yet decided for certain what it is. Tell them that today they will learn how to classify the bigger objects in space.
3. To introduce the concept of classification, give each team of students a box of about twelve objects that are similar but different: different sizes and colors of buttons, for example. Ask the teams to divide the objects into three or four groups, based on the ways they are the same and the ways they are different. Ask students to write descriptions of their groupings in their journals.
4. Inform the class that they will be classifying Solar System objects. Just as they did with the items in the box, Solar System objects are classified based on their physical characteristics.

Explore:
Use the “Ceres and Pluto: Dwarf Planets” activity from NASA’s DAWN Teacher’s Guide http://nasawavelength.org/resource/nw-000-000-001-471/ to introduce the classification of planets, dwarf planets, and asteroids.

Explain:
Ask students to classify the mystery picture, citing evidence from their investigations.
Students add definitions and concepts to their Asteroid journals.

Vocabulary:
dwarf planet, planet, asteroid, Trojan asteroid

Concepts:
• Classification of planetary bodies depends on the object’s orbit around the Sun and shape of the body.
Classification is also based on whether the planetary body is a satellite and whether it has cleared the neighborhood around it in its orbit.

**Elaborate:**
Students research the history of the discovery of Ceres and Pluto.

**Evaluate:**
Assessments include the Venn diagram comparing planet, dwarf planet and asteroid and comet as found in the Explore activity worksheet. The worksheet includes a page of images to classify that can also be used as an assessment.

**Cross-Curricular Link:**
English Language Arts: In the Explore activity, students rewrite and compare definitions, both by writing and using graphic organizers to show the similarities and differences.
Day Four - Asteroids, Comets, and Meteoroids

Objective:
Students will differentiate between asteroids, comets, and meteoroids.

Next Generation Science Standards:
ESS1.A: The Universe and Its Stars
ESS1.B: Earth and the Solar System
PS2.A: Forces and Motion
CCC 3: Scale, Proportion, and Quantity
CCC 4: Systems and System Models
SEP 2: Developing and Using Models
SEP 3: Planning and Carrying Out Investigations
SEP 4: Analyzing and Interpreting Data
SEP 5: Using Mathematics and Computational Thinking

Common Core Standards:
CCSS.ELA-Literacy.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Materials:
Dry ice, dirt, dish liquid, quart-size baggie, two different colors of clay or play dough, balloons, flour, small pebbles, water, funnel, measuring cup, thin stick or skewer, graph paper, student worksheets

Engage:
Tell students that you received another mysterious note about the picture. This one says, “NASA wants to know more about Vesta - have you classified it?” Remind them of their findings from yesterday’s investigation and ask if they are certain of Vesta’s identity. Use the activity “Comets - A Physical Model” http://www.astro virginia.edu/dsbk/resources.php as a teacher-performed demonstration. Tell students that comets are Solar System bodies that formed through accretion.

Explore:
To keep the suspense going, use Exploring Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm Lesson 3, “Searching for Meteorites.” This lesson helps students quantify data scientists learn from meteorite falls. Meteorites are important clues to the composition of asteroids.
OR
The activity “Modeling Asteroid Vesta in 3D” http://dawn.jpl.nasa.gov/DawnKids/SAYourMissionVesta3D.pdf gives students an opportunity to build a clay model to explore the possible explanations of the light and dark patches on the images of Vesta.

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals

Vocabulary:
Vesta, Ceres, comet, ellipse, orbit, asteroid belt, meteor, meteoroid, meteorite
Concepts:
- Know the differences between comets and asteroids
- Understand how meteoroids get from the asteroid belt to Earth

Elaborate:
The interactive rock/meteorite identification website
http://dawn.jpl.nasa.gov/Meteorite/index.asp features an interactive slide show that gives more information about asteroids and the DAWN mission.

Evaluate:
Assess student knowledge with the vocabulary quiz on terms from days one through three.

Cross-Curricular Link:
Art: Students can create an artistic and informative display for the 3D model of Vesta they made in the Explore activity.
Day Five - Observing Asteroids

Objective:
Students will use observations of light, heat, and metals, and then use that information to interpret the information that scientists collect about asteroids.

Next Generation Science Standards
For complete description of each standard, click on the links below.
*ESS1.B: Earth and the Solar System
*PS4.B: Electromagnetic Radiation
*CCC 5: Energy and Matter

Common Core Standards
*CCSS.ELA-Literacy.RST.6-8.3
*CCSS.ELA-Literacy.WHST.6-8.2
*CCSS.Math.Practice.MP4
*CCSS.Math.Practice.MP5
*CCSS.Math.Practice.MP7

Materials:
Metric rulers, calculators, pictures of asteroids, large nail or small piece of metal piping, metal file, white paper, 8 cm squares of construction paper (one each of red, black, blue, and white), thermometers, incandescent light source, 2 ring stands, clamps, cardboard, 50 cm square of non-shiny black paper or cloth, student worksheets

Engage:
Now that the students are certain that Vesta is an asteroid, remind them that NASA wants to know more about it. Have students list ways they could find out about Vesta’s surface features and composition in their journals.
Use worksheet one of the “Asteroid Eros - Finding the Scale” activity to practice measuring asteroid features.

Explore:
Follow the directions for Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm Lesson 5, “Looking at Asteroids.” Activities one and two are completed in lab groups. Activity three can also be completed in lab groups if there is enough equipment and time; otherwise it can be completed as an interactive teacher demonstration. The teacher can then set up the equipment and have students participate by coming forward, evaluating the reflectance of different colors, and taking temperature readings. Students record these observations on their data sheets.

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.
Vocabulary:
Reflectance, light, EM spectrum

Concepts:
* Scientists think that most meteorites are fragments of asteroids, though a few come from planets or other bodies like the Moon.

InVESTAgate Day 5
• Meteorites and asteroids are evaluated using brightness (reflectivity, as well as texture and color of materials.)

**Elaborate:**

**Evaluate:**
The quiz on concepts for days one through four can be administered as an assessment tool, as well as the completed lab worksheets and completion of vocabulary in journals.

**Cross-Curricular Link:**
Math: Challenge questions for “Asteroid Eros - Finding the Scale” activity, worksheet 2
Asteroid Eros - Finding the Scale

This NASA, NEAR image of the surface of the asteroid Eros was taken on February 12, 2001 from an altitude of 120 meters. The image shows an area of the asteroid that is 6 meters wide. (Credit: Dr. Joseph Veverka/ NEAR Imaging Team/Cornell University)

The scale of an image is found by measuring with a ruler the distance between two points on the image whose separation in physical units you know. In this case, we are told the image width is 6.0 meters. We will use this information to calculate the scale of the picture.

Step 1: Measure the width of the image with a metric ruler. How many millimeters wide is the image?

Step 2: What does the caption say is the actual width of the asteroid’s surface that is shown? What is the answer in centimeters?

Step 3: Divide your answer to Step 2 by your answer to Step 1 to get the image scale in centimeters per millimeter to two significant figures. This number is the image scale.

Once you know the image scale, you can measure the size of any feature in the image in millimeters. Then multiply it by the image scale from Step 3 to get the actual size of the feature.
in centimeters to two significant figures.

Asteroid Eros
Challenge Questions

Question 1:
What are the dimensions, in meters, of this image?

Question 2:
What is the width, in centimeters, of the largest feature?

Question 3:
What is the size of the smallest feature you can see?

Question 4:
How big is the stone shown by the arrow?
Asteroid Eros - Answer Key:

This NASA, NEAR image of the surface of the asteroid Eros was taken on February 12, 2001 from an altitude of 120 meters (Credit: Dr. Joseph Veverka/ NEAR Imaging Team/Cornell University)). The image is 6 meters wide.

The scale of an image is found by measuring with a ruler the distance between two points on the image whose separation in physical units you know. In this case, we are told the image width is 6 meters.

Please note that correct answers may be slightly different from what is here depending on document and printer settings!

Step 1: Measure the width of the image with a metric ruler. How many millimeters long is the image?
Answer: 144 millimeters

Step 2: Use clues in the image description to determine a physical distance or length.
Answer: 6.0 meters

Step 3: Divide your answer to Step 2 by your answer to Step 1 to get the image scale in centimeters per millimeter.
Answer: 6.0 meters / 144 mm = 600 cm / 144 millimeters = 4.2 cm/mm

Once you know the image scale, you can measure the size of any feature in the image in units of millimeters. Then multiply it by the image scale from Step 3 to get the actual size of the feature in centimeters.

Question 1: What are the dimensions, in meters, of this image?
Answer: Height = 80 mm = 336 cm or 3.4 meters so area is 6.0 m x 3.4 m

Question 2: What is the width, in centimeters, of the largest feature?
Answer: The big rock at the top of the image is about 60 mm across or 2.5 meters.

Question 3: What is the size of the smallest feature you can see?
Answer: The small pebbles are about 0.5 millimeters across or 2.1 centimeters (about 1 inch).

Question 4: How big is the stone shown by the arrow?
Answer: 4 millimeters or 17 centimeters (about 7 inches).

From NASA Space Math http://spacemath.gsfc.nasa.gov
Day Six - Asteroid Cratering

Objective:
Students will model the process of cratering in the Solar System and use this information to interpret impact crater features on asteroids.

Next Generation Science Standards:
For complete description of each standard, click on the links below.

*ESS1.B: Earth and the Solar System
*PS3.A: Definitions of Energy
*PS3.C: Relationship Between Energy and Forces
*PS3.B: Conservation of Energy and Energy Transfer
*CCC 2: Cause and Effect
*CCC 7: Stability and Change
*SEP 8: Obtaining, Evaluating, and Communicating Information

Common Core Standards:
CCSS.ELA-Literacy.RST.6-8.2
*CCSS.ELA-Literacy.RST.6-8.3
CCSS.ELA-Literacy.WHST.6-8.7

Materials:
Plaster of Paris, one large disposable pan or box (if completed as a class demo) or 3-4 small and deep containers such as margarine tubs or loaf pans (for groups), mixing container, stirring sticks, water, projectiles (e.g. pebbles, steel shot, lead fishing sinkers, ball bearings), powdered gelatin or cocoa or fine colored sand, strainer, meter stick, student lab and data sheets.

Engage:
Tell students that, in order to give a full report to NASA, they must be able to explain how the features on the surface of Vesta were formed. The work they do today will help them understand one of those types of features – impact craters.
Show one of the NASA videos of the human-made impact crater on Comet Tempel 1 at http://solarsystem.nasa.gov/deepimpact/gallery/animation.cfm

Explore:
Follow the directions for Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm Lesson 6, “Impact Craters - Holes in the Ground,” Activity A
Lead students in a discussion to explain their findings and point to evidence of craters on Vesta. Have them answer these questions in their journals: Are all of Vesta’s craters circular? Why?

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.

Vocabulary:
crater, impact, projectile, velocity, ejecta, rim

Concepts:
• Impact craters are formed when pieces of asteroids or comets strike the surface of a planetary body.
• When an impact crater is formed, kinetic energy is transferred from the moving mass to the planetary body that it hits.
• Events that happen after an impact crater is formed can affect the shape of the crater.

Elaborate:
Meteorite Mysteries Lesson 7, “Crater Hunters”

Evaluate:
The completed data table and answers to questions in the day’s activity are the assessments for this day.

Cross-Curricular Link:
Geography: Students research locations of craters on Earth.
Day Seven - Mapping

Objective:
Students will learn how to map craters at the CosmoQuest website “Vesta Mappers” and participate in a citizen science project.

Next Generation Science Standards
For complete description of each standard, click on the links below.

*ESS1.B: Earth and the Solar System
*CCC 1: Patterns
*SEP 4: Analyzing and Interpreting Data

Common Core Standards
*CCSS.ELA-Literacy.RST.6-8.4
*CCSS.ELA-Literacy.WHST.6-8.9

Materials:
Computer access for individual or pairs of students

Engage:
Tell the students that today is the day they really get to work for NASA! The DAWN mission that orbited Vesta collected thousands of images that have to be evaluated. In order to be able to quickly and accurately read and interpret the images, citizen scientists around the world are viewing them and marking the craters they find. Students will now become part of that group of scientists.

Introduce students to the CosmoQuest website http://www.cosmoquest.org, focusing on “Vesta Mappers.”

Explore: Have students complete the tutorial and map crater images on Vesta.

Explain:
Lead a discussion of student findings. Ask them to show their favorite image and explain how they think the features were formed. Other students can be encouraged to agree or disagree, as long as they provide evidence for their ideas.

Elaborate:
The DAWN mission activity “Vegetable Light Curves” http://dawn.jpl.nasa.gov/DawnClassrooms/light_curves/ allows students to explore a three-dimensional model to interpret the differences in light and dark areas of asteroid images.

Evaluate:
Choose one image of Vesta to project for the whole class to see. Have students write an explanation of the cratering observed in one image, using supporting facts from their journals. Collect the journals and use as an assessment tool.

Cross-Curricular Link:
Social Studies/English Language Arts: Students can research and present the life of Kenneth Edgeworth or Gerard Kuiper.
Day Eight - Expedition Asteroid Part 1: Landing on Vesta

Objective:
Students will use engineering practices to design, build, and test a device that meets specifications for a vehicle that will land on a target. Students will compare engineering practices with science practices.

Next Generation Science Standards:
For complete description of each standard, click on the links below.

*CCC 6: Structure and Function
*MS-ETS1-1 Define the criteria and constraints of a design problem
*MS-ETS1-4 Develop a model to generate data for iterative testing
*SEP 1 Asking Questions and Defining Problems
*SEP 6: Constructing Explanations and Designing Solutions

Common Core Standards
*CCSS.Math.Practice.MP6 Attend to precision.
*CCSS.Math.Practice.MP7 Look for and make use of structure.
*CCSS.ELA-Literacy.WHST.6-8.2 Write informative/explanatory texts

Materials:
Meter sticks, metric rulers or tape measures, target, (Draw two concentric rings in the center of a standard paper plate) paper cups, straws, tape, rubber bands, string, index cards, paper clips, and other appropriate building materials
(It is suggested that all teams receive the same number and type of materials. Teachers may want to prepare “kits” of materials in advance so they can easily be distributed to the students. Extra materials may be made available to students at a “charge” of one point per item.)
Pictures of various landers may be displayed to inspire student creativity.

Engage:
NASA is planning human expeditions to the moons of Jupiter, Saturn, Uranus, and Neptune to explore, collect samples, and search for clues to help us understand the formation of the Solar System. Since rocket fuel, water, food, and other essentials are heavy and bulky, it’s impractical to transport them from Earth. Instead, NASA is looking for sources of rocket fuel and other consumables in the asteroid belt. Your team will design a prospecting expedition to the asteroid Vesta to look for resources that could be used for long distance space flights. Today you will be designing a space vehicle that can land on a target and remain upright.

Explore:
1. Divide the students into Engineering Teams of three to five students.
2. Give the students the specifications for their landing vehicles:
   • The lander must be no larger than a 20 cm cube.
   • The lander will be dropped from a height of one meter above a target.
   • The lander must land upright on the target.
3. Tell students how they will be scored:
   • Ten points will be awarded to teams who complete the task as specified and land in the center of the bull’s-eye without bouncing.
   • Eight points will be awarded to teams who complete the task as specified and land in the second ring of the target without bouncing.
• Five points will be awarded to teams who complete the task to specifications but don’t land on the target or flip over after landing.
• One point will be subtracted for each trial drop. One point will also be subtracted for each extra piece of material used beyond the basic materials provided to each team.
4. In their journals, students will record the results of each test. Discuss how they might record the following information:
  • Design plan for the lander (They may choose a sketch or narrative description)
  • Modifications made to the design after each attempt (Sketch or narrative)
  • Comments on the success of one attempt as compared to another
  • The distance from the center of the target to the place where their lander first touched the floor (Suggest a simple table of measurements.)
5. Give students the materials and allow them time to design their landers. Alternatively, a sketch of the planned design could be a requirement to receive the materials. Student teams should have most of the class period to build, test, and rebuild their landers.
6. Allow students to conduct their final test by dropping the lander on the target to score points.

**Explain:**
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.

**Vocabulary:**
Design, analyze, interpret, model, investigation

**Concepts:**
Engineering design is similar to scientific experimentation
  • Both have a problem or question to solve
  • Both plan and carry out investigations to solve the problem or question
  • Both use math to analyze and interpret data
  • Both use evidence to communicate information

There are differences between science and engineering:
  • The difference between science or engineering depends on the goal of the activity you’re doing:
    o Is your goal to answer a question? If so, you’re doing science.
    o Is your goal to define and solve a problem? If so, you’re doing engineering.
  • Engineering usually results in a physical product; experiments usually result in data that support a hypothesis

**Elaborate:**
Invite students to learn more about the GRaND asteroid probe at the interactive website at http://dawn.jpl.nasa.gov/technology/GRaND_inter.asp

**Evaluate:**
Assess student knowledge with the vocabulary quiz on terms from days four through seven. Use the Expedition Asteroid score sheet and students’ journals to check their success in completing the task.

**Cross-Curricular Link:**
English Language Arts: Recording sketches, modifications, thoughts, and results in their journals will improve journaling skills.
Landers 1

Apollo Lunar Lander

Robotic Lunar Lander
Landers 2

Mars Phoenix Lander

Mars Phoenix Lander
Landers 3

Mars Viking Lander
Expedition Asteroid: landing on Vesta
Student Guide

TODAY:
Your team embarks on Expedition Asteroid, a prospecting mission to the asteroid Vesta.

GOAL:
To land your spacecraft on the asteroid so you can begin to explore the resources you can use for a future five-year trip to explore Jupiter’s moon Io.

CHALLENGE:
Design a space vehicle that can land on a moving target and remain upright.

SPECIFICATIONS:
• The lander must be no larger than a 20 cm cube.
• The lander will be dropped from a height of one meter above a target.
• The lander must land upright on the target.

PROCEDURE:
• All notes, sketches, and plans should be included in your journal.
• With your team, design plan for a lander. Sketch your design
• Build your lander and conduct pre-tests to see how close your lander will come to a target.
• Measure the distance from your lander to the target for each test.
• Record the results of your tests.
• List the modifications made between tests
• Compare the success of one test to another.
• Include a results table that includes data from each trial, including the distance from the center of the target to the place where your lander first touches the floor.

POINTS:
• **10 points** will be awarded to teams who complete the task as specified and land in the center of the bull’s-eye without bouncing.
• **8 points** will be awarded to teams who complete the task as specified and land in the second ring of the target without bouncing.
• **5 points** will be awarded to teams who complete the task to specifications but don’t land on the target or flip over after landing.
• **1 point** will be subtracted for each trial drop. One point will also be subtracted for each extra piece of material used beyond the basic materials provided to each team to build the lander.
## Expedition Asteroid Report Form

<table>
<thead>
<tr>
<th>Points Added</th>
<th>Points Deducted</th>
<th>Total Points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vesta Landing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to target</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 points land in center</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 points outer ring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 points on asteroid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lands upright</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 points upright</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of attempts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deduct one point for each attempt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials used</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deduct one point for each extra piece of material used</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mining Vesta</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matter in sorter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 points for any material in any of the containers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matter sorted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 point per gram of mass in correct container</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of attempts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deduct one point for each attempt</td>
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<td>Materials used</td>
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</tr>
<tr>
<td>Deduct one point for each extra piece of material used</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL POINTS**

49
Day Nine - Expedition Asteroid Part 2: Mining Vesta

Objective:
Students will use engineering practices to design, build, and test a device that meets specifications for a device that will separate a mixture of materials into their component parts. Students will identify the natural resources found on asteroids that are important for space travel.

Next Generation Science Standards:
For complete description of each standard, click on the links below.

*ESS1.B: Earth and the Solar System
*CCC 6: Structure and Function
*MS-ETS1-1 Define the criteria and constraints of a design problem
*MS-ETS1-4 Develop a model to generate data for iterative testing
*SEP 1 Asking Questions and Defining Problems
*SEP 6: Constructing Explanations and Designing Solutions

Common Core Standards
*CCSS.Math.Practice.MP6 Attend to precision.
*CCSS.Math.Practice.MP7 Look for and make use of structure.
*CCSS.ELA-Literacy.WHST.6-8.2 Write informative/explanatory texts

Materials:
Per team:
One paper cup that contains 10 small paperclips, 10 plastic beads (5 mm diameter or larger), and about 25 ml of clean sand
3 paper cups to collect sorted materials (labeled “sand,” “beads,” and “clips”)
Building materials such as index cards, tape, magnets, string, straws, construction paper and rubber bands (It is suggested that all teams receive the same number and type of materials. Teachers may want to prepare “kits” of materials in advance so they can easily be distributed to the students. Extra materials may be made available to students at a “charge” of one point per item.)
Electronic or triple beam balance to measure the mass of materials sorted

Engage:
Hold up a clear beaker of sand, plastic beads and paperclips. Ask the students, “How would you separate the items in this beaker?” After they offer a few suggestions, ask “How would you do it without touching the materials?” Allow students to brainstorm possible solutions. Remind students that Vesta has different resources that would have to be separated as part of the mining process. Engineers must develop ways to efficiently sort mined materials.

Explore:
Design a device to separate the given mixture into three different containers.
In their journals, students record the results of each test, including the amount or mass of the material correctly sorted during each attempt, modifications made to the design, and comments on the success of one attempt as compared to another.
1. Students continue to work with their Engineering Teams from the previous day.
2. Give the students the specifications for their sorter:
   • The sorter must be no larger than a 50 cm cube.
   • The mixture will be poured into the sorter at some type of receiving container as indicated by the team.
• The sorter must then automatically separate the sand, beads, and paper clips into the three labeled containers: sand must go in the container labeled “sand,” beads in the containers labeled “beads,” etc.

3. Tell students how they will be scored:
• Ten points will be awarded to teams who complete the task as specified and end the task with any of the materials getting to any of the containers.
• 1 point per gram of mass will be awarded to teams who complete the task as specified and ended the task with the correct matter in the correct container.
• One point will be subtracted for each trial attempted and each time a team member touches the sorter during the sorting process. One point will also be subtracted for each extra piece of material used beyond the basic materials provided to each team.

4. In their journals, students will record the results of each test. Discuss how they might record the following information:
• Design plan for the sorter (They may choose a sketch or narrative description)
• Modifications made to the design after each attempt (Sketch or narrative)
• Comments on the success of one attempt as compared to another
• The mass of each material that was successfully sorted into the correct container (Suggest a simple table of measurements.)

5. Give students the materials and allow them time to design their sorters. Alternatively, a sketch of the planned design could be a requirement to receive the materials. Student teams should have most of the class period to build, test, and rebuild their sorters.

6. Allow students to conduct their final test by pouring the mixture into the sorter to score points.

**Explain:**

Students copy vocabulary, definitions, and concepts into their Asteroid Journals.

**Vocabulary:**
Prospector, metals, volatiles, carbonaceous chondrite, ureilites

**Concepts:**
Two types of materials on asteroids are metals and volatiles, which are essential for space travel. Materials that are already in space can be very valuable for deep space expeditions. It has been proposed that mines and manufacturing plants on asteroids would be able to supply materials for deep space expeditions.

• Metals: An asteroid of the composition of an ordinary chondrite could be processed to provide very pure iron and nickel. Valuable byproducts would include cobalt, platinum, gallium, germanium, and gold. These metals are basic to the production of steel and electronic equipment. Some metals from an asteroid mine might even prove valuable enough to be returned to Earth. Iron meteorites are high-grade ores. Diamonds or platinum may be found and have both monetary and industrial value. In addition, fine surface materials similar to soils may be suitable for nutrient or plant growth material, insulation, or building materials.

• Volatiles: Water, oxygen, and carbon compounds are useful in any space settlement, both for life support and for producing rocket fuel. These volatiles could be found in an asteroid that resembles a carbonaceous chondrite or the nucleus of a former comet. Water contents may range from 5-10% by weight for a chondrite to 60% by weight for a comet nucleus. In some asteroids large quantities of sulfur, chlorine and nitrogen may also be available.
**Evaluate:**
Use the Expedition Asteroid score sheet and students’ journals to check their success in completing the task.

**Elaborate:**
Challenge students to brainstorm the adjustments that would be necessary for the sorter to work in a microgravity environment and then sketch a drawing of their designs.

**Cross-curricular Link:**
Social studies: compare and contrast mining challenges on Earth with those in space

_InVEST_Agate Day 9_
Expedition Asteroid: Mining Vesta
Student Guide

TODAY:
Now that you’re mining on Vesta, how do you separate valuable resources from the rest of the rock you’ve mined?

GOAL:
To separate the resources you’ve mined to allow you to refine and transport them.

CHALLENGE:
Develop a way to efficiently sort materials into separate containers.

SPECIFICATIONS:
• The sorter must be no larger than a 50 cm cube.
• The mixture will be poured into the sorter at some type of receiving container as indicated by the team.
• The sorter must then automatically separate the sand, beads, and paper clips into the three labeled containers: sand must go in the container labeled “sand,” beads in the containers labeled “beads,” etc.

PROCEDURE:
• All notes, sketches, and plans should be included in your journal.
• With your team, design a plan for a sorter. Sketch your design.
• Build your sorter and conduct pre-tests to see how well materials move to each collecting container.
• Measure the mass of sorted material for each test.
• Record the results of your tests.
• List the modifications made between tests.
• Compare the success of one test to another.
• Include a results table that includes data from each trial, including the distance from the center of the target to the place where your lander first touches the floor.

POINTS:
• 10 points will be awarded to teams who complete the task as specified and end the task with any of the materials getting to any of the collecting containers.
• 1 point per gram of mass will be awarded to teams who complete the task as specified and end the task with the correct matter in the correct container.
• 1 point will be subtracted for each trial attempted and each time a team member touches the sorter during the sorting process. One point will also be subtracted for each extra piece of material used beyond the basic materials provided to each team.
Day Ten - Expedition Asteroid Part 3: We Deliver!

Objective:
Students will use engineering practices to design, build, and test a device that delivers a payload to a target.
Students will list the possible benefits and possible impacts of mining an asteroid.

Next Generation Science Standards
For complete description of each standard, click on the links below.

CCC 6: Structure and Function
MS-ETS1-2  Evaluate competing design solutions
MS-ETS1-3  Analyze data from tests
MS-ETS1-4  Develop a model to generate data for iterative testing
SEP 1 Asking Questions and Defining Problems
SEP 5 Using Mathematics and Computational Thinking
SEP 6 Constructing Explanations and Designing Solutions

Common Core Standards
CCSS.Math.Practice.MP6 Attend to precision.
CCSS.Math.Practice.MP7 Look for and make use of structure.
CCSS.Math.Practice.MP8 Look for and express regularity in repeated reasoning.
CCSS.ELA-Literacy.WHST.6-8.1 Write arguments focused on discipline-specific content.
CCSS.ELA-Literacy.WHST.6-8.2 Write informative/explanatory texts.

Materials:
Meter sticks, metric rulers or tape measures, target, (Draw two concentric rings in the center of a standard paper plate) paper cups, straws, tape, rubber bands, string, index cards, paper clips, and other appropriate building materials
(It is suggested that all teams receive the same number and type of materials. Teachers may want to prepare “kits” of materials in advance so they can easily be distributed to the students. Extra materials may be made available to students at a “charge” of one point per item.) Pictures of various landers may be displayed to inspire student creativity.

Engage:
Now that you have collected resources from Vesta, we need to transport them to a space vehicle, either to take them back to Earth or to fuel an expedition to the outer Solar System.

Explore:
If necessary, students can use part of this class to complete the sorting activity from the previous day. When students are ready, they will repeat the launch activity from day eight, but this time they must fill their lander with the paper clips they sorted in the Mining Vesta activity and land it on the target without spilling any of the clips.
1. Students continue to work with their Engineering Teams.
2. Remind the students of the specifications for their landing vehicles:
   • The lander must be no larger than a 20 cm cube.
   • The lander will be dropped from a height of one meter above a target.
   • The lander must land upright on the target.
   • Paperclip payload must remain inside the lander.
3. Tell students how they will be scored:
• Ten points will be awarded to teams who complete the task as specified and land in the center of the bull’s-eye without bouncing or losing any of the paperclip payload.
• Eight points will be awarded to teams who complete the task as specified and land in the second ring of the target without bouncing or losing any of the paperclip payload.
• Five points will be awarded to teams who complete the task to specifications but don’t land on the target or flip over after landing or lose paperclips from the lander.
• One point will be subtracted for each trial drop. One point will also be subtracted for each extra piece of material used to build the lander.

4. In their journals, students will record the results of each test. Discuss how they might record the following information:
   • Design a plan for adapting the lander (They may choose a sketch or narrative description)
   • Modifications made to the design after each attempt (Sketch or narrative)
   • Comments on the success of one attempt as compared to another
   • The distance from the center of the target to the place where their lander first touched the floor (Suggest a simple table of measurements.)

5. Give students the materials and allow them time to redesign their landers. Alternatively, a sketch of the planned design could be a requirement to receive the materials. Student teams should have most of the class period to redesign, test, and rebuild their landers.

6. Allow students to conduct their final test by dropping the lander on the target to score points. In their journals, students record the results of each test, including the distance from the center of the target to the place where their lander first touched the floor, modifications made to the design, and comments on the success of one attempt as compared to another.

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.

Vocabulary:
Cost benefit analysis, impact

Concepts:
• Any mining activity has an impact on the area being mined.
• Sometimes the impacts are not easy to see, or take months or years to become evident.
• Careful research must be conducted to choose the method that has the least impact on the mining environment while still maintaining a high yield of resources.
• Companies involved in mining and other activities conduct a cost benefit analysis to see if the amount of resources gained is worth the cost of mining them.

Elaborate:
Challenge students to list the possible impacts of mining activity on an asteroid. Point out that changing the surface of the asteroid should be considered, as well as the effects of material floating away from the asteroid’s low gravity environment.

Evaluate:
Use the Expedition Asteroid score sheet and students’ journals to check their success in completing the task.

Cross-Curricular Link:
Mathematics: using the points they earned or deducted on their score sheets as dollars, students calculate the cost-effectiveness of their expeditions and compare their findings with other teams.

InVESTAgate Day 10
Expedition Asteroid: We Deliver!
Student Guide

TODAY:
Now that you have collected resources from Vesta, we need to transport them to a space vehicle, either to take them back to Earth or to fuel an expedition to the outer Solar System.

GOAL:
To land your spacecraft on the asteroid so you can begin to explore the resources you can use for a future five-year trip to explore Jupiter’s moon Io.

CHALLENGE:
Design a space vehicle that can land on a moving target and remain upright.

SPECIFICATIONS:
• The lander must be no larger than a 20 cm cube.
• The lander will be dropped from a height of one meter above a target.
• The lander must land upright on the target.
• The paperclip payload must remain inside the lander.

PROCEDURE:
• All notes, sketches, and plans should be included in your journal.
• With your team, design a plan for a lander. Sketch your design.
• Build your lander and conduct pre-tests to see how close your lander will come to a target.
• Measure the distance from your lander to the target for each test.
• Record the results of your tests.
• List the modifications made between tests.
• Compare the success of one test to another.
• Include a results table that includes data from each trial, including the distance from the center of the target to the place where your lander first touches the floor.

POINTS:
• 10 points will be awarded to teams who complete the task as specified and land in the center of the bull’s-eye without bouncing or losing any of the paperclip payload.
• 8 points will be awarded to teams who complete the task as specified and land in the second ring of the target without bouncing or losing any of the paperclip payload.
• 5 points will be awarded to teams who complete the task to specifications but don’t land on the target or flip over after landing or lose paperclips from the lander.
• 1 point will be subtracted for each trial drop. One point will also be subtracted for each extra piece of material used beyond the basic materials provided to each team to build the lander.
Day Eleven - The Universe is Out to Get You

Objective:
Students will learn how meteorites get to Earth from the asteroid belt and how rare it is for Earth to be hit by a large asteroid. They will observe relative distances and sizes within the inner Solar System and gain an appreciation of the large amount of empty space in the Solar System.

Next Generation Science Standards
For complete description of each standard, click on the links below.

ESS1.B: Earth and the Solar System
ESS1.C: The History of Planet Earth
ESS3.B: Natural Hazards
CCC 3 Scale, Proportion, and Quantity
CCC 7 Stability and Change
SEP 8 Obtaining, Evaluating, and Communicating Information

Common Core Standards
RST.6-8.1: Cite specific textual evidence to support analysis of science and technical texts.
WHST.6-8.7: Conduct short research projects to answer a question
WHST.6-8.8: Gather relevant information from multiple print and digital sources
MP.2: Reason abstractly and quantitatively.

Materials:
Activity B: 1.2 meter square of stiff poster board or corrugated cardboard, 60x30 cm piece of stiff poster board or corrugated cardboard, pushpins, colored and regular pencils, string, scissors, ruler, protractor, clay dough in yellow or white, magazine with colored pictures; Activity C: paper (60 cm square), pencil an colored pencils, ruler, protractor, table #4

Engage:
Tell students that an asteroid is detected just hours before impacting the Earth. Scientists predicted that the object would impact Chicago in about 19 hours. Ask them to write in their journals what they think NASA should tell the public about the impending impact and what they think citizens should do to prepare. Then show and discuss the “TC3 Impact” power point http://dps.aas.org/files/dps/education/dpsdisc/2009/TC3Impact.ppt.

Explore:
Follow the directions for Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm 4: Meteorite Asteroid Connection (Choose either B. Long road to Earth, or C. Collision Course)

Explain:
Students copy vocabulary, definitions, and concepts into their Asteroid Journals.
Vocabulary:
• Ellipse, orbit, asteroid, asteroid belt, ecliptic plane, retrograde, eccentricity of orbit

Concepts:
• The Solar System is mostly empty space.
• Many asteroids are in a belt between Mars and Jupiter.
• It is rare for Earth to be hit by a large asteroid because such asteroids are rare and because of the huge distances involved.

InVESTAgate Day 11
Elaborate:
OR
Meteorite Mysteries http://ares.jsc.nasa.gov/ares/education/program/expmetmys.cfm
Meteorite Asteroid Connection Activity A, Finding orbits

Evaluate:
Assess student worksheets

Cross-Curricular Link:
Current events: Research meteors and asteroids in the news
English Language Arts: Evaluate news articles about meteor strikes for scientific accuracy
The Long and Winding Road to Earth
Adapted from "The Meteorite-Asteroid Connection" in NASA's Exploring Meteorite Mysteries

Objective:
- To construct a scale model of the inner Solar System including: the Sun, the inner planets, the asteroid belt, and the orbits of a few selected asteroids.
- To construct circular and elliptical planetary orbits
- To observe relative distances and sizes within the Solar System
- To plot the path meteoroids might take in traveling from the asteroid belt to Earth.
- To observe that the Earth is a small target.

Materials:
- 1.2 meter square (or larger) piece of corrugated cardboard or stiff poster board
- Pushpins, two per group
- Colored and regular pencils
- String, or loops of string in the lengths indicated in Table 1
- Scissors, ruler and protractor
- Clay-dough in yellow or white
- Magazine with colored pictures

Procedure:
1. Prepare your cardboard by marking the center; this will be the Sun’s location.
2. Draw a circle 1.8-2 mm in diameter around this point; this is the scaled diameter of the Sun. Then, using a pencil, draw a light reference line from the Sun’s center toward the side of the board.
3. Prepare the strings for each orbit using the string lengths in Table 1. Measure, cut, and carefully tape the ends so that they just touch. You will have a loop for each orbit.
4. Secure the string to the board using a glue stick. Check Table 1 (below) to see which planetary bodies follow a circular orbit and which ones need an elliptical orbit. Two pins mean an elliptical and one pin means that planet has a circular orbit.
5. Label each orbit, as well as the asteroid belt.
6. Now it is time to add the Sun and planets to your model. You need to add the Sun and planets at the same scale as their orbits. Table 2 (below) provides you with real and to-scale diameters. For example, at this scale the Sun should be a ball just under 2 mm in diameter, about the size of a BB. Use a metric ruler and clay-dough to fashion a representation of the Sun.
7. The Earth and Venus should be 1/50 mm across, which is almost invisible, smaller than a grain of salt or pinprick in paper, and about the thickness of standard copier paper. If you
look at a picture in a magazine with a 5 or 10X magnifying glasses, you will see individual dots. These dots are about three times too large, but will give you an idea of the correct scale. As best you can, make tiny dots to represent the Earth and Venus.

8. The Moon, Mercury, Mars and the asteroids are too small to be visible at this scale!

### Table 1. Drawing Orbits in Scale Model

<table>
<thead>
<tr>
<th>Orbit</th>
<th>Loop Circumference (knot to knot)</th>
<th># pins</th>
<th>Pin 2 from Sun Distance</th>
<th>Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>18 cm</td>
<td>2</td>
<td>3.1 cm</td>
<td>270°</td>
</tr>
<tr>
<td>Venus</td>
<td>27 cm</td>
<td>1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Earth</td>
<td>39 cm</td>
<td>1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Mars</td>
<td>64 cm</td>
<td>2</td>
<td>5.6 cm</td>
<td>45°</td>
</tr>
<tr>
<td>Asteroid Belt:</td>
<td>84 cm</td>
<td>1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Inner Edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asteroid Belt:</td>
<td>122 cm</td>
<td>1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Outer Edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asteroid Ceres</td>
<td>114 cm</td>
<td>2</td>
<td>8.4 cm</td>
<td>78°</td>
</tr>
<tr>
<td>Asteroid 1983RD</td>
<td>118 cm</td>
<td>2</td>
<td>39 cm</td>
<td>173°</td>
</tr>
<tr>
<td>Asteroid Icarus</td>
<td>85 cm</td>
<td>2</td>
<td>38 cm</td>
<td>330°</td>
</tr>
</tbody>
</table>

Note: Asteroid 1983RD is now known as 3551 Verenia, and its spectrum indicates that it has a similar composition to Vesta.

### Table 2. Real and Scaled Diameters of Solar System Objects

<table>
<thead>
<tr>
<th>Object</th>
<th>Real Diameter</th>
<th>Scaled Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>1,400,000 km</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Mercury</td>
<td>4,880 km</td>
<td>1/150 mm</td>
</tr>
<tr>
<td>Venus</td>
<td>12,100 km</td>
<td>~1/50 mm</td>
</tr>
<tr>
<td>Earth</td>
<td>12,800 km</td>
<td>~1/50 mm</td>
</tr>
<tr>
<td>Moon</td>
<td>3,480 km</td>
<td>1/200 mm</td>
</tr>
<tr>
<td>Mars</td>
<td>6,800 km</td>
<td>~1/100 mm</td>
</tr>
<tr>
<td>Ceres</td>
<td>940 km</td>
<td>~1/1000 mm</td>
</tr>
<tr>
<td>1983RD</td>
<td>0.8 km</td>
<td>~1x10⁻⁶ mm</td>
</tr>
<tr>
<td>Icarus</td>
<td>0.9 km</td>
<td>~1x10⁻⁶ mm</td>
</tr>
</tbody>
</table>

*InVESTAgate Day 11*
Questions:

1. As you constructed your scale model of the inner planets and asteroid belt, what did you notice about the relative distances between astronomical bodies within the inner system?

2. What did you notice about the relative sizes of the astronomical bodies in the inner Solar System?

3. Where is the asteroid belt located?

4. Does the Solar System appear crowded or is there mostly open space?

5. Looking at the size of the Earth on your model and considering that it is a moving target, what do you think are the chances of the Earth being hit by large asteroids or comets? Give a reason for your answer.
Collision Course

Objective:
• To graph the locations of the Earth and a near-Earth asteroid.
• To observe from the graph that both time and location in space are important.
• To estimate when an asteroid would cross the Earth’s orbit.
• To determine if a collision would take place.

Materials:
• Paper- approximately 60 cm x 60 cm
• Pencil and colored pencils (optional)
• Ruler
• Protractor
• Table 4

Procedure:
1. Mark the Sun point in the center of the paper. Use a pencil to draw a line from the Sun extending 30 cm in any direction. This will be the reference line from which angles are measured (see diagram).
2. Graph the orbit of the Earth and one asteroid on the paper. To draw an orbit from the numbers in Table 4 (see below), begin with a single time at the left in Table 4. On that time in the Table, read the angle and distance for that time in orbit.
3. On the paper, use a protractor to measure the angle (clockwise) from the Sun and the reference line, and draw a line at that angle. Measure outward along that line to the distance listed in the table, and draw a dot at that distance (color-coded perhaps). Label the mark with month and half month.
4. After all the points are graphed and labeled, connect them freehand to make a smooth curve. The points may not make a full orbit.
5. Estimate when (month number and a fraction), that the asteroid crosses the Earth’s orbit.
6. Measure the closest approach between the asteroid and the Earth by measuring the distances between corresponding time steps in their orbits.
7. Compare data with other lab groups. Determine which asteroid comes closest to hitting the Earth and how close it comes. (The scale here is 1 cm = 10,000,000 kilometers. The Earth (to scale) would be 1/100 mm).
<table>
<thead>
<tr>
<th>Month</th>
<th>Earth Dist</th>
<th>Earth Angle</th>
<th>Asteroid 1 Dist</th>
<th>Asteroid 1 Angle</th>
<th>Asteroid 2 Dist</th>
<th>Asteroid 2 Angle</th>
<th>Asteroid 3 Dist</th>
<th>Asteroid 3 Angle</th>
<th>Asteroid 4 Dist</th>
<th>Asteroid 4 Angle</th>
<th>Asteroid 5 Dist</th>
<th>Asteroid 5 Angle</th>
<th>Asteroid 6 Dist</th>
<th>Asteroid 6 Angle</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>15 cm</td>
<td>0°</td>
<td>8.4 cm</td>
<td>0°</td>
<td>23.7 cm</td>
<td>32°</td>
<td>30.6 cm</td>
<td>15°</td>
<td>55.4 cm</td>
<td>50°</td>
<td>23.6 cm</td>
<td>56°</td>
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<td>261°</td>
</tr>
<tr>
<td>1</td>
<td>15 cm</td>
<td>30°</td>
<td>10.8 cm</td>
<td>72°</td>
<td>23.5 cm</td>
<td>33°</td>
<td>27.0 cm</td>
<td>20°</td>
<td>53.9 cm</td>
<td>48°</td>
<td>21.4 cm</td>
<td>71°</td>
<td>49.5 cm</td>
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</tr>
<tr>
<td>2</td>
<td>15 cm</td>
<td>60°</td>
<td>14.8 cm</td>
<td>110°</td>
<td>22.6 cm</td>
<td>34°</td>
<td>23.1 cm</td>
<td>21°</td>
<td>52.1 cm</td>
<td>46°</td>
<td>19.9 cm</td>
<td>90°</td>
<td>47.7 cm</td>
<td>267°</td>
</tr>
<tr>
<td>3</td>
<td>15 cm</td>
<td>90°</td>
<td>18.2 cm</td>
<td>133°</td>
<td>20.8 cm</td>
<td>36°</td>
<td>19.2 cm</td>
<td>22°</td>
<td>50.1 cm</td>
<td>44°</td>
<td>16.7 cm</td>
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<td>45.6 cm</td>
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<td>120°</td>
<td>20.7 cm</td>
<td>149°</td>
<td>18.2 cm</td>
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<td>26°</td>
<td>47.7 cm</td>
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<td>146°</td>
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<td>23.3 cm</td>
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<td>42.0 cm</td>
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<tr>
<td>7</td>
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<td>185°</td>
<td>8.6 cm</td>
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<td>17.2 cm</td>
<td>21°</td>
<td>38.6 cm</td>
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<td>17.5 cm</td>
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<td>8</td>
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<td>22.5 cm</td>
<td>197°</td>
<td>11.1 cm</td>
<td>192°</td>
<td>21.0 cm</td>
<td>43°</td>
<td>34.7 cm</td>
<td>29°</td>
<td>19.9 cm</td>
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<tr>
<td>9</td>
<td>15 cm</td>
<td>270°</td>
<td>20.9 cm</td>
<td>210°</td>
<td>15.0 cm</td>
<td>24°</td>
<td>25.0 cm</td>
<td>59°</td>
<td>30.3 cm</td>
<td>24°</td>
<td>22.2 cm</td>
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<td>300°</td>
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<td>272°</td>
<td>28.8 cm</td>
<td>70°</td>
<td>25.2 cm</td>
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</tr>
<tr>
<td>11</td>
<td>15 cm</td>
<td>330°</td>
<td>15.2 cm</td>
<td>247°</td>
<td>20.9 cm</td>
<td>290°</td>
<td>32.2 cm</td>
<td>79°</td>
<td>19.1 cm</td>
<td>6°</td>
<td>26.2 cm</td>
<td>311°</td>
<td>15.6 cm</td>
<td>338°</td>
</tr>
<tr>
<td>12</td>
<td>15 cm</td>
<td>0°</td>
<td>11.2 cm</td>
<td>283°</td>
<td>22.7 cm</td>
<td>304°</td>
<td>35.4 cm</td>
<td>86°</td>
<td>11.9 cm</td>
<td>342°</td>
<td>27.7 cm</td>
<td>321°</td>
<td>10.7 cm</td>
<td>21°</td>
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<tr>
<td>13</td>
<td>15 cm</td>
<td>30°</td>
<td>8.5 cm</td>
<td>352°</td>
<td>23.6 cm</td>
<td>317°</td>
<td>38.3 cm</td>
<td>92°</td>
<td>5.4 cm</td>
<td>240°</td>
<td>28.8 cm</td>
<td>331°</td>
<td>10.0 cm</td>
<td>94°</td>
</tr>
</tbody>
</table>

Asteroid 1 = Castalia,  (0 month is 1.5 months after perihelion at 0°)
Asteroid 2 = Cerebus,  (oriented so perihelion is on-line with Earth and Sun)
Asteroid 3 = Atuncus,  (starting 71 half-months after perihelion)
Asteroid 4 = Hephiatos,  (starting at perihelion, but tuned to retrograde orbit)
Asteroid 5 = Nereus,  (arranged for a near-miss)
Asteroid 6 = Oljato,  (starting at 51 half-months after perihelion, angle advanced by 85°)
Questions:

1. When did the asteroid that you chose to graph cross the Earth’s orbit?

2. What was the closest approach between your asteroid and the Earth?

3. Which asteroid came closest to hitting the Earth and how close did it get?

4. What do you think the chances are of an asteroid hitting the Earth? Explain your answer.
Day Twelve - Review

**Objective:**
Students will review concepts and vocabulary introduced in the unit.

**Standards:**
All Next Generation Science Standards and Common Core Standards included in the unit.

**Materials:**
Student journals, review game of choice

**Engage:**
Preview the material that will be covered in the test, highlighting the format of the test, i.e. multiple choice only, lab practical, etc.

**Explore:**
None

**Explain:**
Explain concepts as necessary. It is suggested that a game format such as Trivial Pursuit, Jeopardy, etc. be used to keep the students engaged throughout the review.

**Elaborate:**
None

**Evaluate:**
Informally assess student knowledge during review game

**Interdisciplinary Link:**
None
Day Thirteen - Assessment

Objective:
Final assessment of student knowledge

Standards:
All Next Generation Science Standards and Common Core Standards included in the unit.

Materials:
Paper, pencil, test

Engage:
Prepare students for test, as necessary.

Explore:
None

Explain:
None

Elaborate:
None

Evaluate:
Administer posttest

Interdisciplinary Link:
None
Appendix A – Assessment
InVESTAgate Pre-Test

Match the following words with their definition:

1. _____ Astronomer  A. Stony meteorite containing chondrules embedded in a fine matrix of pyroxene, olivine, and metallic nickel-iron
2. _____ Prospector  B. One who studies the science of celestial bodies
3. _____ Accretion  C. A closed curve of oval shape
4. _____ Crater  D. Material thrown out from and deposited around impact craters
5. _____ Planet  E. One of the largest asteroids in the Solar System
6. _____ Vesta  F. The amount of light of a particular color reflected by a surface
7. _____ Sphere  G. Any of the eight large celestial bodies revolving around the Sun
8. _____ Impact  H. One who explores an area for minerals and other materials
9. _____ Orbit  I. Accumulation under the influence of gravity and some minor forces
10. _____ Meteorite  J. The amount of matter in an object
11. _____ Ejecta  K. An object that is round or almost round
12. _____ Mass  L. A hole or depression
13. _____ Ellipse  M. The forceful striking of one body against another such as a moon or planet
14. _____ Reflectance  N. The path of an object in space moving around another
15. _____ Chondrite  O. A metallic or stony body that has fallen on the Earth, Moon, or other planetary body
Write the words true or false in the blank.
16. _______ Gravity is related to movement, nearness of Earth, or magnetic fields.
17. _______ The Moon has no gravity.
18. _______ Gravity is a force.
19. _______ Planets far away from the Sun have less gravity.
20. _______ Gravity keeps the planets in orbit around the Sun.

Short Answer
21. If a baseball and a wad of paper the same size as the ball are dropped in a vacuum from the same height and at the same time, which one will land first? Explain your answer.

___________________________________________________________________________________________________

___________________________________________________________________________________________________

___________________________________________________________________________________________________

22. Where in the Solar System are most asteroids located?

___________________________________________________________________________________________________

___________________________________________________________________________________________________

23. What is the difference between an asteroid, planet, and dwarf planet?

___________________________________________________________________________________________________

___________________________________________________________________________________________________

___________________________________________________________________________________________________

24. What is the difference between an asteroid and meteoroid?

___________________________________________________________________________________________________

___________________________________________________________________________________________________

___________________________________________________________________________________________________

25. What are the chances of the Earth being hit by a meteoroid? Explain your answer.

___________________________________________________________________________________________________

___________________________________________________________________________________________________

___________________________________________________________________________________________________
InVESTAgate Pre-Test Answer Key

1. B  
2. H  
3. I  
4. L  
5. G  
6. E  
7. K  
8. M  
9. N  
10. O  
11. D  
12. J  
13. C  
14. F  
15. A  
16. False  
17. False  
18. True  
19. False  
20. True  

21. They would land at the same time because the force of gravity on them is the same.  
22. The asteroid belt is located between Mars and Jupiter.  
23. An asteroid orbits the Sun inside the orbit of Jupiter, is not round shaped, is not a satellite, and has not cleared the neighborhood around its orbit of most bodies. A planet is a celestial body that orbits the Sun, is nearly round, is not a satellite, and has cleared the neighborhood around its orbit of most bodies. A dwarf planet is in orbit around the Sun, is nearly round, is not a satellite, and has not cleared the neighborhood around its orbit.  
24. Asteroids are smaller than planets, usually located in the belt between Mars and Jupiter, and, in general, are rocky bodies with no atmosphere. Some have high metallic content. Meteoroids are interplanetary objects that are smaller than asteroids. When they enter the atmosphere of another object, they often vaporize. If they survive to impact the surface, they are called meteorites.  
25. Meteoroids can and have impacted the Earth, as evidenced by impact craters found in several places on Earth. However, because the Solar System is mostly empty space, it is rare for the Earth to be hit by one.
Vesta Concept Quiz

1. How do planetary bodies build and what is this called?

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

2. List two things that you know about gravity?

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

3. What is the difference between the gravity and mass of an object?

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

4. On the back of the paper, make a Venn diagram comparing an asteroid, planet, and dwarf planet.

5. Why are meteorites difficult to find on the surface of the Earth?

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________

______________________________________________________________________________________________
Vesta Concept Quiz Answer Key

1. Planetary bodies build by collecting smaller pieces of unrelated materials such as stardust. The process is called accretion.

2. Answers vary, but may include:
   - Gravity affects planetary bodies.
   - Gravity was a force present at the formation of the Solar System.
   - Gravity is a force of attraction pulling any two things toward each other.
   - Gravity keeps the planets in orbit around the Sun.
   - The amount of gravity depends upon the mass of an object.

3. Gravity is the force of attraction pulling two objects together and mass is the amount of matter in a given object.

4. **Dwarf Planet**
   - Is nearly round
   - Orbits the Sun
   - Is not a satellite
   - Has not cleared neighborhood around its orbit
   - Not round

5. **Planet**
   - Has cleared its orbital path
   - Only orbits inside Jupiter’s orbit

6. **Asteroid**
   - Not round

5. Meteorites are hard to find because most of them look like Earth rocks to an untrained eye. Sometimes they break into fragments when they enter the Earth’s atmosphere. They are often black or dull gray and do not stand out.
Vocabulary Quiz 1

1. _____ Astronomer
   A. One of thousands of small, solid planetary bodies orbiting the Sun

2. _____ Sphere
   B. One who studies the science of celestial bodies

3. _____ Gravity
   C. A push or pull upon an object

4. _____ Accretion
   D. The process by which rocks are altered in composition, texture, or structure

5. _____ Planet
   E. Area of the surface with distinctive physical features

6. _____ Chondrite
   F. A force of attraction pulling any two things to each other, depending on the mass of objects

7. _____ Mass
   G. The amount of matter in an object

8. _____ Force
   H. An object that is round or almost round

9. _____ Matrix
   I. Any of the eight large, celestial bodies revolving around the Sun

10. _____ Asteroid
    J. Accumulation under the influence of gravity and some minor forces

11. _____ Metamorphism
    K. The forceful striking of one body against another such as a moon or planet

12. _____ Dwarf Planet
    L. Stony meteorite containing chondrules embedded in a fine matrix of pyroxene, olivine, and metallic nickel-iron

13. _____ Terrain
    M. A spherical celestial body revolving around the Sun but not large enough to gravitationally clear its orbit of other celestial bodies

14. _____ Impact

15. _____ Meteorite
    N. The smaller sized grains in a rock that consists of large grain fragments surrounded by smaller grains

O. Metallic or stony body that has fallen on the Earth, Moon, or other planetary body
Vesta Vocabulary Quiz #1 Answer Key

1. B
2. H
3. F
4. J
5. I
6. L
7. G
8. C
9. N
10. A
11. D
12. M
13. E
14. K
15. O
Vocabulary Quiz 2

1. ______ Vesta
2. ______ Orbit
3. ______ Ellipse
4. ______ Meteor
5. ______ Meteoroid
6. ______ Asteroid Belt
7. ______ Reflectance
8. ______ Crater
9. ______ Impact
10. ______ Ejecta
11. ______ Ceres
12. ______ Rim

A. The amount of light of a particular color reflected by a surface
B. One of the largest asteroids in the Solar System
C. The forceful striking of one body against another
D. The path of an object in space moving around another
E. A hole or depression
F. A dwarf planet that orbits within the asteroid belt
G. A closed curve of oval shape
H. Area between Mars and Jupiter
I. Material thrown out from and deposited around an impact crater
J. A piece of interplanetary matter smaller than one km
K. The border of a landform
L. A relatively small body of matter traveling through interplanetary space
Vesta Vocabulary Quiz 2 Answer Key

1. B
2. D
3. G
4. L
5. J
6. H
7. A
8. E
9. C
10. I
11. F
12. K
In-Vesta-Gate Post-Test

Match the following words with their definition:

1. _______ Vesta
2. _______ Accretion
3. _______ Astronomer
4. _______ Planet
5. _______ Meteorite
6. _______ Mass
7. _______ Ejecta
8. _______ Reflectance
9. _______ Orbit
10. _______ Chondrite

A. A metallic or stony body that has fallen on Earth, Moon, or other planetary body
B. Stony meteorite containing chondrule embedded in a fine matrix of pyroxene, olivine, and metallic nickel-iron
C. One who studies the science of celestial bodies
D. One of the largest asteroids in the Solar System
E. The amount of matter in an object
F. The path of an object in space moving around another body
G. Material thrown out from and deposited around impact craters
H. Accumulation under the influence of gravity and some minor forces
I. Any of the eight large celestial bodies revolving around the Sun
J. The amount of light of a particular color reflected by a surface

Write the words true or false in the blank.

11. _______ Gravity is a force.
12. _______ There is no gravity in space.
13. _______ Most asteroids are located between Mercury and Venus.
14. _______ An ellipse is a closed curve of oval shape.
15. _______ Gravity is related to movement, nearness of the Earth, and magnetic fields
Multiple Choice

16. ________ All asteroids:
   A. Are round in shape
   B. Are satellites
   C. Are larger than a planet
   D. Orbit the Sun

17. ________ A planet is:
   A. Not round
   B. Is a satellite
   C. Has cleared the neighborhood around its orbit of most bodies
   D. Is smaller than an asteroid

18. ________ A dwarf planet:
   A. Does not orbit the Sun
   B. Is larger than Earth
   C. Is not round
   D. Has not cleared the neighborhood around its orbit

19. ________ Gravity:
   A. Keeps planets in orbit around the Sun
   B. Guides the growth of plants
   C. Exists between objects on Earth
   D. All of the above

20. ________ Craters are:
   A. Holes or depressions in the surface of a planetary body
   B. Not caused by impacts
   C. Only on the Moon
   D. Never changed once they are formed

Short Answer

1. Compare and contrast an asteroid and meteoroid. How are they alike? How are they different?

___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
___________________________________________________________________________
2. If a bowling ball and a marble are dropped in a vacuum from the same height at the same time, which one would land first? Explain your answer.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

3. If a golf ball and feather are dropped by your teacher at the same time and at the same height, which would land first? Explain. Suppose they were dropped by an astronaut on the Moon, which would land first? Explain your answer.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

4. What is the difference between a meteoroid and a meteorite?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

5. Although it is possible for the Earth to be hit by a meteorite, it does not happen very often. Explain why?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________
In-Vesta-Gate Post-Test Answer Key

1. D
2. H
3. C
4. I
5. A
6. E
7. G
8. J
9. F
10. B
11. True
12. False
13. False
14. True
15. False
16. D
17. C
18. D
19. D
20. A

21. Asteroids and meteoroids are both celestial bodies. Asteroids are smaller than planets and are usually located in the belt between Mars and Jupiter. They are rocky with no atmosphere; some have high metallic content. Meteoroids are interplanetary bodies that are smaller than asteroids.

22. The bowling ball and marble would land at the same time because they are accelerating at the same rate.

23. The golf ball would land first because the feather is affected by greater air resistance, which is a form of friction. If they were dropped on the Moon, they would land at the same time because they would accelerate at the same rate and there would be no air resistance influencing the feather.

24. A meteoroid is an interplanetary body that often vaporizes when it enters the atmosphere of another object. A meteorite is a meteoroid that has survived to impact the surface.

25. Meteorites do sometimes impact Earth. However, it is rare because the Solar System is mostly empty space.
Appendix B - Educator Feedback/Unit Evaluation
InVESTAgate Educator Survey

Name ____________________________ School ___________________ I teach ______ grade.

1. Think about any lesson or part of a lesson that you tried with your students. Did your students find the lessons/activities engaging? Using the rubric below, please rate each lesson and/or activity, if specified. Write a number from 1 to 4 in the “Rating” column, and explain your choice in “Comments.” If you only did part of a particular lesson, please identify which part.

<table>
<thead>
<tr>
<th>Not engaging for my students</th>
<th>Somewhat engaging for my students</th>
<th>Engaging enough to hold my students’ interests most of the class time</th>
<th>Very engaging--my students will be excited about this activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

**Unit Day/Lesson/Title/Activity** | **Rating** | **Comments**
--- | --- | ---
Day One/Solar System Formation | | |
Day Two/The Role of Gravity/Gravity Misconceptions | | |
Day Two/The Role of Gravity/Gravity Pulls You Down | | |
Day Three/It's Not a Planet? | | |
Day Four/Asteroids, Comets, & Meteoroids | | |
Day Five/Observing Asteroids | | |
Day Six/Asteroid Cratering | | |
Day Seven/Mapping/ CosmoQuest Asteroid Mappers: Vesta | | |
Day Eight/Expedition Asteroid Part I: Vesta Landing | | |
Day Nine/Expedition Asteroid Part II: Mining Vesta | | |
Day Ten/Expedition Asteroid Part III: We Deliver! | | |
Day Eleven/The Universe is Out to Get You | | |
Assessment Activities (any or all) | | |
2. Is the unit content grade-appropriate for your students?

3. Is the unit the right length?
   Too long -------------------------------- right length -------------------------------- too short
   Comments:

4. How easily would you be able to get the supplies necessary if a kit were not provided?
   Would not be able to get -------------------- Would not be able to get ------------------
   Would be able to get most of the supplies at any supplies the expensive supplies
   Already have most of the supplies at my school

5. What might prevent you from using this unit in your classroom?

6. What level of training do you think the average (non-science specialist) teacher needs to successfully conduct this unit?
   No training (Can use right out of the box) 1 – hour training 1- day training
   Need a science background

7. If you have any other helpful comments or suggestions, please write them below.

Please email completed survey to educate@cosmoquest.org

Thank you so much for your help!
The CosmoQuest Education Team